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Effects of Hurricane Andrew on Natural and Archeological Resources

Big Cypress National Preserve
Biscayne National Park
Everglades National Park

Technical Report NPS/NRGCC/NRTR/96-02

United States Department of the Interior · National Park Service · Gulf Coast Cluster
Big Cypress National Preserve · Biscayne National Park · Everglades National Park

NATIONAL PARK SERVICE
WATER RESOURCES DIVISION
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Effects of Hurricane Andrew on Natural and Archeological Resources

Big Cypress National Preserve
Biscayne National Park
Everglades National Park

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Summary

This report describes the conditions of the resources and the effects of Hurricane Andrew on the resources of the national park system units in South Florida. We also recommend the immediate and long-term protection of threatened resources and the collection of data that will help us better understand the effects of human and natural disturbances on the parks' resources. Immediate responses of the South Florida park ecosystems to the hurricane appeared normal, but the National Park Service must now determine the current level of natural resiliency of the ecosystems; the ability of the ecosystems to recover normally before the next disturbance; the effects of habitat fragmentation, altered air and water resources, nonnative species, and human disturbance on the natural recovery of the parks.

Hurricane Andrew, small but intense, made landfall in South Florida as a category four hurricane at 5:00 a.m. on 24 August 1992. With a minimum pressure of 922 millibars and maximum sustained winds of 240 km/h (150 mph; National Weather Service), this hurricane was one of the most intense storms ever recorded in Florida. The eye of the storm passed through Biscayne and Everglades national parks and southern Big Cypress National Preserve with a forward speed of 50 km/h (32 mph).

The storm hit near the time of high tide and produced a large but local storm surge in the coastal portion of southeastern Dade County, 25 km (15 miles) south of Miami. The storm surge overtopped coastal water control structures and levees. The U.S. Geological Survey estimated Hurricane Andrew's maximum storm surge at 5.2 m (17 feet). A 34-m (111.55-foot) vessel was blown inland from its deep water anchorage and came to rest on the bank of the C-100 canal, upstream of a water control structure. Coastal flooding was minor, but high winds caused extensive damage throughout the 40-km-wide (25 mile) storm path across the state.

Rainfall from the storm was low, presumably in response to the storm's rapid forward movement. Average rainfall on 24 August in Dade County was about 5 cm (2 inches), and the highest reported rainfall was 14.6 cm (5.75 inches) near the Atlantic Coast. Rainfall in central Dade County was generally less than 5 cm. Rainfall and water levels were above normal throughout most of South Florida before Hurricane Andrew arrived. Inland flooding was a problem primarily in southeastern Dade County, where saltwater inundated a large portion of the farming areas.

Although some effects of the storm on natural resources were drastic, initial ecosystem responses seemed normal. Trees, especially mangroves and tropical hardwoods, sustained severe damage. Many defoliated trees resprouted leaves within weeks of the storm, and rare plants in hammock and forest understories were relatively unaffected. Coastal wading bird rookeries, eagle nests, and cavity trees of the red-cockaded woodpecker were damaged, but no mass die-off of wildlife occurred. Hurricane winds and water almost certainly spread nonnative plants. Nonnative animals escaped from storm damaged facilities and entered the parks. Some freshwater fish populations were dispersed and may have profoundly declined after the storm. Storm damage to the southern Dade County water delivery system interrupted the normal freshwater flow into Florida Bay. The storm scoured shallow marine communities and altered marine water quality. An artificial reef broke up and moved into Biscayne National Park. Sea turtle nesting beaches may have been enhanced by inundation, and sea grass beds survived remarkably intact. Windthrown trees and storm scour exposed previously buried archeological artifacts on ship wrecks and upland sites. Disposal of urban debris from the hurricane threatens air and water quality in the parks.

Chronic anthropogenic stress, such as habitat fragmentation, nonnative species, altered water resources, and air pollution have affected ecosystem stability in South Florida. Whether such stressed ecosystems recover to prestorm conditions before the next major perturbation and whether storm clean up threatens resources and human health and safety in the parks are not known. These questions need to be addressed to protect park resources immediately and to develop long-term strategies.

Current Resource Conditions

Upland Resources

Hurricane Andrew affected a 50-km-wide (31 mile) swath of vegetation from Old Rhodes to Sands Keys in Biscayne National Park, across Long Pine Key, the Shark River Slough and southern Big Cypress National Preserve, to the western coast of Everglades National Park (Fig. 1). Portions of Big Cypress National Preserve north of the storm track were also affected by the storm. The northern edge of Cape Sable marked the southern boundary of the affected area.

Perhaps the most drastic direct effect of the storm was major structural damage to trees. Most damage occurred in hardwood hammocks, coastal mangrove *(Rhizophora mangle)* forests, and pine forests on Long Pine Key in Everglades National Park and the old-growth pine forest at Lostmans Pines in Big Cypress National Preserve. In the storm's path, virtually all large hammock trees were defoliated, and 20-30% were wind-thrown or experienced broken trunks or loss of major branches. About 25% of the royal palms were wind-thrown, many others were defoliated but began resprouting within 2 weeks. The damage to upland woody vegetation was most severe near the eye of the storm where winds were strongest. The severity of damage

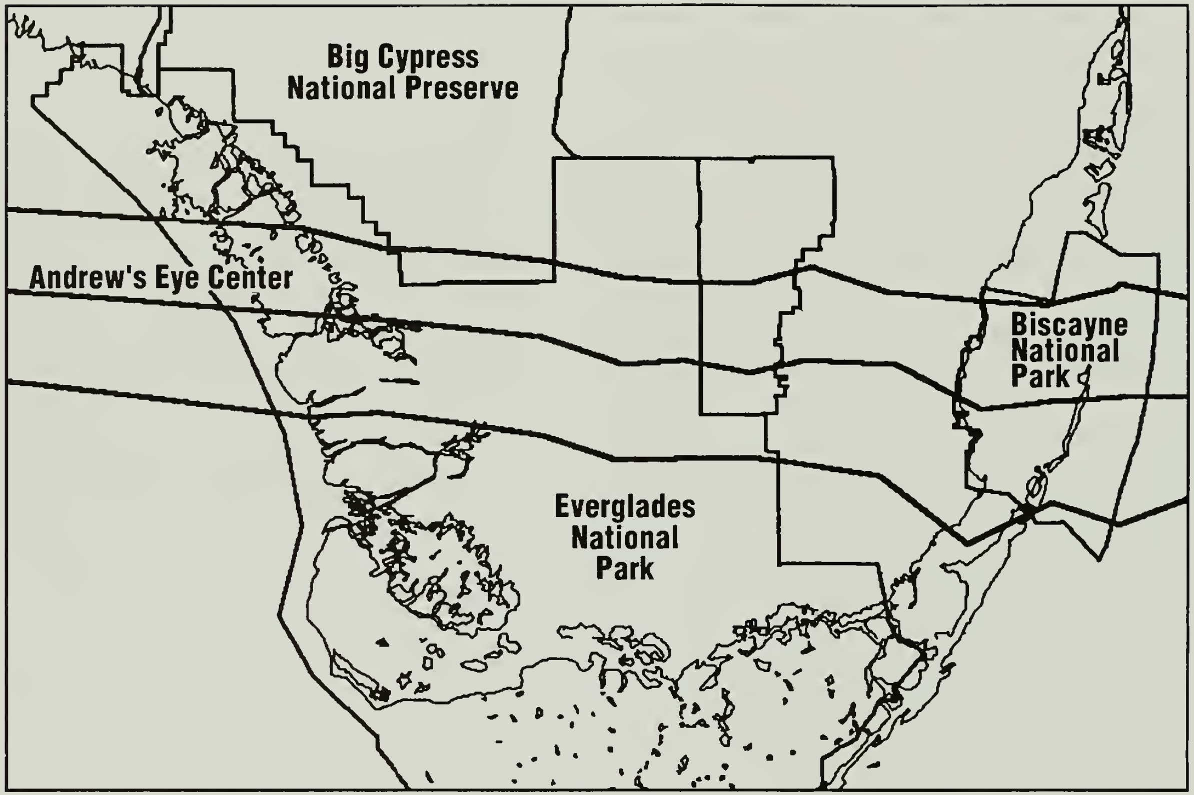

Figure 1. Path of Hurricane Andrew across South Florida, 24 August 1992, showing the area covered by the eye of the storm and the surrounding cloudwall.

decreased away from the center of the storm track. Evidence of extreme wind gusts also decreased with distance from the central storm track.

In Everglades National Park, 25-40% of the pines (*Pinus* spp.) were damaged by windthrow or breakage. In Big Cypress National Preserve, pines were the most affected species; 30% were downed and 10% had broken trunks in the southern part of the preserve. Baldcypress *(Taxodium* *distichum)* fared much better than pines and hammock hardwoods. The baldcypress generally held their needles, but what appeared to be intense local gusts leveled a few domes. In Big Cypress, nearly 90% of the known nest trees of the red-cockaded woodpecker *(Picoides borealis)* were blown down, and none of the trees with active nest cavities in the storm's path remained standing.

The storm knocked down about 28,000 ha (70,000 acres) of mangrove forest in the parks. In contrast to the gradation of effects on upland trees, the boundary of effects in mangrove forests was sharply defined. At Highland Beach, at the center of the storm track on the western coast, 85-90% of the mature mangroves were downed. Mortality in mangrove forests will probably continue for a year or longer. Trunks on many of the surviving trees are cracked. Experience from other hurricanes (Duever and McCollom 1992) suggests that many of these trees will eventually die from damage by the storm.

Determining the fate of other damaged communities is not yet possible. After Hurricane Gilbert, which struck vegetation on the Yucatan Peninsula similar to South Florida hammocks with 300 km/h (188 mph) winds, only 16% of the windthrown trees and 29% of the broken trees died within 2 years. Most of the defoliated trees in the South Florida parks were resprouting leaves within a few days of the storm, especially the tropical hardwoods.

Damage to the understory plant communities was only moderate, mostly from falling limbs and trunks. Many understory plants retained their leaves and even fruits formed after the storm.

Most rare and endemic plants in South Florida are in the forest understory. Although immediate storm effects on rare and endemic plants appeared minimal, long-term effects may be more substantial. Effects of reduced canopy and increased light penetration to the forest floor will change the competitive interactions between herbaceous endemics and hardwoods with unknown consequences.

After previous hurricanes in South Florida, nonnative plants spread extensively. Hurricane Donna spread Australian pine (*Casuarina* spp.) up the western coast of Everglades National Park in 1960, requiring an expensive eradication program in the 1970s. Brazilian pepper *(Schinus terebinthifolius)* introduced to South Florida in 1898, was not perceived as a problem until after the hurricanes in 1960 and in 1965. Invasive nonnative plant species, such as melaleuca *(Melaleuca quinquenervia)*, may have been spread by wind and water during Hurricane Andrew, but determining the extent immediately after the storm was difficult. Seed pods were found scattered as far as 20 m (63 feet) from potential parental stocks, but the pods may have been carried much farther. Until seedlings appear, the actual extent of the spread cannot be determined.

The status of nonnative plants in Biscayne National Park is not well known and must be evaluated before management can be designed. Local control of *Schinus* and *Colubrina asiatica* may be effective in Biscayne National Park if they are not yet widespread. In Everglades National Park and Big Cypress National Preserve, many nonnatives seemingly had reached equilibrium before the storm. Their statuses may change if ecological conditions were altered by the storm.

Wildlife

Storm surge, extreme rainfall, and flooding are generally the major causes of wildlife mortality in hurricanes. Because the major damage of this storm was from high winds, wildlife fared relatively well. Extensive surveys of the parks and contacts with field observers throughout South Florida revealed little evidence of direct storm-caused deaths. Nevertheless, recruitment in several species may be low for the next year or longer. The only large destruction of wildlife was about 200 wading birds, mostly white ibis and egrets, near the Chicken Key roost in Biscayne Bay. Only one dead deer was found, in the Stairsteps area between Everglades National Park and Big Cypress National Preserve, but this deer may have died from other causes. Many species seemed unharmed by the storm. All radio-marked Florida panthers *(Felis concolor)* survived the storm. Radio-tagged black bears *(Ursus americanus)* and snail kites *(Rostrhamus sociabilis)* survived the storm and seemed relatively normal, although some of the kites moved from storm-damaged roosts and feeding areas.

Deer seemed to be unaffected 3 weeks after the storm. New leaves of hammock vegetation provided both food and cover. All 32 radio-collared deer survived, but about one-third shifted their home ranges. Evidence of over-browsing was not apparent, and the current water levels of less than 0.5 m (20 inches) did not force the deer onto limited high ground.

Adult alligators seemed unaffected by the storm, but nests and young-of-the-year may have been harmed. The 1992 season was already a poor year for alligators before the storm arrived. In a normal year, egg mortality is 25%. In 1992, 43% died before the storm. The storm destroyed nests containing 27% of the annual egg production. The fate of those eggs, which were hatching as the storm struck, is unknown. Some may have hatched, and the hatchlings survived.

About 10% of the 160 wading bird rookeries in South Florida were in the storm path. Many interior marshes were in willow (*Salix* spp.) heads and therefore are relatively unaffected, but coastal rookeries in mangroves were severely altered. Except for the losses already described in Biscayne Bay, resident white ibis and egret populations seemed unaffected. Virtually all trees with nest cavities occupied by red-cockaded woodpeckers were knocked down, but the effects on the population will not be known until surveys can be conducted. Most bald eagle *(Haliaeetus leucocephalus)* nests in the parks were outside the zone of major disturbance. Several nests were lost or damaged, and effects on the population will not be known until surveys are conducted.

A monkey was observed at the East Cape dock on Cape Sable. The extent and nature of other nonnative animals in the parks remain unknown. Because several facilities adjacent to the parks housed nonnative animals and were destroyed by the storm, nonnative animals are now in the parks.

Freshwater Resources

Freshwater fish and macroinvertebrate (small invertebrates that can be seen without a microscope) populations seemed relatively unaffected by the storm, but historical data allow detection of only 10-fold changes in populations. Assessing short-term changes of strong seasonal and annual cycles in fish populations is difficult, even with optimal sampling schemes. The dynamics of these aquatic populations also vary with hydroperiod. In some areas, fish abundance declined, seemingly because of the loss of periphyton cover. At two central Shark River Slough sites, fish abundance after the storm dropped by one magnitude of normal seasonal levels (from 20 fish/m^2 to 2 fish/m^2, and from 54 fish/

m^2 to 5 fish/m^2). The high variability in the spotty historical record complicates determining a statistically significant decline of the abundance from the storm.

Storm effects on hydrology and interior water quality were not remarkable within the time frame of this investigation. The hurricane was a relatively dry storm. The maximum precipitation in the parks was 11.4 cm (4.5 inches), and most areas received less than 4 cm (1.5 inches) of rainfall. Prestorm overland discharges of freshwater were normal for the summer wet season, and water levels were slightly higher than normal. Storm winds affected water levels, especially in Taylor Slough, where they rose briefly more than 30 cm (1 foot) during the passage of the storm. The gradual rise in northwestern Shark River Slough at station P-34 during the weeks after the storm reflected high discharges through water control structures (S-12), after abnormally high rainfall in water management zones to the north. Suspension of flows into northeastern Shark Slough and loss of the two pump stations that deliver water to Taylor Slough reduced wetland water levels, hastened the drying of marshes, and reduced freshwater flow into northeastern Florida Bay. If the southern Dade County water delivery system is not restored quickly, marshes in eastern Everglades National Park will dry, persistent dry season flows will cease, and critically high salinities of Florida Bay will increase even more. Paradoxically, Hurricane Andrew has thus far exacerbated the drought-like conditions in northeastern Florida Bay rather than relieving it by flushing the bay with freshwater.

According to limited data from grab samples the storm had minimal effect on water quality in Everglades National Park. After the storm, nearly all water quality parameters were within the range of values recorded from 1986 to July 1992. The exceptions were temperatures at two central Shark River Slough stations that briefly increased 4 days after the storm, perhaps because of loss of periphyton cover. Short-term effects on water quality may not have been apparent in samples taken 4 days and 24 days after the storm. Evaluations of potential long-term storm influences on the biogeochemistry of the Everglades are recommended.

The most significant effect on freshwater resources was the destruction of the hydrologic and meteorological monitoring networks. In the storm track, 80% of the monitoring stations sustained significant damage, virtually all gauges must again be examined to ensure accurate reference to sea level.

Marine Resources

The major storm effects in the marine environment were changes in nearshore water quality, patches of intense bottom-scouring, and beach inundation. Drastic turbidity persisted in some areas at least 30 days after the storm, particularly in western Biscayne Bay where mangrove peat soils continued to break down and enter the water column. In northeastern Florida Bay, at the southern edge of the affected area, dissolved phosphate, ammonium, and dissolved organic carbon increased drastically. Plankton blooms intensified turbidity that, combined with low oxygen levels, could have severe, long-term effects on fish and invertebrate populations. Fuel from hundreds of damaged boats in Biscayne Bay and adjacent marinas continued to discharge into the water at least 27 days after the storm.

Hard-bottom (rock reef) communities in central Biscayne Bay were scoured heavily in some areas, appearing as if they were repeatedly trawled. Sponges, octocorals, and corals were sheared from the substrate and were lying amongst expansive wracks of debris of sea grasses, algae, and mangrove leaves. Half of the sponges were missing from fixed plots sampled before and after the storm, and some remaining individuals were killed by sedimentation. In other areas, more than 90% of the larger sea whips and sponges were missing; the smaller individuals survived. Most of the juvenile spiny lobsters *(Panulirus argus)* that resided under the sponges and corals in central Biscayne Bay were not present after the storm. Their fate may not be known for several years, until that cohort is recruited into the offshore fishery. In eastern Biscayne Bay within 1 km (0.6 miles) of Elliott Key, and in southeastern Florida Bay, benthic communities appeared relatively unaffected: lobster, sponge, and coral abundance were virtually the same before and after the storm.

Cape Sable and other western coast beaches experienced inundations of 3-13 m (9.8-42.7 feet); the deposition in a new beach ridge was as much as 100 cm (39.4 inches). Beach modifications from this storm are minor in comparison with those from slower moving historical storms in Florida.

Disturbance to coral reefs was patchy but locally severe. Some reef tops were scoured, 200-year-old corals were rolled over, and branching corals were broken. Loose sponges of unknown origin accumulated at the bases of deep reefs. The levels of disturbance, however, are consistent with normal reef diagenesis.

The most severe reef damage was from anthropogenic debris. Lobster and crab traps smashed into corals and sponges. An artificial reef at a depth of 23 m (75.5 feet) broke up and moved into Biscayne National Park, where it was deposited on natural reefs.

Sea grass beds in the storm track survived intact. Propeller cuts in grass beds did not widen. Only some areas south of Key Biscayne showed evidence of storm surge or wave action in the form of elongate scour patterns cut 50-100 cm (19.7-39.4 inches) into the sea grass bed surface. These effects were in marked contrast with those of Hurricane Betsy in 1965 and other storms that caused extensive destruction to sea grass beds. Fishes in the mangrove zone also seemed relatively unaffected, as evidenced by the presence of tagged fish in virtually the same places they were before the storm.

Direct effects on marine wildlife by the storm were not remarkable. A standard aerial count of manatees in Everglades National Park revealed 209 manatees in 9.5 hours, the most counted since monitoring began several years ago. Sea turtle nesting beaches were probably improved by the inundation and deposition of more sand. Hatching after the storm indicated that surge and runoff did not inundate all nests. Known crocodile nesting beaches were south of the major storm influence and seemed unaffected. The status of adult and young-of-the-year crocodiles is unknown, but storm-related carcasses were not found.

Special Resource Issues

Hurricane-generated debris was deposited in metropolitan areas and had to be removed. A team identified the amount and types of debris, disposal sites, transportation of deposits, probable effects on resources, points of control, mitigation of damage, and management options for restoration of normal conditions.

The storm generated 15.3 million m^3 (20 million $yards^3$) of debris (six times the volume of Cheops great pyramid at Giza, Egypt). Most of the debris was trees and shrubs (73%) and building materials (24%), but some was hazardous waste such as paint, solvents, insecticides, and batteries. In spite of the urgency to dispose of this material, the Florida Department of Environmental Regulation recognizes in its Emergency Final Order of 26 August 1992, that "The hurricane has . . . created a risk of further substantial impact on the environment" in addition to direct devastation. As of 21 September 1992, the Dade County Department of Environmental Resources Management had authorized 81 dump sites and estimated that 100 will eventually be authorized. The U.S. Army Corps of Engineers manages most of the dump sites near National Park Service interests and prepared an environmental assessment describing their plans that was reviewed by the assessment team and Everglades National Park staff. If this material is burned, some will enter the parks, and, if it is stored in or on the ground, some will leach into ground water that will enter Everglades National Park or Biscayne National Park. As burning began, no one, including the National Park Service, was monitoring air quality in Dade County because the storm destroyed all monitoring equipment.

Archeological Resources

Marine archeologists resurveyed 14 of the 40 known shipwrecks in the parks and searched for newly uncovered sites. The storm removed sediment from at least two vessels revealing new artifacts, including a cannon and a wooden cannon truck from an early 18th century man-of-war. The degree to which hurricanes rework sediments and compromise the stratigraphic integrity of submerged archaeological material is not known. This storm revealed that hurricanes do not necessarily jumble entire wrecks, as suggested by some. Shipwrecks in Biscayne National Park were recently looted, and losses on at least one 1733 vintage site were significant.

Archeologists assessed a representative sample of 22 of more than 500 known upland sites in the three parks. Sampling was stratified by proximity to the storm track and site type (i.e., hammock, shell mound) so that a predictive model could be constructed to estimate total site disturbance.

Disturbance to upland archeological sites was generally minor. About 75% of the interior hammocks contained windthrown trees that exposed about 5% of each site. Sites along the Gulf Coast were similarly affected; about 80% of the sites contained windthrown trees that disturbed 10% of each site. Storm surge deposited about 30 cm (11.8 inches) of shell and sand on about one-third of the sampled Gulf Coast sites.

Recommendations for Immediate Action

Highest priorities:
1. restore environmental monitoring
2. protect exposed archeological material on shipwrecks
3. remove nonnative animals
4. determine short-term ecological storm effects
5. replace boat warning signs that protect manatees

Second-order priorities:
1. determine nonnative and native plant population status
2. determine wildlife population status
3. improve environmental monitoring networks
4. limit effects of urban debris disposal on the environment

Third-order priorities:
1. survey disturbed archeological resources
2. remove artificial reef remains from Biscayne National Park
3. restore integrity of Cape Sable coastal marshes
4. protect resources threatened by cleanup activities
5. evaluate storm-altered management practices
6. determine effects of urban debris disposal on parks

The storm destroyed most of the National Park Service networks in the parks that monitor the quality of hydrology, marine water quality, meteorology, and air. The networks must be replaced to measure the potential effects of posthurricane cleanup on air and water quality and to evaluate short-term ecological responses. Historic shipwrecks exposed by the storm must be stabilized and monitored to enhance site protection. Backcountry patrols must be increased to above normal levels to detect and remove nonnative animals before they become established in the parks. Techniques for removing nonnative animals may need to be developed and tested.

Studies of the short-term ecological effects of Hurricane Andrew must be initiated while the first, most profound changes are taking place. Historical data must be compiled and analyzed for a basis of studies and monitoring plots stratified by hurricane influence. Opportunities to determine spatial variability of storm effects, to examine the roles of storm-altered detritus distribution and nutrient cycling, and to evaluate storm effects on fishery recruitment, subtidal (the area, or zone, below the influence of tides, not exposed during normal low tides) sediments, and heavy metals in hardwood hammocks will be soon lost.

Seedling nonnative plants must be surveyed to assess the extent and magnitude of storm-caused spread and to determine whether new control methods must be developed. The status of mangrove forests and rare plant populations will not be apparent until a year after the storm. The environmental monitoring networks must be strengthened to survive future storms. Additional monitoring sites are needed to evaluate storm effects on park resources and to link effects on upland to effects on estuarine and marine systems. Detection of storm effects on fish and wildlife requires intensified surveys during reproduction seasons to document natality and recruitment.

Significant park staff time is required to coordinate debris disposal regulated by other agencies to ensure protection of park interests. The National Park Service must evaluate emissions from debris burning, model air quality and visibility, and monitor air quality, visibility, and meteorology to determine the effects on park resources.

The hurricane exposed significant amounts of archeological material on upland sites that must be surveyed, monitored, and protected from vandalism. Debris of the artificial reef must be removed from natural reefs before it is incorporated into the sediment and overgrown. Its damage to the reef must be documented for developing guidelines for future artificial reef placement. Storm-breached plugs in canals on Cape Sable permit accelerated saltwater intrusion into coastal marshes and will continue to widen with tidal flushing if not repaired soon. More permanent restoration of these marshes, such as filling in longer sections of the canals near the coast, must be employed to prevent this kind of damage and to avoid repair costs with each hurricane. Fire management practices must be verified after storm-altered fuel loads. The effects of cleanup on rare plants and archeological resources and opportunities for interpreting hurricane influences on native communities must be evaluated. The effects of storm-altered shelter for manatee and crocodile populations must be considered before public facilities and access are fully restored.

Recommendations for Long-term Actions

Long-term actions must be taken to protect park resources. These actions will provide a basis for understanding resource dynamics, the relative effects of human activities on park resources in South Florida, and the effects of natural extreme events like hurricanes.

Without long-term data sets, natural dynamics driven by hurricanes, fires, and freezes, cannot be differentiated from changes caused by chronic environmental stresses like habitat fragmentation, nonnative species, and altered air and water quality. Correlations among system components are the best indications of ecological cause-and-effect relations until large-scale, long-term controlled experiments can be conducted. Such experiments may never be possible in South Florida. Systematic measuring reveals what drives the systems and human effects on the environment. For example, vegetation plots established to monitor effects of Hurricane Donna in 1960 were lost because the park did not maintain them. As a result, the effects of Hurricane Andrew cannot be compared with previous storms or human activities. As long as the effects of human and natural forces on park resources are not known, defense of the parks from chronic stress will continue to be delayed and uncertain. The monitoring should be designed to determine current and future health of ecosystems, establish empirical limits of variability, diagnose abnormal conditions early enough to implement remedial actions, and identify potential agents of ecological change.

Research is also needed to assess the potential of Hurricane Andrew to alter flows of energy and nutrients in South Florida ecosystems. Potential nutrient release from storm-related detritus and the effect of changes in landscape heterogeneity on large animals must be measured over time. Because the Everglades landscape may be described as a mosaic of terrains or drainage basins that traverse several physiographic subregions in South Florida, a variety of approaches will be necessary to address these questions. Past research and restoration focused on individual species or habitats, usually within limited spatial or temporal scales. A lack of integrated understanding of the system's response to anthropogenic and natural perturbations, such as Hurricane Andrew, severely restricts restoration and management efforts.

Introduction

The eye of Hurricane Andrew made landfall at Homestead, Florida, at 0455 hours on 24 August 1992. This compact, intense storm, with winds of 250 km/h and with one of the lowest central pressures ever recorded, created a path of destruction across the Florida Peninsula, from Key Largo to north Miami (Fig. 1). The storm swept through the center of Biscayne National Park, Everglades National Park, and the southern portion of Big Cypress National Preserve. Park ecosystems in South Florida have evolved under a regime of hurricanes and other extreme environmental events. Chronic stress from fragmented habitats and altered water resources has probably reduced ecosystem resilience, as well as the ability of populations to restore themselves after severe natural events like Hurricane Andrew.

Purpose

The National Park Service (NPS), because of the efforts of Regional Chief Scientist Dominic Dottavio, Southeast Region, assembled a professional resource assessment team to evaluate the ecological and archeological effects of the hurricane on the resources of the three national park system units in South Florida. This scientific team determined the resource conditions immediately after the storm, prescribed immediate actions to stabilize threatened resources, and identified long-term activities to ensure continuance of park ecosystems.

As soon as support systems and facilities could accommodate additional personnel, 23 scientists joined the park staffs and began to determine the boundaries of the storm's influence on coral reefs, sea grass beds, hardwood hammocks, mangrove forests, saw grass marshes, pine forests, historic shipwrecks, and archeological sites. The status of populations and habitats of endangered species, such as panthers, crocodiles, and bald eagles, and more common species that characterize the park ecosystems were evaluated. The team also examined the quality of air and water and measured organic debris and sediments that shape biological communities. The team examined archeological, freshwater, marine, and upland resources (Fig. 2).

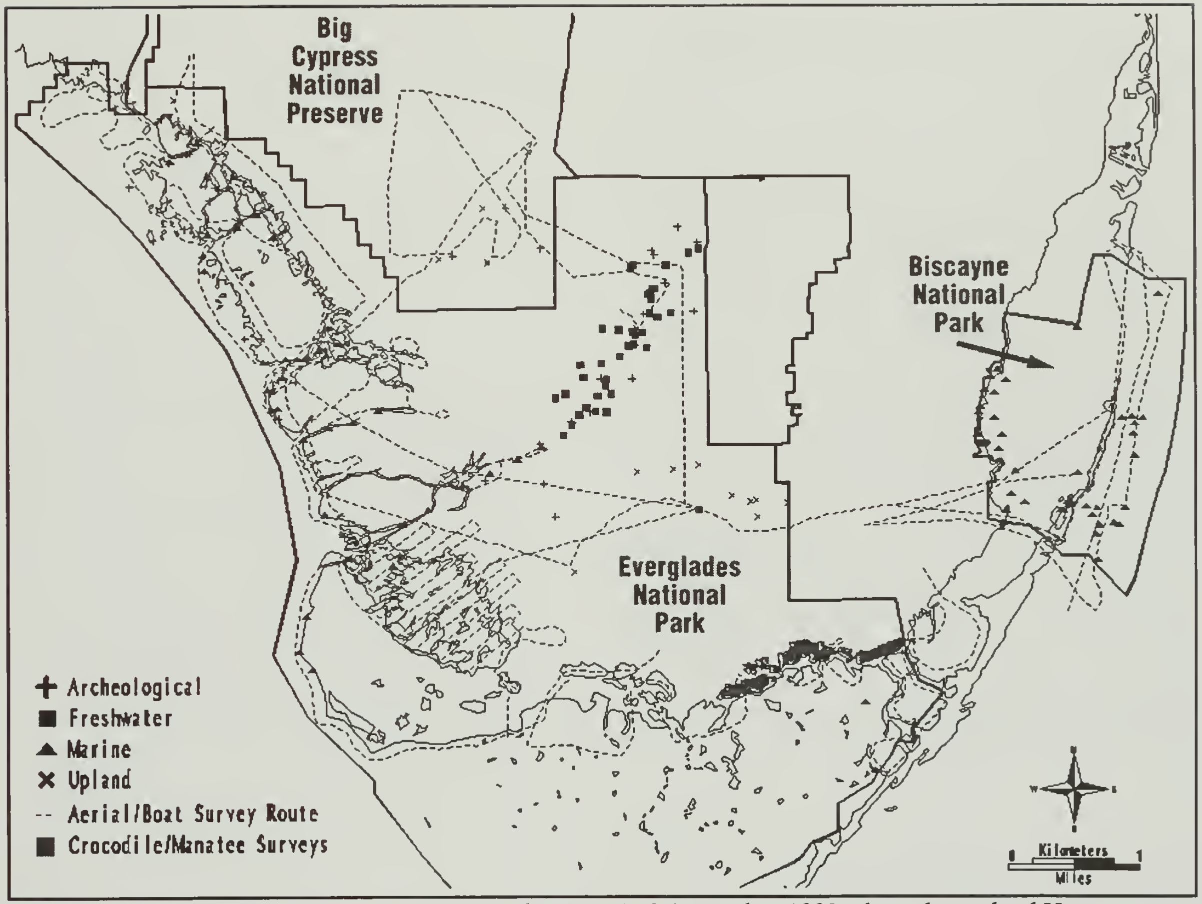

Figure 2. Sites surveyed to assess resource conditions, 14-23 September 1992, along the path of Hurricane Andrew across South Florida.

Objectives

The objectives of the resource assessment team were to:

1. assess resource conditions in Big Cypress, Biscayne, and Everglades following passage of Hurricane Andrew,
2. identify cultural and natural resources most at risk,
3. plan immediate mitigation and interim monitoring, and
4. identify long-term resource recovery issues and monitoring needs.

Participants

The team was composed of specialists from many fields, ranging from archeologists and curators to marine biologists and systems ecologists. They were drawn from government agencies, universities, and private conservation organizations and were selected for their outstanding knowledge of South Florida ecosystems. Some members served as consultants in survey design and report review. Others coordinated field teams in their general areas of expertise, whereas still others compiled existing information on and conducted observations of resource conditions. Virtually all of the specialists contributed to identifying the research, monitoring, and management actions that will be required for long-term protection of the park resources.

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Freshwater Resources

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Assessment Procedures

Assessment Procedures

Upland Resources

The upland resource team focused on the following:

1. determining the effects of Hurricane Andrew on upland vegetation types: pinelands, tropical hardwood hammocks, bayheads and bayhead swamp forests, and cypress forests
2. determining the effects of the storm on selected plant and animal species, with special attention to rare, threatened, endangered, and keystone taxa
3. determining the probable effects of the storm on the future spread of invasive nonnative (exotic or alien) species.

The team surveyed the storm-affected area by helicopter, car, boat, and on foot; consulted with specialists knowledgeable of the resources; reviewed the available literature on hurricane effects and on South Florida ecosystems; and contributed personal experience.

The team measured severity in terms of the general degree of effect in an area (i.e., trees showing evidence of major damage, uprooting, or loss of only branches instead of stem breakage) and in terms of the frequency of local patches of severe damage that was associated with isolated strong wind gusts.

For this report, the upland resource team considered major structural damage to canopy trees to be that which would likely result in long-term effects on the community and the trees themselves. This damage included loss of all larger branches, bent stems, main stem breakage, and uprooting. Defoliation and loss of small branches will also affect community productivity in the short-term, but recovery to predisturbance conditions should occur rapidly from these impacts. These damages are considered minor.

Wildlife and Other Species of Concern

The upland and freshwater resource teams conducted wildlife assessments. The teams made and recorded general observations of habitat status during the posthurricane assessment. They also conducted more quantitative assessments (e.g., surveys of wading birds, alligator nests, and deer, and telemetry tracking of panthers, deer, and bears).

Freshwater Resources

In addition to the wildlife assessments, the freshwater resource team also focused on the hurricane effects related to hydrology, surface water quality, poststorm detrital flux, and fish and macroinvertebrate community responses. The team's general approach included quantitative data collection and analyses, with numerous observations and qualitative assessments of freshwater resource and habitat conditions. The quantitative aspects of the assessment enabled the team to interpret the hurricane effects with some certainty. The team considered this approach to be especially important, and they focused much of the assessment on resampling long-term study sites and monitoring sites and conducting routine systematic aerial surveys. Clearly, a 1-week assessment was not even remotely adequate to investigate the delayed responses of biotic ecosystem components or system recovery dynamics.

Both short- and long-term investigations will be necessary to completely assess the effects of Hurricane Andrew on the freshwater aquatic resources of Everglades and Big Cypress. Recommendations for immediate, short-term (1-2 years), and longer-term research and monitoring efforts are presented in the recommendations section.

The parallel effort to plan and coordinate the research and monitoring programs in the Everglades system, required as part of the Everglades lawsuit settlement agreement and the Marjory Stoneman Douglas Everglades Protection Act (373.4592 FS), deserves mention when considering the effects of Hurricane Andrew on the freshwater resources of Everglades, Big Cypress, and adjacent areas. Part of the Everglades Nutrient Threshold Research Plan will prescribe the research that is needed to assess the responses of the Everglades to nutrient inputs and to determine maximum levels of nutrients that will not cause ecological imbalances. The experimental approach will combine field monitoring, field perturbations (nutrient-dosing studies), and laboratory experiments.

Some overlap may exist between the studies proposed in this hurricane assessment and in the threshold plan. Because the plan is still being developed and because of the limited time that was available to prepare this report, linkages between the two efforts could not be made. The freshwater resource team recommends that the technical oversight committee that is responsible for reviewing the threshold plan incorporate appropriate research to account for potential impacts from Hurricane Andrew.

Marine Resources

The marine resource team assessed water quality, sediment erosion and deposition, sea grass beds, hard-bottom communities, coral reefs, mangrove forests, and fish and wildlife populations.

The team conducted general surveys by overflights and by boat to map turbidity after the hurricane, to determine maximum turbidity areas, and to retrieve data from the Florida Bay monitoring station. They also sampled selected water quality and chemistry stations existing before Hurricane Andrew in Biscayne Bay, Florida Bay, and along the west coast of the Florida Peninsula.

The Dade County Department of Environmental Resources Management (DERM) operates a number of water quality monitoring stations in Biscayne Bay. After the storm, DERM personnel collected and evaluated data from these stations. Everglades National Park, along with the Florida International University and the South Florida Water Management District, maintains 28 stations in Florida Bay and 21 stations on the southwest coast, from Coot Bay to Lostmans River. These stations were sampled as part of the resource assessment. Parameters that were measured included salinity, temperature, tide stage, dissolved inorganic nutrients (ammonium, nitrite, nitrate, phosphate), total nitrogen, total phosphorus, dissolved organic carbon, chlorophyll A, alkaline phosphatase activity, dissolved oxygen, and turbidity.

The team analyzed storm runoff and pollution potential from the southern Dade County landfill and coastal canals and documented pollution and nutrient-loading impacts to identify potential problem areas. They also obtained storm information data from the other monitoring sources (e.g., the Florida Institute of Oceanography CNET program, the Florida Power & Light, and the National Oceanic and Atmospheric Administration).

The team mapped scoured and depositional areas, delta changes, and new channel formations and identified areas of shore erosion and deposition.

Many of these observations were visual comparisons with personally known (and photographed) preexisting conditions. They sampled established sediment-coring stations, from Caesar Creek to Pacific Light and in Biscayne Bay, and evaluated suspended sediment-loading in nearshore areas.

The team established immediate reference marks at selected locations for sediment accumulation and movement. They determined changes in beach position, thickness of storm layers, and amount of landward encroachment of inundation sand lobes. They also determined shore erosion by examining the surviving tree-root systems, measuring the seaward extent of penetrating roots, and recording the amount of eroded trees to landward.

The team measured elevations of flood levels on the west coast, from the post-storm high-water wrackline 30-60 cm (1-2 feet) above mean water level. Whether this level persisted landward from the shore berm determined whether this was a true flooding level or just a berm inundation level. They also surveyed surviving outhouses in wilderness campsites for a waterline inside that records flood levels.

The team determined the thickness of beach, swamp, and land storm layer by trenching with a shovel. The layer was sampled by pushing a 7.62-cm (3-inch) diameter aluminum core tubing into the sediment sequence, capping and removing it, and capping the bottom. Shallow subtidal layers were sampled in a similar manner. Sediment samples from the deeper subtidal layers (bays and channels) were attached to a longer tube having a one-way valve. From the boat, the core assembly was inserted vertically, removed, and the bottom capped before the top-valve seal was broken. The core was then taped to prevent water-sediment leakage, labeled, and transported in an upright position to the laboratory. The sample was then drained of water, the aluminum tube was slit open, and the core sample was split in half, lengthwise. Half of the core was photographed and subsampled, and the other half was archived. Cores and subsamples were stored in jars or sealed plastic bags at 3°C (37°F).

The team collected suspended particulate samples by lowering a flask into the water to about 30 cm (11.8 inches) beneath the surface, turning it right-side up to fill, capping it with Saran® wrap and a rubber band, labeling the sample, and keeping the jar on ice or in a refrigerator until filtering (0.5-micron filter). The samples will provide a reconnaissance baseline for future samples, and analysis is not included in this report.

The general protocol was to survey an area by air then examine it from the ground. In addition to flights during the assessment period, some team members had flown over Biscayne Bay, Florida Bay, and the lower southwest coast immediately following the storm. Each scene was initially surveyed to determine any outstanding anomalies. Following that, specific questions were answered. Is the litter layer present? Is abnormal sedimentation or erosion present along the short shoots? Is epiphytism normal? Are typical grass-bed fishes and invertebrates present?

The Dade County Department of Environmental Resources Management has maintained a network of epibenthic community monitoring stations in Biscayne

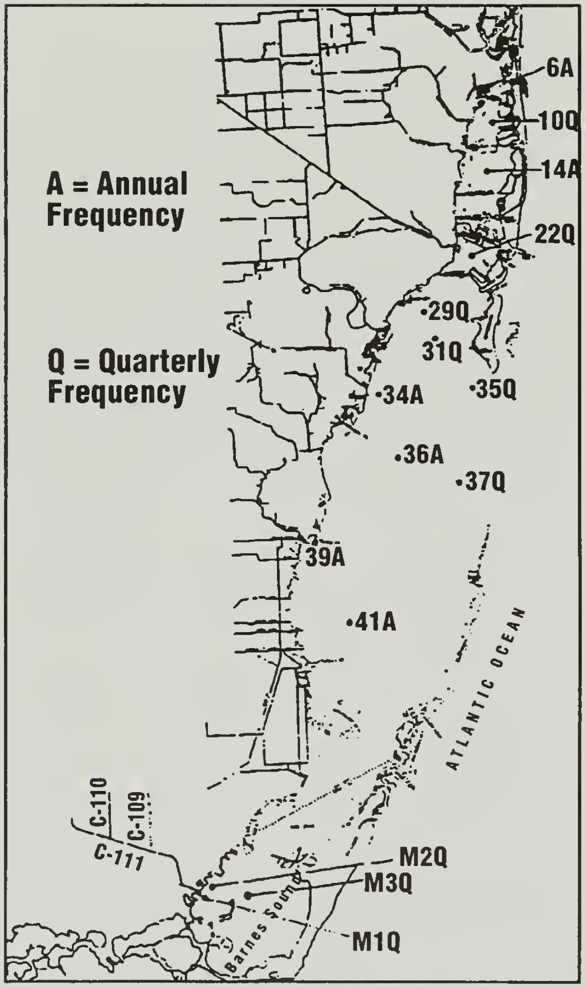

Figure 3. Epibenthic monitoring stations in Biscayne Bay, Florida.

Bay since September 1985 (Fig. 3). Stations are sampled quarterly. Three stations, in the direct path of the hurricane, were resampled on 29 September 1992. Three fixed 1- x 1-m grids (3.3- x 3.3-foot), subdivided into 25 equal subunits, were located along a line transect at each station. Within each grid, 5 of the subunits were randomly selected for counting. Sea grass short shoots and blades were counted for each species of sea grass present within each subgrid. Standing crop and productivity stations in Florida Bay were resampled after Hurricane Andrew using the standard marking methods of Zieman (1974). The abundance, composition, and occurrence of sea grass shoreline rack and floating mat were used as indicators of bed losses.

In 1990, Biscayne established monitoring plots and since then has periodically recorded at several locations the density, recruitment, and mortality of commercial sponge species. An attempt was made to resample each of these monitoring plots, as some plot markers were moved or destroyed by the storm.

The team assessed reefs from 16 September through 22 September 1992. They started at the southern end of the Biscayne reef tract and progressed north through Rubicon, Elkhorn, Alias, Pacific, Ajar, Long, and Triumph and ended at the Kavorkian Memorial artificial reef site on the northern

Biscayne boundary. An east-west component was defined by evaluating the reefs at Bache Shoals, the Fowey shipwreck site, and at Triumph Reef.

We obtained a simple, qualitative, snapshot of the damage that the storm did to the coral reef platform. At each of the sites, the team recorded signs of breakage, abrasion, out-of-place or new rubble piles, an excessive or unusual silt cover, tissue loss, excessive abrasion, and finally, sediment structure.

In addition, the team collected samples for water quality and sediment analyses. A concern existed that a major impact of the hurricane on both Biscayne Bay and offshore marine communities would be a longer-term deterioration of water quality from sediment resuspension and decaying organic matter.

Ground and aerial surveys were used to assess damage in the mangrove forests. The surveys were conducted to obtain information concerning damage on both north-south and seaward-landward gradients in the forest. At each site, observations were made on the forest species composition, height before the storm, stem diameter, presence or absence of regrowth of damaged stems, presence of seedlings or saplings or both that had survived the storm, and whether sediment had been deposited at the site.

Special Resource Issues

Air Resources

Special issues relating to air and water resources included storm debris disposal and discharges from canals into Biscayne Bay. The potential effects of the poststorm burning and disposal activities on the air and water resources of the national parks in South Florida were assessed by:

1. sharing reports with appropriate federal, state, and local regulatory officials;
2. determining and mapping the location of all county-approved debris-burning sites;
3. assessing the potential impacts of air-curtain incineration and other available disposal methods on air quality and water resources, such as landfill, recycling, and enclosed incineration methods;
4. evaluating the potential for resource degradation in the national park system units in South Florida from airborne pollutants, atmospheric deposition, and potential surface runoff or groundwater contamination; and
5. assessing the impacts and possible management actions to limit, where possible, resource degradation.

Water Resources

Five coastal water management canals discharge into Biscayne Bay between the northern boundary of Biscayne and Convoy Point. Of these, the Black Creek Goulds canal (C-1 watershed), the Princeton canal (C-102 watershed), and the Mowry canal (C-103 watershed) drain into relatively large watersheds that contain a mix of urban-suburban and agricultural landscapes. In addition, the southern Dade County solid waste plant and landfill and the Miami-Dade Water and Sewer Authority's southern Dade County regional wastewater treatment facility are located adjacent to Black Creek, less than 1.6 km (1 mile) from its discharge point into Biscayne Bay. Two additional canals, the Military canal, which drains Homestead Air Force Base, and the North canal, which drains into relatively small watersheds, also discharge into this section of Biscayne Bay.

Water quality and the effects of canal discharge into southern Biscayne Bay are long-standing management concerns at Biscayne. The impacts of storm-water runoff and leaching from the southern Dade County solid waste landfill have seriously degraded water quality in the Black Creek/Goulds canal system, and in bay areas around Black Point. Storm-water runoff has also created periodic problems in both the Princeton canal and Mowry canal.

Over the past several years, the National Park Service, the Dade County Department of Environmental Resources Management, and the South Florida Water Management District (SFWMD) have undertaken a number of unilateral and cooperative monitoring efforts and studies. The purpose is to better characterize and understand the impacts of these upland canal discharges on the bay ecosystem.

Hurricane Andrew devastated large portions of Biscayne National Park, and destroyed the park water quality laboratory. Fortunately, DERM and SFWMD laboratories and the Florida International University (FIU), Drinking Water Research Center, were not seriously affected by the storm. The Dade County Department of Environmental Resources Management, the South Florida Water Management District, and the Florida International University, working with the National Park Service, were able to conduct posthurricane water quality sampling in the coastal canals to determine what effects, if any, Hurricane Andrew had on the quantity and quality of water discharged into Biscayne Bay.

Archeology

The archeology team selected those sites nominated to the National Register of Historic Places or seem to be eligible for inclusion. Sites that contained human burials were also included. The selected sites were reached by helicopter or boat.

Site type, environmental setting, and distance and direction from the hurricane centerline were used in selecting terrestrial sites. The team selected representative sites in the Shark River Slough archeological district (Everglades), the Ten Thousand Islands archeological district (Everglades), the southeastern portion of Big Cypress adjoining the Shark River Slough area, and the island sites at Biscayne (Tables 1-3; Fig. 4).

The team surveyed 8 sites in the Shark River Slough archeological district, 20 sites in the Ten Thousand Islands archeological district, 3 terrestrial and 7 submerged sites in Biscayne, and 3 sites in Big Cypress. The team flew over several other sites.

They collected the following information at the surveyed terrestrial sites: site size, number of fallen trees, size of fallen trees, species of the fallen trees, soil type, artifacts exposed, human burials exposed, and amount of shoreline erosion.

The team selected submerged sites in Biscayne to reflect various ocean depths and exposure in relation to the offshore reefs, site types and age, previous level of data recorded, extent of exposure, and location within the park (Table 3; Fig. 4). They recorded moved and damaged structures and artifacts, damaged corals, natural *vs.* human impacts, sand wave heights and widths, and sediment accumulation or erosion.

The team selected the following sites to represent specific environmental variables: shallow, offshore exposed reeftop sites (Pacific Reef, Alicia, Mandalay, and Lugano); deep, offshore exposed site (Bell Wreck); open, reef-protected midrange 9.1 m (30 feet) depth northern site (Fowey); open, reef-protected midrange 9.1 m (30 feet) depth southern site (Populo); inshore, shallow, turtle grass bed protected (Hubbard); inshore, shallow, turtle grass bed channel exposed site (Safety Valve); southern, protected, shallow (less than 6.1 m [20 feet]) depth patch-reef sites Captain Ed's (turtle grass) and Black (exposed reef); and deep, open, sandy bottom, southern site (Pillar Dollar Wreck).

Sites were organized in relation to the storm path in the south, central, and north zones (Fig. 4): the south zone (below Pacific Reef) included Pillar Dollar, Captain Ed's shipwreck, and Black and Populo; the central zone (Pacific to Triumph reefs) included Pacific Reef, Morgans shipwreck, Hubbard-Ledbury, Alicia, Mandalay, Lugano, and Brick shipwreck; and the north zone (Triumph to Fowey Light) included Fowey, Safety Valve, and Bell shipwreck.

A visual survey by tow sled was required to locate many of the sites. The team conducted surveys for newly exposed sites in areas of known sites only while searching for known sites. Because the potential was not high for new sites being exposed, the team did not conduct a comprehensive visual survey for new sites.

Table 1. Archeological sites on Shark River Slough, Everglades National Park, Florida, that were examined for damage by Hurricane Andrew.

Site Numbers	Rank	Site Type
Everglades EVER-28	2	Shell Midden, Agricultural
Everglades EVER-34	3	Habitation Midden, Dirt Midden
Everglades EVER-21	1	Habitation Midden, Dirt Midden, Camp
Everglades EVER-24	1	Habitation Midden, Agricultural Camp
Everglades EVER-171	3	Dirt Midden, Artifact Scatter
Everglades EVER-19	3	Habitation Midden, Dirt Midden, Burial
Everglades EVER-15	1	Habitation Midden, Dirt Midden, Burial
Everglades EVER-17	3	Dirt Midden, Camp
Everglades EVER-110	1	Habitation Midden, Dirt Midden, Habitation
Everglades EVER-118	3	Habitation Midden, Dirt Midden
Everglades EVER-119	1	Habitation Midden, Dirt Midden, Habit
Everglades EVER-101	1	Dirt Midden, Habitation
Everglades EVER-102	1	Dirt Midden, Agricultural
Everglades EVER-103	3	Habitation
Everglades EVER-186	1	Habitation Midden, Dirt Midden, Camp
Everglades EVER-188	1	Habitation, Recreation
Everglades EVER-107	2	Dirt Midden
Everglades EVER-99	2	Dirt Midden, Habitation Midden
Big Cypress BICY-52	1	Dirt Midden, Burial
Big Cypress BICY-44	1	Shell Midden
Big Cypress BICY-58	2	Dirt Midden, Camp

Note (Tables 1 and 2): Rank refers to the priority, based on resource significance, assigned to an archeological site for examination by the assessment team. Number 1 denotes the highest priority.

Table 2. Ten Thousand Islands archeological sites selected for investigation.

Site Numbers	Rank	Site Type
Everglades EVER-37	3	Shell Midden, Habitation Midden, Agricultural
Everglades EVER-42	3	Shell Midden, Habitation Midden
Everglades EVER-49	1	Shell Midden, Habitation Midden, Agricultural
Everglades EVER-40	2	Habitation Midden, Agricultural, Camp
Everglades EVER-36	1	Shell Midden, Habitation Midden, Agricultural
Everglades EVER-150	3	Shell Midden, Dirt Midden
Everglades EVER-52	3	Scatter
Everglades EVER-136	3	Shell Midden
Everglades EVER-4	3	Habitation Midden Agricultural, House
Everglades EVER-140	1	Burial Midden
Everglades EVER-151	1	Shell Midden
Everglades EVER-3	1	Shell Midden, Habitation Midden, Shell Work
Everglades EVER-143	1	Artifact Scatter
Everglades EVER-90	1	Artifact Scatter
Everglades EVER-85	1	Shell Midden, Habitation Midden, Agricultural
Everglades EVER-89	1	Shell Midden, Dirt Midden, Habitation Midden
Everglades EVER-81	2	Shell Midden
Everglades EVER-91	1	Habitation
Everglades EVER-158	3	Shell Midden
Everglades EVER-159	1	Shell Midden, Shell Work

Table 3. Florida Keys and submerged archeological sites selected for investigation.

Site Numbers	Site Type	Location Name
Biscayne BISC-48	Midden/Mound	Totten Key/Cane Creek
Biscayne BISC-49	Shellworks Complex	Sands Key #2
Biscayne BISC-46	Shell Midden	Elliott Key
Biscayne BISC-2	Shipwreck	Hubbard/Ledbury
Biscayne BISC-35	Wreck	Pillar Dollar
Biscayne BISC-22	Wreck	Glauber-Biggers
Biscayne BISC-23	Vessel	Populo
Biscayne BISC-20	Warship/sunk	HMS Fowey
Biscayne BISC-29	Wreck	Pacific Reef
Biscayne BISC-36	Wreck	Ledbury Reef

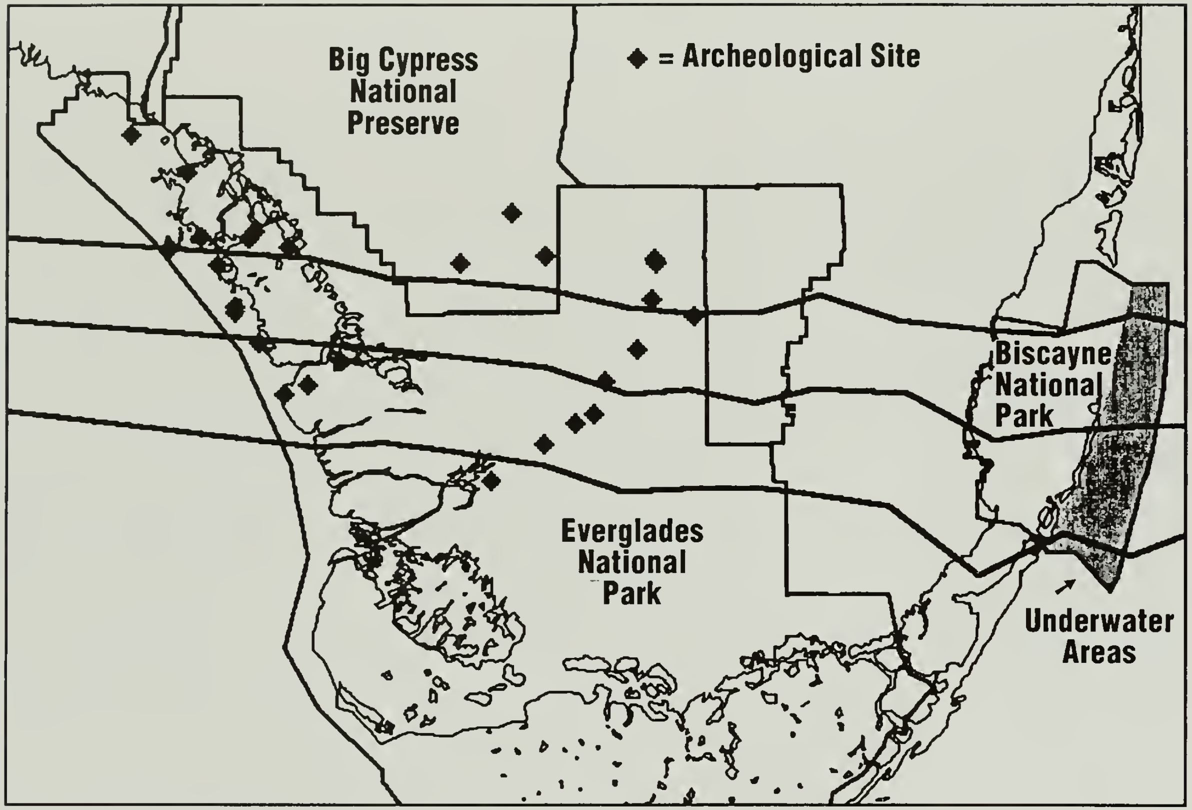

Figure 4. Archeological sites and underwater areas surveyed to assess resource conditions in Everglades National Park and Big Cypress National Preserve, Florida.

Resource Conditions

Resource Conditions

Upland Resources

General Observations and Overview

Hurricane Andrew drastically affected a band of vegetation about 50-km wide. The east-west path was from Elliott and Sands keys in Biscayne, across the Long Pine Key and Shark River Slough areas of the Everglades, to the Ten Thousand Islands area of the Everglades (Fig. 5). The north-south boundary was from the portion of Big Cypress south of the Tamiami Trail to Cape Sable in the Everglades. Significant effects were detectable north of the Tamiami Trail (e.g., felling of red-cockaded woodpecker nesting trees). The northern edge of Cape Sable approximated the southern boundary of the affected area.

Damage to woody vegetation was most severe near the hurricane eye, where winds were strongest. The severity of the damage decreased with the distance from the eye. Loss of woody biomass was most severe in hardwood communities in the eye of the storm. In these sites, virtually every tree of the canopy or subcanopy was damaged. Many were uprooted or had their main stems broken; others lost numerous larger branches. Many smaller trees and shrubs were buried under the fallen canopy of larger trees. Away from the center of the hurricane, these same kinds of damage were found, although fewer trees were affected at any particular site and sites with any damage became less common. Both cypress and pine communities exhibited a similar pattern of decreasing damage from the hurricane eye to its margin. The damage to cypress was less severe than for the hardwood communities, even in the center of the hurricane. Pine stands in the hurricane path lost 25-40% of the trees (snapped trunks or uprooted). Trees not downed generally sustained only minor damage. The term "downed" is used to refer to trees that were either uprooted or snapped along the main stem.

Trees in the center of the storm lost all their leaves, but the loss decreased to a general thinning near the margins of the storm-affected area. The hardwood forests were most affected, both in terms of branch loss and defoliation. Cypress retained much of their foliage, although many of the leaves were killed. Pines undoubtedly lost some needles, but still had much live foliage after the storm. Leaves quickly resprouted in the weeks after the storm, particularly in the tropical hardwood forests. Hardwood forest canopies along the margins of the storm path will likely be near normal by the end of the 1993 growing season, as will cypress forests throughout the area. Hardwood forests in the center, however, will likely require a decade or more to develop a canopy cover comparable to what existed before Hurricane Andrew. This slow recovery is because of the extensive loss of stems and branches that will have to be replaced before a closed canopy will again develop on these sites. The opening of the pineland canopy, through loss of entire trees, will allow seedling and sapling pines to gradually recruit into the overstory in the coming decades.

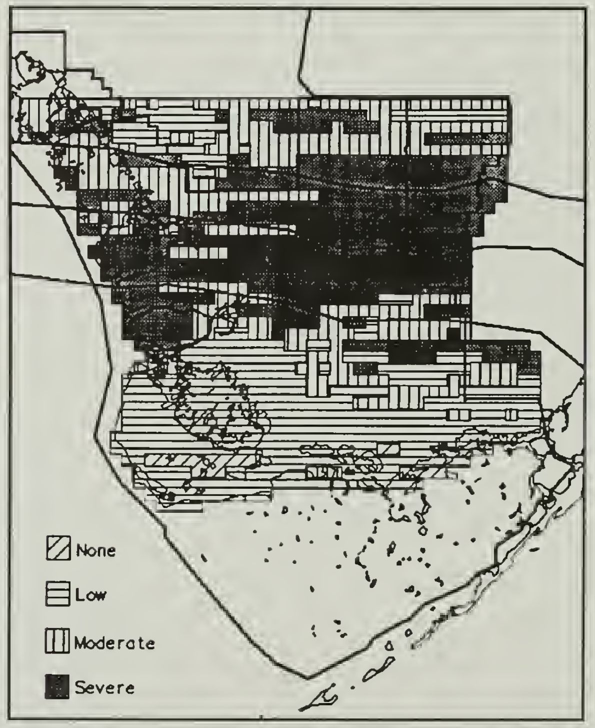

Figure 5. Severity of damaged vegetation (combined effects of windburn, defoliation, and stems fallen) on approximately 6 September 1992, in Everglades National Park and Big Cypress National Preserve, Florida.

Pinelands

The Long Pine Key area is the largest upland area of Everglades (about 7,500 ha [18,500 acres]). This area is a mosaic of pineland and tropical hardwood vegetation on a rough limestone (Miami oolite) substrate with abundant crevices, solution holes, and little soil development. South Florida slash pine *(Pinus elliottii* var. *densa)* forms an open canopy, with much light reaching the forest floor. The understory is diverse, composed of about 50 woody species, primarily of West Indian origin, and over 120 forbs and graminoids (details given in Olmsted et al. 1983, Snyder et al. 1990), including about 20 taxa endemic to South Florida.

Robertson (1953) described the fire adaptations and fire dependence of the pineland vegetation type. He pointed out that the presence of a number of light-requiring endemic species suggests a long history of fire in the area. Largely based on Robertson's work, the National Park Service has intensively managed the pinelands for almost 30 years using prescribed fire at intervals of 3-7 years (Everglades National Park 1991). This fire regime maintains a diverse understory, preventing shading out of the numerous herbaceous species. Almost all species, both herbaceous and woody, normally survive fire by resprouting. The mature pines 50 years old, 15-20 m (49-66 feet) tall, and 20-30 cm (7.9-11.8 inches) in diameter are only rarely killed by prescribed fires.

Hurricane Andrew has radically changed the structure of Long Pine Key pinelands by wind-throwing about 33% of the mature pines (17.8 cm [7 inches] or more dbh [diameter at breast height]; Everglades National Park 1992). Larger diameter (and probably taller) trees were more likely to have been wind-thrown. Based on data gathered by the Everglades National Park Fire Management Program, the pre-Andrew pine forest contained about 127 large trees/acre. Of these pines, about 40/acre were downed by Hurricane Andrew—vs. 1 or 2 pines/acre wind-thrown by Hurricane Donna, according to Craighead and Gilbert (1962). The pines snapped at heights of 1-6 m (3-20 feet); the mean seems to have been at about 3 m (9.8 feet). In the Long Pine Key area, about 2-3 times as many pines snapped as were uprooted. The downed pines will create openings in the canopy and allow pine saplings to recruit into the overstory. Seedlings and saplings will grow more rapidly with more light and nutrients. Fires will be less hot for a period because annual needle accumulation will be less in the gaps of the canopy, thus allowing many young trees to survive.

The hurricane did not affect the pineland understory. The pines apparently broke the force of the wind, and virtually no damage occurred to the leaves of shrubs and herbs in the understory. On hardwoods in the understory less than about 3 m (9.8 feet) tall, leaf damage, minor stem breakage, and some bark damage are the maximum effects that the team observed. At one site, the portion of 4 m (13 feet) *Lysiloma* shoots above 3 m (9.8 feet) were sheared by the wind.

The pinelands of Big Cypress most affected by Hurricane Andrew were those south of the Loop Road in the Stairsteps unit. This area, known as the Lostmans Pines, contains several islands that had not been logged, and some red-cockaded woodpecker colonies. The largest trees suffered the greatest damage. Many had broken boles 1-7 m (3.3-23 feet) above ground level, and a smaller number were wind-thrown with the roots lifted out of the ground. Many of the large old-growth trees remained standing, but lost most or all of their needle-bearing branches. Most of these will die. Estimates from three 50 x 50 m (164 x 164 feet) plots indicate that for trees more than 10 cm (3.9 inches) dbh, 56% were relatively undamaged, 24% suffered major branch losses, 2% were uprooted, and 18% had broken boles. If only trees greater than 25 cm (9.9 inches) dbh are considered, the number of undamaged trees drops to 21%, 38% suffered major branch losses, 9% were uprooted, and 32% had broken boles.

Smaller trees, particularly those less than 10 cm (3.9 inches) dbh, were often completely bent over, with their crowns pointing to the southwest. Whether this situation will result in significant mortality is not yet known.

In the Loop unit of Big Cypress, areas of hydric pinelands (with standing water in early September) showed a small percentage of windthrown trees, with large circular plates of roots and soil. This introduction of small-scale topographic relief into an otherwise flat, seasonally flooded landscape should increase local species diversity. The increase in diversity, however, could result in part from nonnative species that are otherwise excluded by hydrologic conditions. In pineland areas north of U.S. 41, the number of damaged trees declined rapidly to 1% or less of the mature trees.

Normally, fuels in pinelands consist of a relatively even layer that is dominated by pine-needle litter, with lesser amounts of live and dead fuels in the understory (Snyder 1986). The amount of fuels added to the understory by the storm should result in relatively little change in fire behavior (Everglades National Park 1992). The patchy nature of the fuels (i.e., entire pine crowns) should result in local areas experiencing higher intensity fires of longer duration. This situation may have important consequences on the effects of fires on shrubs and herbs of the understory, perhaps killing most individuals and opening sites on the order of a few square meters for colonization. This situation may serve to favor the endemic herbaceous species over the taller growing hardwoods.

As part of the fire management program, park personnel evaluated the fuels and reached the conclusion that no substantive change in prescriptions would be needed because the quantity of added fine fuels was small in relation to the fine fuels normally present. Increased coarse fuels will, however, result in 2-4 times more smoke, with air quality consequences that are not entirely clear. Long Pine Key hammocks would recover a canopy of sorts (though with little resemblance to a mature canopy) and regain normal soil moisture retention after about 2 years. Caution is needed during at least a 2-year period while this prediction is confirmed. Soil moisture readings should continue to be an adequate indication of when burning is permissible. The team, with reservation, concurs with the conclusions of the park personnel.

Historically, bark beetles have not been a problem in the Long Pine Key pinelands of Everglades. Given the large number of pines killed by the storm, however, a monitoring program would be prudent to watch for outbreaks.

Tropical Hardwood Hammocks

Tropical broad-leaved forests are found in the South Florida peninsula in disjunct units, locally referred to as hammocks (see Snyder et al. 1990 for discussion of what hammocks in South Florida are and what species they contain). For this report, hammocks refer to forest vegetation that is composed of flood-intolerant, West Indian tree species.

Hammocks are generally found on a limestone substrate, and less commonly found on a sandy or marl substrate. Hurricane Andrew affected those hammocks that are primarily on rock with tree roots firmly anchored in the channels and fissures in the limestone and in the shallow veneer of organic soil. In the Ten Thousand Islands region of Everglades, hammocks form on aboriginal shell mounds.

On 19 September 1992, the uplands resource team and W.B. Robertson, Jr., a member of the peer review team, conducted a field survey and aerial observations of the hammocks in the southern portion of Old Rhodes Key and the northern section of Totten Key in Biscayne. Damage to these hammocks by Hurricane Andrew was modest.

Occasional trees were thrown or snapped by the wind, or lost major branches, but the majority of the trees suffered only minor damage. Many smaller trees in the understory of the hammocks were apparently unaffected by the storm, and many retained leaves. Most of the plants also had many new leaves, and several species were flowering. A *Guettarda elliptica* plant even had immature fruit from flowers formed before the hurricane.

The effects on the hammock forests of Elliott Key at Biscayne were dramatic. Large trees were extensively damaged—20-30% downed and large branches sheared off nearly 100% of the remaining. Stands of shorter, smaller trees (particularly the forest that has grown up along the Spite Highway) survived with much less damage. Occasional areas of fallen trees were seen in this forest, but many of the plants apparently lost only minor branches. During an aerial survey on 16 September, we observed that trees along the Spite Highway were resprouting leaves more rapidly than trees in the more mature forests on either side. Few prestorm leaves were seen on any trees in the forest, so defoliation must have been virtually total, but recovery is proceeding rapidly. Gumbo limbo *(Bursera simaruba)* and *Lysiloma*, in particular, were resprouting leaves faster than most other species.

Buttonwood *(Conocarpus erectus)*, on the east coast of Elliott Key, was heavily battered by the storm with all leaves and small-to-medium branches removed. A few were uprooted. Leaves and stems were resprouting, but the regrowth was modest at the time of the survey and easy to miss until the plants were examined closely.

Litter was removed within 100-200 m (328-656 feet) of the shore in areas hit by a high storm surge. A heavy deposit of litter and debris often marked the inland limit of the storm surge. Storm surge affected both sides of Elliott Key, but seemed to have been stronger on the side of the island facing the mainland. A few inches of soil were apparently washed from the eastern coast by the storm surge in the vicinity of the Breezeway, but the erosion evidently did not kill any of the coastal trees.

In Everglades National Park, Mahogany hammock was less damaged by Hurricane Andrew in 1992 than by Donna in 1960, based on the account and photos of Craighead and Gilbert (1962). Mahogany hammock was also less affected by Andrew than were the Long Pine Key hammocks 16 km (10 miles) to the northeast. Many large branches of mahogany were broken off by the wind, but few trees were wind-thrown (about 1% of all trees >10.2 cm (4 in) diameter), and most trees making up the canopy still retained the majority of their prehurricane crown. Resprouting of leaves was well under way 3 weeks after the storm. Plants less than 4 m (13 feet) tall showed little sign of any wind damage, and most were apparently not defoliated. Several of the fallen trees and large branches hit the boardwalk. Traversing the boardwalk was still possible, but significant damage existed at several points and broken vegetation was resting on the boardwalk trail. Special care will be needed in boardwalk rehabilitation to avoid removing all evidence of the storm's effect.

The effects were as spectacular in the Long Pine Key hammocks as anywhere in natural vegetation of South Florida. We estimate that 20-30% of trees (> 4 in diameter) were blown down (mostly uprooted), but virtually 100% of those still standing lost major branches. Canopy cover was reduced from nearly 100% to about 30% (as measured 3-4 weeks after the storm), and gaps in the canopy on the order of 10-20 m (33-66 feet) wide are common. The abundance of fallen trees and large limbs on the ground made movement through the hammocks extremely difficult.

Hammock trees are shorter in stature—as tall as 14-16 m (46-52.5 feet) for wild tamarind *(Lysiloma latisiliqua)*, live oak *(Quercus virginiana)*, willow bustic *(Bumelia salicifolia)*, gumbo limbo *(Bursera simaruba)*—than pines (as tall as 20 m [66 feet]), but more susceptible to wind damage. Taller, larger diameter trees, however, seemed more susceptible to damage of all types. Live oaks and large wild tamarinds were hit particularly hard by Hurricane Andrew. Large oaks 75 cm (30 inches) in diameter, for example, lost 45 cm (18 inches) diameter branches. Several large wild tamarinds were wind-thrown in Osteen Hammock. Shorter trees were frequently knocked over or broken by larger ones, but rarely showed major damage that could be unambiguously attributed to wind. Virtually all tree-sized plants in Long Pine Key hammocks, except oaks, were defoliated; oaks were only partly defoliated, but the remaining leaves were in poor shape. For most hammock species, resprouting of leaves was well advanced 3-4 weeks after Hurricane Andrew. Oaks were slower at resprouting than other species; gumbo limbo and wild tamarind were faster.

Plants of the understory as tall as 2 m (6.6 feet), and seedlings and saplings of the trees of the overstory, seem to have fared well during the storm. Many of these plants apparently retained at least part of their foliage through the hurricane, except those near the edges of the hammocks.

In Long Pine Key hammocks, grapevines (*Vitis* spp.), poison ivy *(Toxicodendron radicans)*, and Virginia creeper *(Parthenocissus quinquefolia)* were already responding to canopy openings. These vines are capable of producing foliage much more quickly than the hardwoods. They will conserve soil moisture, but prevent seedling establishment and possibly smother some of the partially uprooted trees.

In Royal Palm Hammock on the edge of Taylor Slough, as in the Long Pine Key hammocks, estimates of the percentage of trees downed ranged from 20-30% to 50-60%, including about 20% of the royal palms. The predominance of gumbo limbo trees in the area of the Gumbo Limbo Trail is more conspicuous than before Hurricane Andrew. As viewed from the Old Ingraham Highway, these trees were stripped of most small branches, but few had thrown or broken stems. They will survive and continue to dominate.

Hammocks in Shark Slough were damaged to the same degree as the Long Pine Key hammocks. In the hammock at Panther Mound, many of the dominants of the canopy were downed, although a few gumbo limbo and hackberry *(Celtis laevigata)* remained erect. These standing trees were all missing major branches, but were resprouting 3 weeks after the hurricane.

Dr. Tiger Hammock and Fritz Hammock in the southern portions of Big Cypress were also strongly affected by Hurricane Andrew, although less so than hammocks in Long Pine Key. Local areas in these hammocks were damaged, with many windthrown trees and large broken branches. Gaps in the canopy on the order of 10 m (33 feet) were formed within these areas. Such areas of damage covered about 50% of the hammock and the remainder was notably less damaged. Walking through these hammocks was possible by skirting the areas of maximum damage. As with other hammocks, the largest trees were more susceptible to wind damage (Steve Sparks, personal observations). An estimated 70% of the large wild tamarinds were wind-thrown during the storm in four hammocks in southern Big Cypress. Between the areas of major damage, most trees, even large emergents in the canopy, sustained only minor damage. Much of the prehurricane foliage remains in the understory and less damaged areas of these hammocks.

Farther north in Big Cypress, the hammocks again contained local areas of major damage, but the percentage of hammock affected was less at about 30% of the hammock. Pinecrest #40 contained patches of major damage. In contrast to other sites, large trees were not commonly wind-thrown in this hammock. Instead, large trees mostly lost major branches and smaller trees were more commonly wind-thrown.

Cabbage palm *(Sabal palmetto)* is a widespread understory species of the hammock that seems to have withstood the high winds of Hurricane Andrew better than most. In the areas experiencing the highest winds, few stems were wind-thrown, although the petioles of the older fronds were damaged and the newly emerging leaves were frayed. The leaves looked green and healthy 3 weeks after the storm. In some instances, sufficient mechanical damage may have been done to the stem apex that the plants will die. Damage to the leaf bases will possibly attract the palmetto weevil (*Rhynchophorous cruentatus*), which attacks stressed and dying palms much like bark beetles attack dying pine trees. The weevil larvae kill the palms by boring through the apical meristem.

Whigham et al. (1991) reported on the effect of a hurricane on a dry tropical forest in the northeast Yucatan Peninsula that resembles hammocks of South Florida. Common species include gumbo limbo *(Bursera simaruba)*, pigeonplum *(Coccoloba diversifolia)*, *Drypetes lateriflora*, *Sapindus saponaria*, and *Myrcianthes fragrans*. Hurricane Gilbert had winds of 300 km/h (187.5 mph). Effects were roughly similar to those observed in the Long Pine Key hammocks in Everglades and locally on Elliott Key of Biscayne after Hurricane Andrew. All trees were damaged and defoliated by Hurricane Gilbert, and most had only their largest branches remaining. Data for Gilbert were based on a sample of 1,447 trees in plots, with percentages as follows: tree uprooted (4.5%); trunks snapped (12.4%); trunk not snapped, but crown removed (10.7%); only largest branches remaining (41.3%); most large branches remaining (31.3%); and only twigs and small branches removed (7.3%).

After 2 years, 12.3% of the 1,447 trees in the plots had died, including 16% of those uprooted and 29% of those with snapped trunks. The authors suggest that low rates of tree mortality indicate that forest composition may change little as a result of the hurricane. Frangi and Lugo (1991), Walker (1991), Yih et al. (1991), and Duever and McCollom (1992) reported similar findings (little expected change in species composition). Whigham et al. (1991) stated that "most species at our site resprouted within one month, and the canopies of most trees had recovered dramatically within one year."

According to Whigham et. al. (1991), fires following the hurricane affected tree mortality in forests of the northeast Yucatan more than the hurricane itself. The mean annual precipitation of the northeast Yucatan is about 1,100 mm (43.3 inches) *vs* 1,161 mm (45.7 inches) at Flamingo and 1,600 mm (63 inches) at Homestead. Similarly, Craighead and Gilbert (1962) reported that severe fires followed the 1935 hurricane in South Florida with losses particularly severe to mahoganies between Crocodile Point and Flamingo.

Hilsenbeck (1976) sampled vegetation plots in old-growth hammock forests of southern Totten Key in Biscayne and on northern Key Largo. W. Robertson (personal communication) told the upland resource team that the south Totten Key hammock is the best example of old-growth hammock forest in the Florida Keys, much better than Lignum Vitae Key, for example. This fact is particularly notable for large diameter trees in general and for its many large individuals of lignum vitae (*Guaiacum sanctum*, Zygophyllaceae), which have been repeatedly rolled by hurricanes but resprouted. The Key Largo hammocks were south of the major area of hurricane effects, but Totten Key was affected. The team was not able to visit the southern Totten Key hammock during the assessment period because access was more difficult after Hurricane Andrew, but this area should be checked for effects of the hurricane. Resampling Hilsenbeck's plots would be especially valuable.

Defoliation and loss of small branches were widespread (occurring even far from the storm eye) and are probably of little long-term significance. Loss of major limbs, broken trunks, and uprooting are going to produce long-term changes because many seasons growth may be necessary to reconstruct the lost canopy and close the gaps in the canopy. During that period, the microclimate of the hammocks will be different from prehurricane conditions. Hammock soils will dry out faster from increased radiation and decreased relative humidity in the hammocks. As pointed out previously, fire managers at Everglades will continue to use hammock soil moisture as an index of whether or not burning in pinelands is safe. Big Cypress staff will take a similar approach. The greatest fire hazard of all may be on the islands at Biscayne, where drier conditions prevail and an ignition could cause a conflagration.

Bayheads and Bayhead Swamp Forests

Mature bayheads are closed-canopy forests on peat substrate consisting of tree species adapted to prolonged flooding (ground surface inundated 2-6 months/ year). Maximum canopy height is 8-10 m (26-32.8 feet). Red bay *(Persea borbonia)*, sweet bay *(Magnolia virginiana)*, dahoon holly *(Ilex cassine)*, red maple *(Acer rubrum)*, willow *(Salix caroliniana)*, wax myrtle *(Myrica cerifera)*, and cocoplum *(Chrysobalanus icaco)* dominate these stands. Pondapple *(Annona glabra)* often grows at the forest margin. The canopy of a mature bayhead is often so dense that the shaded understory is composed only of scattered individuals of swamp fern *(Blechnum serrulatum)* and leather fern *(Acrostichum danaefolium)*.

Bayhead swamp forests resemble bayheads in most characteristics except the canopy is open with a luxuriant understory (with saw grass, buttonbush, cattail, etc.). They typically exist in Shark Slough as the downstream portion of tree islands that have a tropical hardwood hammock on a bedrock platform at the upstream end.

Hurricane Andrew had strong, immediate effects on the structure of bayhead vegetation, but effects were quite variable. Few tree trunks were broken by the wind, although large branches were often snapped. Windthrows were common, but scattered in occurrence (except for wax myrtle). Many bayhead trees were left standing even in Shark Slough. Less damage occurred to the woody canopy structure in bayheads than adjoining hammocks at Panther Mound and other Shark Slough hammock-bayhead complexes. At the same time, local areas of major damage occurred in bayhead communities both north and south of the Tamiami Trail in Big Cypress. One such local event was seen in a red maple grove on the margin of Dr. Tiger Hammock. Approximately 40 trees were wind-thrown in a small area whereas a far greater number of trees nearby remained erect.

Striking differences were noted in the responses of individual bayhead species to Hurricane Andrew. Most wax myrtle were wind-thrown far away from the center of the hurricane effects. North of the Tamiami Trail wax myrtle were commonly downed, whereas the number of individual plants of other species affected was small. Dahoon holly seemed to be less susceptible to wind damage than most bayhead species, presumably, because of the narrow crown. Surprisingly, willows seemed to be the least susceptible to major wind damage. Most were left erect and suffered little more than defoliation. This lack of damage was particularly striking in the bayhead swamp forests downstream of Panther Mound. Wax myrtle and willow are essentially the only woody species in this community. The wax myrtle were all wind-thrown, but the willows were all erect. Similarly, willows in the Taylor Slough region of Everglades seemed to have suffered only minor damage.

Baldcypress Forests

In general, cypress *(Taxodium distichum)* showed modest effects over the area of the storm influence. Some scattered and local sites contained numerous trees that suffered major damage. Even in the most affected areas, cypress retained many of its leaves, although most of these were dead. In less affected areas, only some thinning of the leaves occurred; these leaves had begun to show their fall colors before the hurricane. September is well past the growing season for cypress, but some of the trees were resprouting leaves in Raccoon Point, far north of the path of the hurricane. Because the vast majority of the trees retained even small branches, resprouting leaves should be normal during the coming growing season. In the vicinity of the hurricane eye, 1-2% of the cypress suffered major damage (i.e., broken stems or uprooting). Moving away from the eye, major damage became less frequent and was confined primarily to scattered individuals. This pattern held for dwarf cypress and larger trees in the more dense domes and strands. Damage to cypress was less frequent and damage patterns related to tree size and proximity to the hurricane eye were less clear than for some of the other communities. Duever et al. (1984), however, noted that virtually all of the old-growth (300+ years) cypress at Corkscrew Swamp in southwest Florida showed obvious loss of upper portions of their stems or at least major branches, most likely as a result of past hurricanes. Staff at Corkscrew Swamp Sanctuary estimated that Hurricane Donna in 1960 caused major damage to about 30% of the large cypress trees. This information suggests that larger trees are more vulnerable to major damage.

On 18 September 1992, Duever visited a number of sites along the Flamingo road in the vicinity of Pa-hay-okee to look at the hurricane effects on cypress. At six small sites—where from a distance it looked as if the interior hammock vegetation had blown down leaving a surrounding partial or complete ring of cypress—the hammocks had been burned recently, possibly in the 1989 Ingraham fire. The hammocks have a large component of cabbage palms with recent fire scars, as well as bracken fern and sumac. A few hammocks did have some hurricane-damaged, medium-sized hardwoods, a minor remnant of the community present before the fire.

A number of the dwarf cypress sites in the vicinity of Rock Reef and Pa-hay-okee road junction were also obviously damaged by an earlier fire. Many sites still had standing dead stems, but 1-2 m (3.3-6.6 feet) tall, healthy resprouts were associated with most of these. With the exception of a few broken stems and uprooted trees, the majority of the dead cypress stems were definitely not a result of hurricane damage.

About 15 broken cypress stems were seen at the first cypress dome northwest of the road junction to Flamingo and Pa-hay-okee. They were mostly larger trees near the open center of the dome. A few broken stems of smaller cypress were seen closer to the outside edge of the dome. A number of both the smaller and larger damaged trees seemed to be in a line, suggesting that a single gust of wind could have done most of the damage. The stems were broken about 2-4 m (6.6-13.2 feet) above the ground. Numerous bromeliads from about 1-4 m (3.28-13.2 feet) above the ground were on the cypress trunks, suggesting that their distribution was influenced by the vertical wind intensity of the storm.

A number of downed trees were seen in another dome south of Flamingo road about 1.6 km (1 mile) from the Pa-hay-okee road junction. These trees were all uprooted cypress with what was obviously organic soils trapped in their upturned roots. The center of this dome did not seem to be open before the hurricane, and organics had filled in the deeper mineral depression in the dome center. Apparently this substrate provided a less secure foothold for the cypress, resulting in numerous tip-ups and no stem breaks among the many downed trees. Two apparently similar situations were seen in Big Cypress. In both instances, 20-40 trees were uprooted in a small area, although other nearby cypress showed no signs of major damage. At the site near Oasis, the uprooted trees were clearly growing in deep organic soils.

Forest Effects of Hurricanes Andrew and Hugo

Some interesting comparisons may be made between the effects of Hurricane Andrew on South Florida plant communities and the effects of Hurricane Hugo on an old-growth floodplain forest in South

Carolina. The floodplain forest, about 65 km (40 miles) from the coast, was in the eye of Hurricane Hugo. Three major community types were in the floodplain forest. These communities included a cypress-tupelo swamp forest on the deepest sites, an intermediate elevation bottomland hardwood forest, and a ridge bottom community that occupied low ridges in the floodplain about 1.5 m (4.7 feet) higher than the cypress-tupelo sites.

Trees on ridge bottom sites were severely affected and many died. The degree of major damage on ridge bottom sites—essentially high islands within a large wetland—was similar to the effects on hammocks in South Florida. The fact that the South Florida hammocks are dominated by tropical, relatively small, second-growth species, however, suggests that mortality will be significantly lower here than in South Carolina.

The most dramatic difference in the effects between the two storms was the high levels of damage and mortality of the pines in South Carolina, and the relatively low level of damage in South Florida. By the end of the second growing season, mortality was high (91%) for spruce pine (*Pinus glabra*; $n = 43$). Loblolly pine (*Pinus taeda*; $n = 7$) had only 57% mortality at this time, but at least two of the remaining three individuals died during the third growing season. Loblolly pine, showing severe damage, is taking longer to appear than spruce pine. Whereas species differences in the pines present in the two areas may be a significant factor in the different degrees of effects that were observed in the two areas, an additional factor could be size differences in the two populations. Many of the South Carolina trees were well over 0.5 m (1.6 feet) in diameter and more than 30 m (98.4 feet) tall, as compared to less than 0.3 m (.98 feet) dbh and 15-20 m (49-66 feet) tall in South Florida. Because the degree of damage generally seems to be directly related to size, the smaller trees in South Florida would have been expected to be relatively less vulnerable to hurricane winds.

Cypress in South Florida also suffered less damage from Hurricane Andrew than in South Carolina from Hurricane Hugo. A total of 46% of the cypress sampled in South Carolina sustained major damage, whereas in South Florida major damage was restricted to less than 5% of the trees. Again the smaller size of cypress in South Florida could have significantly influenced this difference.

Duever and McCollom (1992) assessed damage primarily on the basis of structural effects on vegetation of the canopy. Damage categories (and the percentage of trees over 15 cm (5.9 inches) dbh in each) included major branch loss (13%), bent stems (3%), main stem break (30%), and uprooting (13%). A total of 40% of the 1,233 trees in the sampled plots did not exhibit major damage. Whereas main stem breaks were the most frequent type of major damage, mortality was twice as high for uprooted trees (70% of uprooted trees).

Mortality for all trees living before Hurricane Hugo was 13% during the hurricane, 3% additional at the end of the first growing season, and 5% additional at the end of the second growing season. Mortality continued during the third growing season, although the data are not all available at this time. Thus, delayed mortality is a significant aspect of total hurricane damage, even for some trees that did not seem to be significantly damaged immediately following the storm. Of all the trees dying in a particular year, mortality of uprooted trees has declined in the 2 years since the hurricane (from about 50% to less than 30%), whereas broken stem tree mortality has remained steady (about 50%), and mortality of trees with major branch loss has increased over time (from about 0% to about 20%). Few (9%) of the bent stem trees have died during the first 2 years after the hurricane.

Effects of Hurricane Hugo were quite variable depending on the species involved. Water ash *(Fraxinus caroliniana)* exhibited relatively little damage (33%) and low mortality (7%). Blackgum (*Nyssa sylvatica*) and tupelo gum *(Nyssa aquatica)* exhibited moderate damage (46% and 47%) but low mortality (3% and 1%). Red maple (*Acer rubrum*) exhibited much damage (77%) but low mortality (8%). Spruce pine exhibited much damage (93%) and high mortality (91%). Loblolly pine exhibited moderate damage (57%) but high mortality (86%). Other species, which were well represented in the samples, exhibited a variety of damage and mortality patterns that are within these bounds.

The factors that influenced susceptibility to hurricane impacts included species, community type, tree size (larger trees were more affected), location in the site (most likely because of erratic strong gusts and varying degrees of exposure to hurricane winds), and random factors such as being in the way of a falling large tree. Undoubtedly significant interactions were involved among these factors.

Hurricane Effects on Rare Plants

Not much information is available in the ecological literature of the hurricane effects on rare plants. Craighead and Gilbert (1962) gave some detailed information after Hurricane Donna; in the mangrove area of Everglades, an estimated 90% of epiphytes were destroyed. In hammocks, glades, and pinelands, the loss was about 50%.

As a result of Hurricane Andrew, perhaps 80-90% of the epiphytes—orchids, bromeliads, and ferns—of Long Pine Key hammocks were destroyed, either by direct wind damage, through breakage of limbs they were on, or through sunburn after the hurricane. Yet in the pondapples along Anhinga Trail, most *Tillandsia* individuals seem to have survived. Such estimates are, however, severely hampered by lack of baseline data on epiphyte distribution and abundance. Loope and Avery (1979) made some predictions about which species were likely to be threatened by hurricanes. The team was not able to fully document a negative impact of Hurricane Andrew on any species, however, or to fully address the status of rare epiphytes because of time constraints, difficulty in reaching the hammocks because of downed pine trees over fire roads, and the difficulty in getting around in the hurricane-affected hammocks, and the lack of adequate baseline data.

Many of the rare plants in South Florida are endemic herbs or small shrubs that grow in the understory of pinelands. Others are West Indian species that have their northern distributional limits in South Florida. Epiphytes are a subset of West Indian species, treated separately here because of their distinctive growth form.

Endemics

Numerous endemic plants exist in South Florida (Table 4), particularly in the rocky pinelands. These endemic species are locally abundant but are of special concern to the National Park Service because the pinelands habitat outside of NPS protection has been almost eliminated (Snyder et al. 1990).

These species are mostly herbaceous plants, but three shrubs or small trees are also included. In general, the herb and shrub layers in the pinelands were not noticeably affected by the storm winds, so the endemics are not likely to have suffered significant damage. Fallen trees are the most significant source of direct hurricane damage, and they affected less than 2% of the ground surface.

Of the woody endemics, *Forestiera pinetorum* and *Lantana depressa* were seen during the survey of Long Pine Key in Everglades and, as expected, no significant damage was seen. *Colubrina cubensis* var. *floridana* was not seen because of the distance of known sites from cleared roads.

Many of the pineland herbaceous endemics were seen during the pineland surveys. No notable wind damage was seen in any site, and, based on past experience, these herbaceous plants under the fallen pines will largely resprout (A. Herndon, personal observation). Several of the endemics (*Borreria terminalis, Cassia deering-*

Table 4. *Endemic plants of national park system units in South Florida.*

Scientific Names	Scientific Names
Aeschynomene pratensis	*Galactia pinetorum*
Andropogon cabanisii	*Hedyotis nigricans var. floriana*
Argythamnia blodgettii	*Jacquemontia curtissii*
Borreria terminalis	*Lantana depressa*
Cassia deeringiana	*Linum carteri*
Chamaesyce conferta	*Ludwigia curtissii*
Chamaesyce garberi	*Melanthera parvifolia*
Chamaesyce pinetorum	*Phyllanthus caroliniensis subsp. saxicola*
Chamaesyce porteriana	*Phyllanthus pentaphyllus var. lloridanus*
Colubrina cubensis var. floriana	*Poinsettia pinetorum*
Digitaria pauciflora	*Ruellia caroliniensis var. succulenta*
Dyschoriste oblongifolia var. angusta	*Schizachyrium rhizomatum*
Elytraria carolinensis var. angustifolia	*Stylosanthes calcicola*
Forestiera pinetorum	*Tragia saxicola*

iana, Chamaesyce pinetorum, Chamaesyce porteriana, Melanthera parvifolia, Schizachyrium rhizomatum, and *Tragia saxicola)* were seen in bloom during the survey, particularly in the recently burned pinelands south of the Long Pine Key road near the Boy Scout camp.

Chamaesyce garberi is the only federally listed plant (as *Euphorbia garberi*) in national park system areas in South Florida. This species is currently known at two locations in Everglades. A population occurs in the prairies of the Cape Sable region (the type locality) and in the pinelands at the southern end of Deer Hammock in Long Pine Key. Populations at Cape Sable were not checked because they were outside the area of hurricane damage, and the population on Long Pine Key was not easily accessible. Based on the lack of damage to the similar *Chamaesyce porteriana* in accessible areas of the pinelands, it is likely that *C. garberi* was not adversely affected by Hurricane Andrew. An attempt should be made to verify this by surveying the Long Pine Key population as soon as the fire roads are passable.

Aeschynomene pratensis is the only endemic species in South Florida found in long-hydroperiod prairies, and *Ludwigia curtissii* is an inhabitant of short-hydroperiod prairies. Known sites for *Aeschynomene* in Shark Slough were not surveyed, but the species was observed in flower near Dr. Tiger Hammock in Big Cypress. No specific search was made for *Ludwigia* either, but the short-hydroperiod prairies near Taylor Slough showed no evidence of significant wind damage.

Although short-term effects of the hurricane on the endemics seem to be minimal, the long-term effects may be more substantial. For several years, the thin pine canopy will allow more light to reach the ground than in past years. This increased light will benefit all the understory plants in general. Whether the herbaceous plants will benefit more or less than the hardwood understory is unknown. If the hardwoods grow faster than normal because of the extra light, the net effect on herbaceous endemics may be negative.

West Indian Species

Many West Indian plants reach their northern limits in South Florida and several are uncommon or rare. Most of these species fall into four groups (excluding the epiphytes which are treated separately): the terrestrial ferns, the terrestrial orchids, the palms, and the tropical hardwoods.

Tropical terrestrial ferns of special interest in the national park system areas affected by Hurricane Andrew are *Adiantum melanoleucum, Lomariopsis kunzeana,* and *Sphenomeris clavata*. The first two are known from Osteen Hammock in Everglades. They were not seen during the survey of this hammock; the difficulty of travel through the hammock prevented a detailed search. Two ferns with similar habitat requirements, *Adiantum tenerum* and *Tectaria lobata*, were seen in Osteen. A small proportion of individuals in both species was sunburned, but all others seemed healthy. *Adiantum melanoleucum* and *Lomariopsis kunzeana* probably survived, but given the small populations, these species possibly were badly damaged. Further attempts should be made to locate these plants.

Terrestrial orchids of special interest in the hurricane-affected area are *Centrogenium setaceum, Galeandra beyrichii, Erythrodes querceticola, Spiranthes costaricensis,* and *S. cranicoides*. These orchids can only be studied for a brief period during the year, because the plants are totally underground except for a month or two around the blooming season. The damage will have to be assessed during the flowering season for each species. The plants would have suffered little direct damage during the storm. The effect of the thinned canopies on future population dynamics is unknown. *Centrogenium* and *Spiranthes costaricensis* had undergone rapid range expansion in the past decade (C. McCartney, and A. Herndon, personal observations). This expansion may suggest that those species prefer a denser shade and that their populations would be severely hurt by the thinning of hammock canopies.

Four species of palms considered uncommon or rare exist in the national park system areas affected by Hurricane Andrew. These species are silver thatch palm *(Coccothrinax argentata)*, buccaneer palm *(Pseudophoenix sargentii)*, royal palm *(Roystonea elata)*, and Florida thatch palm *(Thrinax radiata)*. All of these species, except the buccaneer palm, have substantial wild populations outside the area of major hurricane damage. In general, palms survived the hurricane with less apparent damage than any other group of plants, and these less common species did not fare substantially worse than the common palmetto *(Sabal palmetto)*. The major population of *Coccothrinax*, in the path of the storm, is found in the shrub layer of the Long Pine Key pinelands. A few plants were seen during the hammock surveys in this region, and, as expected, they showed little damage. *Thrinax* was not encountered during the survey of Biscayne, although it occurs on Elliott Key (Ward; pages 114-115 *in* Ward 1979). A search for known localities is needed to assess the damage to this species.

Royal palms are considered rare in Florida (F.C. Craighead, Sr., and D.B. Ward; pages 155-156 *in* Ward 1979). Wild populations are known in several hammocks in Everglades, although the largest wild population in the state is found in the Fakahatchee Strand (north of the area of major hurricane damage). Based on an aerial survey, many of the royal palms in Royal Palm Hammock (Everglades) survived, although the crowns of the trees were badly damaged. On the basis of a ground survey along the Old Ingraham Highway, approximately 20% of the emergent royal palms were blown down. Another 5% lost their crown shafts (usually killing the tree) but remained standing. Surviving royal palms were also observed during an aerial survey in a hammock (Johnson Mound) near the mouth of Lostmans River. The damage to crowns is dramatic but does not seem to be worse than the damage to crowns caused by freezes in the Fakahatcheee population (A. Herndon, personal observation). The standing palms are expected to recover fully, but a monitoring program would be advisable.

Buccaneer palm is considered endangered in Florida (F.C. Craighead, Sr., and D.B. Ward. Pages 54-55 *in* Ward 1979), although this palm is not uncommon in the Caribbean and in Mexico. A population of 13 wild individuals was known on Elliott Key (Biscayne) before Hurricane Andrew.

The team did not visit this population during the survey of Biscayne on 19 September 1992 because of time limitations, but, with a Biscayne guide, we were shown two groups of seedlings planted on Elliott Key 2 years ago by the curator of endangered plants at Fairchild Tropical Garden. The Center for Plant Conservation and Biscayne National Park supported this planting, with Biscayne personnel watering the plants for a year after planting. The three seedlings off the trail near Petrel Point were not damaged in spite of growing in the midst of a hammock with many large windthrown and broken trees. All were about 1 m (3.3 feet) tall and looked healthy. Of the three seedlings planted near the visitor center on Elliott Key, one was healthy, one was uprooted and dead, and the third was not located. Presumably it was hidden under some fallen vegetation. The currently open canopy in the hammock will allow the surviving seedlings to grow rapidly during the coming year. Studying the growth rates would be useful to determine whether this is true, because the answer has important implications for the role of disturbance in the life history of these palms. An attempt should also be made to survey the wild population as soon as possible.

Tropical hardwoods of interest in the affected areas are *Colubrina arborescens*, *Eupatorium villosum*, *Guaiacum sanctum*, *Hypelate trifoliata*, *Ilex krugiana*, and *Jacquinea keyensis*. *Guaiacum sanctum*, *Hypelate trifoliata*, and *Jacquinea keyensis* also have substantial populations outside the affected areas. *Colubrina*, *Eupatorium*, *Hypelate*, *Ilex*, and *Jacquinea* are shrubs or small trees in the shrub layer of Long Pine Key pinelands. This layer suffered little direct damage from the storm, so we assume that they were not strongly affected. This assumption was confirmed for *Eupatorium* and *Ilex* by direct observation during the survey of Wild Lime Hammock. *Hypelate* and *Ilex* also exist in hammocks in the Long Pine Key area, but a great majority of the population is found in pinelands for both of these species. The known populations of *Guaiacum* were not surveyed, but the largest stands are south of the area of greatest hurricane damage.

One final tropical species of special interest is the tree cactus, *Cereus gracilis* var. *simpsonii*. Populations of this cactus are scattered along the southwestern coast in the Ten Thousand Islands region of Everglades. No plants were seen during the surveys, but the low degree of damage makes it likely that the species survived intact. Loss of tall branches is quite common for this plant and has no notable impact on survival. Also, in most sites, this species seems to be light-limited, so the opening of the canopy may actually provide a more favorable habitat.

Epiphytes

Vascular epiphytes are overwhelmingly tropical in distribution, and several species reaching their northern limits in South Florida are uncommon or rare (Table 5). As a group, epiphytes probably suffered more mortality from the storm than any other plants because of their growth in locations that are particularly susceptible to wind damage (i.e., tree branches and tree trunks).

No confirmed locations were known for several of the epiphytes *(Brassia caudata*, *Macradenia lutescens*, *Peperomia glabella*, *Polypodium triseriale*, and *Rhipsalis baccifera)* before the storm, so no damage assessment was possible.

A few of the epiphytes found in South Florida *(Guzmania monostachia*, *Ophioglossum palmatum*, and *Trichomanes holopterum)* were only known from single sites in the national park system areas affected by Hurricane Andrew. Some of these populations were possibly eliminated. The *Trichomanes*, however, is the only species that does not have known populations outside

Table 5. Vascular epiphytes of special concern in national park system units in South Florida.

Scientific Names	Scientific Names
Asplenium serratum	*Peperomia glabella*
Brassia caudata	*Peperomia humilis*
Campylocentrum pachyrrhizum	*Peperomia obtusifolia*
Cyrtopodium punctatum	*Polypodium heterophyllum*
Catopsis berteroniana	*Polypodium plumula*
Catopsis floribunda	*Polypodium triseriale*
Encyclia boothiana	*Polyrrhiza lindenii*
Epidendrum anceps	*Pleurothallis gelida*
Epidendrum nocturnum	*Rhipsalis baccifera*
Guzmania monostachia	*Tillandsia flexuosa*
Macradenia lutescens	*Tillandis pruinosa*
Maxillaria crassifolia	*Trichomanes holopterum*
Oncidium luridum	*Vanilla barbellata*
Ophioglossum palmatum	*Vittaria lineata*
Peperomia floridana	

the storm area. *Guzmania monostachia* is the species most likely to have been hurt during the storm, because the Florida population is unable to grow in full sun. Loss of the hammock canopy could lead to the rapid death of an entire colony. An attempt was made to find the *Guzmania* population in Wild Lime Hammock, but no plants, either live or dead, were found. Most likely the area containing the *Guzmania* was missed during the survey because of the difficulty of moving through the hammock. A more detailed search will be necessary to determine the actual effect of the hurricane on this population.

The only epiphytes of special concern seen during the surveys of the Long Pine Key hammocks were *Epidendrum nocturnum*, *Peperomia floridana*, and *Vittaria lineata*. Plants of the *Epidendrum* were seen both in Wild Lime Hammock and the small hammock along the road to Pine Island. At both sites, the plants were small and unhealthy, but this may have been due largely to the effects of a freeze in December 1989 rather than Hurricane Andrew. The freeze of 1989 severely damaged plants of the more tropical orchids and greatly reduced the populations of *Encyclia cochleata*, *Epidendrum nocturnum*, and *Epidendrum rigidum* in the Long Pine Key hammocks (C. McCartney, personal communication and A. Herndon, personal observation). The small *Epidendrum* plants did not seem to be sunburned or in danger of dying, so they will likely survive. The lack of sightings of the less common epiphytes is not necessarily an ominous sign. Before the storm, considerable distances of hammocks could be traversed without seeing any of these species (A. Herndon, personal observation). After the hurricane, only short distances in the hammocks could be covered in the time available, so the lack of sightings may be more a function of the limited coverage of hammocks during the survey than a great loss of the epiphytes. Both the *Peperomia* and the *Vittaria* were healthy where seen and are expected to survive.

Polypodium heterophyllum, a species of the subcanopy, was seen in both Dr. Tiger Hammock and Pinecrest #40. A great majority of the populations seemed healthy, so the storm had only a small effect on this species. *Vittaria lineata* was also seen in these Big Cypress hammocks and seemed healthy.

A general impression from observing more common epiphytes *(Encyclia cochleata, Epidendrum tampense, Tillandsia balbisiana, T. fasciculata, T. setacea,* and *T. valenzuelana)* in the hammocks of Long Pine Key and Mahogany during the surveys was that a sufficient number of the species survived to ensure recovery. Many individuals of the

Tillandsia species in the subcanopy were badly sunburned from loss of canopy shade, but many other healthy individuals were found in more protected locations. With the active resprouting of the vegetation in these hammocks, more epiphytes will unlikely die of exposure to sunlight. A rough estimate is that 50% of the epiphytes of the subcanopy were lost. The orchids seem to be less susceptible to sudden increases in light level than the bromeliads. The epiphytes will now be more susceptible to freezes and droughts for the next few years, however, because the canopy will not provide as much protection.

Epiphytes of the canopy certainly suffered more than those of the subcanopy simply from their exposed location. Ariel Lugo (personal communication) reported that Hurricane Hugo stripped many of the epiphytes from trees in the Luquillo Forest of Puerto Rico, and the same can be expected in the areas of South Florida most strongly hit by Hurricane Andrew. It is likely that 90% or more epiphytes of the canopy were lost during the storm, but enough healthy epiphytes of the canopy were seen during the survey to ensure survival of the populations. Thinning of the canopy from the hurricane will eventually lead to an increase in the epiphyte populations of the canopy in Long Pine Key. The epiphytes of the canopy of most concern, *Catopsis berteroniana*, *C. floribunda*, *Tillandsia flexuosa*, and *T. pruinosa*, exist over a large portion of the national park system areas, and, whereas the loss of local populations in the Long Pine Key and Ten Thousand Islands area is likely, the species in Florida is not in danger as a result of this storm. Surveys of known populations of these species are still required to determine the degree of population reduction.

Populations of *Asplenium serratum*, *Campylocentrum pachyrrhizum*, *Epidendrum anceps*, *Maxillaria crassifolia*, *Peperomia humilis*, *Pleurothallis gelida*, and *Polyrrhiza lindenii* exist mostly north of the area of extensive damage, so they are not expected to suffer. Local populations of these species in Everglades, however, may have been destroyed. *Cyrtopodium punctatum* populations on Long Pine Key were probably devastated by the hurricane, but extensive populations exist both to the north and the south of the area of greatest damage. Whether these populations are sufficiently close to allow recolonization of the Long Pine Key area in a reasonable period of time is not known. Populations of *Encyclia boothiana* in Biscayne were likely devastated, but populations in Everglades were found in the Flamingo area, well south of the area of greatest damage. *Oncidium luridum* likewise was found in the Flamingo area and is not expected to suffer.

Potential damage to populations of *Asplenium serratum* and *Vanilla barbellata* cannot be assessed at present because of lack of information.

Nonnative Plants

Melaleuca quinquenervia is the most invasive nonnative plant species in South Florida as a whole and in Big Cypress specifically. Everglades has, to date, been kept largely free of *Melaleuca*. In the past several years, an Everglades crew has worked to push back the *Melaleuca* population in East Everglades. After 5 years, they have done control work within a zone 8 km (5 miles) behind the front edge of invasion, which is near the old park boundary. Efforts have been most intensive within a 3.2-km (2-mile) strip back from the front so that most individuals have been eliminated within this zone. Surviving seed-producing individuals, however, probably still exist (Doug Devries, personal observation). Less than 5% of *Melaleuca* at Monroe and Paolita stations in Big Cypress was uprooted or broken off. Uprooted trees will resprout along the bole. Broken-off trees will resprout vigorously along the break. The seed capsules left on the trees are not likely to open, but severed branches will undoubtedly release seeds.

The hurricane will probably exacerbate the *Melaleuca* problem by dispersing propagules (small branches with seed capsules) to new areas. Hurricane winds along the north edge of the eye would have tended to disperse *Melaleuca* propagules from East Everglades toward Shark Slough. Seeds will likely be released this fall and germinate with falling water levels. *Melaleuca* seedling survival will depend on rainfall and soil moisture during the dry season. With normal drought conditions, seedling survival will be low. A wet winter could result in a large crop of *Melaleuca* seedlings.

Schinus terebinthifolius is currently perceived as the most serious nonnative plant threat to native vegetation in Everglades. This species is capable of tolerating a wide range of hydroperiods (0-6 months) and is somewhat salt-tolerant. Beginning in the late 1970s, the plant has extensively invaded the hammocks, beaches, and higher (less wet and less saline) areas in the mangrove areas, and as of 1987 was found to be invading within an area covering 39,000 ha (96,368 acres; M. Rose, South Florida Water Management District, personal communication) or about 10% of the land area of the park (Fig. 6). For the past 15 years, *Schinus* has been increasing geometrically in this zone and is now found in most areas of Everglades where it can grow.

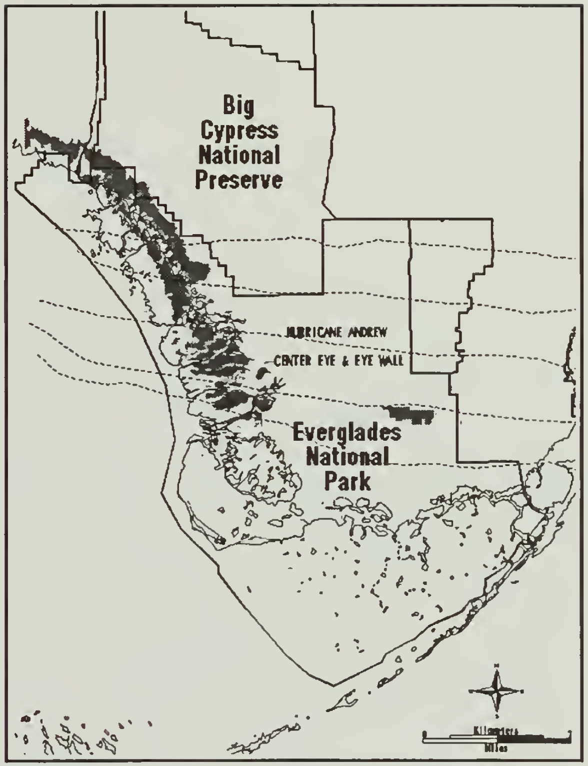

Figure 6. Location of Schinus terebinthifolius *populations in Everglades National Park, Florida.*

A brief survey of the Ten Thousand Islands region confirmed the existence of large *Schinus* thickets around some hardwood hammock-shell mound communities (e.g., Turner River Mound and the Watson Place). Scattered individual plants were also noted in many smaller hardwood hammocks and in some of the *Spartina* marshes in the mangrove zone. At the northern end of Highland Beach, *Schinus* is common on the back of the foredune and in the swale behind the foredune, but has not yet formed a thicket. At each of these sites, the *Schinus* seemed to suffer as much hurricane damage as associated native species, so it may not necessarily gain a substantial advantage because of the storm.

Whereas propagules of all four mangrove species were present in August and have been dispersed widely by hurricanes (Loope 1980), *Schinus* seeds are normally produced after hurricane season (November-December). The relative success of mangrove propagules versus *Schinus* regrowth and seedling dispersal bears close attention. The team anticipates that the hurricane damage to *Schinus* in the maximum zone of hurricane disturbance may preclude most seed production in 1992-93, although birds (robins) disperse seeds long distances (from other areas) in some years. We doubt that *Schinus* has a long-lasting seed bank in the soil. Nevertheless, *Schinus* will probably continue to increase geometrically until it occupies its potential in the upper mangrove zone—mostly in the 39,000-ha (96,368-acre) area the species occupied in 1987. We believe that the rate of spread will not be significantly changed by Hurricane Andrew.

The *Schinus* situation at Biscayne may be different. The team saw little *Schinus* on the survey at Elliott Key on 19 September 1992, but was told that it is locally common. The nonnative plant situation at Biscayne needs to be thoroughly evaluated and consideration given to *Schinus* control if the species is sufficiently localized.

The major area of Australian pine (*Casuarina* spp.) in Everglades (in the southeastern corner of the park) was outside the main path of Hurricane Andrew. East Everglades, where a high density of *C. glauca* exists, was in the path and many individuals were wind-thrown, but abundant resprouting will occur. Following Hurricane Donna, *C. litorea* seeds were dispersed to beaches of the Gulf Coast requiring an active removal program in the 1970s to mitigate the impact of this species on turtle nesting, beach erosion, and aesthetics. Although storm surge from Hurricane Andrew was much less on the Gulf Coast than from Donna, large-scale dispersal of *Casuarina* by the recent storm is a possibility. Storm surge was high for the islands of Biscayne and control of *Casuarina* may be needed there in coming years.

To our knowledge, almost no work has been done to survey *Colubrina asiatica* lately, and we are uncertain of its status on Elliott Key. This species was defoliated by the storm, and we saw only a small amount of it at Petrel Point on Elliott Key. This species has been increasing in hammocks along Florida Bay and could respond rapidly to open canopy on islands at Biscayne and smother surrounding vegetation. *C. asiatica* should be carefully monitored during the next 5 years at Biscayne and controlled if its invasion accelerates.

Scaevola taccada, a Pacific species, has been widely planted at oceanfront houses in South Florida and is beginning to show up extensively in the South Florida strand zone (W. Robertson, A. Herndon, personal observations). *Scaevola plumieri* is a South Florida native *Scaevola*. Potential exists for the explosive spread of *S. taccada* following the hurricane. The team noted this species in a strand at Petrel Point, Elliott Key, on 19 September 1992. This species should be carefully monitored during the next 5 years at Biscayne and controlled if its invasion accelerates.

Oeceoclades maculata, a nonnative orchid, is present in many hammocks of Long Pine Key. This nonnative species was not included on the Avery and Loope (1980) plant checklist, but was present at the time in some Dade County hammocks. *Oeceoclades* will likely increase with the opening of hammock canopies by Hurricane Andrew and can be expected to compete with other ground orchids. This orchid was flowering in several Long Pine Key hammocks 3-4 weeks after Hurricane Andrew, perhaps stimulated to flower by the canopy opening.

Two nonnative lianas in the Araceae *(Epipremnum aureum* and *Syngonium podophyllum)* at the site of Old Royal Palm lodge have become invasive elsewhere and could spread with the opening of the canopy following Hurricane Andrew. Control measures may be required to keep these from spreading into new areas of the hammock.

Molnar (1990) noted that nonnative lianas and other species invade gaps in tropical hardwood stands in Castellow Hammock, preventing recruitment of native species and perhaps hastening the senescence of canopy dominants. Molnar predicted a massive nonnative plant invasion in Castellow Hammock with a hurricane.

Albizzia lebbeck, *Bischofia javanica*, and *Schefflera actinophylla* are examples of species that may spread extensively and invade upland habitats (pinelands and hammocks) following Hurricane Andrew. Predicting which species may explode as a result of canopy opening and nutrient release is difficult. Many instances have occurred where nonnative species remained in a quiescent state for years, then underwent a demographic explosion (e.g., *Schinus terebinthifolius*). Although introduced into South Florida in 1898, this explosion was not perceived as a problem until the 1960s. The hurricane is likely to be an event that triggers a number of such explosions.

National park system areas in South Florida should have a program to monitor hammocks of Dade County, such as Castellow Hammock, to observe incipient problems with nonnative plant invasion of hurricane-damaged hammocks.

Wildlife and Other Species of Concern

In general, the effects of Hurricane Andrew on wildlife were not immediately obvious, largely because the hurricane involved primarily wind instead of storm surge. Three major factors must be present during a hurricane to adversely affect wetland wildlife: storm surge, excessive rain, and high winds. During Hurricane Andrew, the storm surge in Biscayne Bay was estimated at 5.2 m (17 feet). The storm surge in the Florida Bay, Flamingo, and Ten Thousand Islands areas was generally less than 1.5 m (4.9 feet), and the mangrove areas absorbed this surge with minimal damage to the interior freshwater habitats. Preliminary information indicates that local surges occurred on interior wetlands. Based on wrack deposits, composed primarily of dead saw grass, this surge seems to be restricted to the Shark River Slough and East Everglades areas, south of U.S. 41. The second factor, rainfall, does not seem to be a significant element in evaluating wetland wildlife effects, particularly mortality. The high winds from Hurricane Andrew had the greatest effect on wetland wildlife. Whereas the herbaceous wetlands were probably the least affected, the associated tree islands and hammocks were significantly altered by the high winds. Wildlife throughout the storm path was subjected to these same high winds. Although wildlife was probably affected, direct death, injury, and secondary effects were not seen during this assessment.

The freshwater resource team received only one report of a hurricane-related death. This report involved a wading bird roost on Chicken Key, just east of the Deering estate in Big Cypress. A local resident (D. McDonald, personal observation) reported collecting over 200 dead birds immediately following the storm and burning the carcasses. White ibis (148; *Eudocimus albus*) accounted for 68% of the known mortality. Great blue heron (2; *Ardea herodias*), cattle egret (28; *Bubulcus ibis*), great egret (4; *Casmerodius albus*), little blue heron (22; *Egretta caerulea*), and snowy egret (12; *Egretta thula*) were the other wading birds identified. Six crows (unidentified species) and three double-crested cormorants *(Phalacrocorax auritus)* were also collected. The site was examined on 17 September 1992, and an additional 48 carcasses were counted (30 white ibis, 18 unidentified). The prestorm population of this roost site is not known but, based on the above accounts, this particular roost experienced high mortality.

The only other observed storm-related death may have occurred in the eastern Stairsteps of Big Cypress. On 26 August 1992, an adult doe deer was observed in the prairie just south of Lostmans Pines and a dead raccoon was also found. These deaths may have been storm-related.

Florida Game and Fresh Water Fish Commission (1992) reported finding dead cattle egrets in the Homestead area. The commission also received reports of 200 grackles killed in the Cutler Ridge area.

White-tailed Deer

Responses of white-tailed deer *(Odocoileus virginianus)* to Hurricane Andrew were monitored by two processes: field surveys and monitoring radio-collared deer in Big Cypress (eastern Stairsteps; Fig. 7). R.F. Labisky, University of Florida, completed in March 1992 an NPS-sponsored 3-year study of the population ecology of white-tailed deer. The study area was entirely in the area of hurricane impact: the southern Stairsteps unit of Big Cypress and adjoining Everglades to the south. Before the hurricane, 32 radio-transmitting deer had been monitored once a month for mortality. Survey flights conducted after the hurricane indicated that 12 of the 32 deer had moved outside their individual home ranges that had been documented during the 3-year study. No radio-transmitting deer died during the study.

Following the storm, the team conducted field surveys throughout Big Cypress and Everglades to evaluate general environmental conditions. During these surveys, 53 deer were observed, including 1 dead animal, and 1 adult buck that was observed in deep water in northern Shark Slough. (Most water levels were measured at 8-10 cm [3.15-3.94 inches] at this location.) Although the deer seemed healthy, its movements were obviously impaired by the deep water. The remaining 51 deer were observed in water less than 8 cm (3.15 inches), and their movements and health seemed normal.

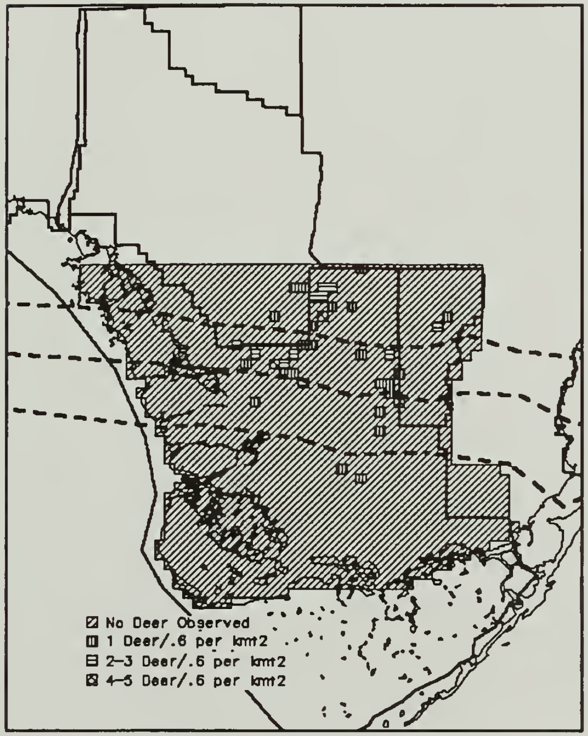

Figure 7. Posthurricane distribution of white-tailed deer (Odocoileus virginianus) *in southern Everglades National Park, 21 September 1992, Florida*

The team observed significant browse on tree islands in Shark Slough in Everglades but not at other locations. The combination of high water in the slough and lack of preferred aquatic deer foods (especially *Crinum* sp. and *Nymphaea odorata*) may have caused increased browsing on these islands. Browse was most noticeable on Gumbo Limbo Hammock and Panther Mound. Willow, hackberry, and an unidentified shrub were the three species being browsed. In other areas, particularly in East Everglades and Stairsteps of Big Cypress, tree islands were also severely damaged from the hurricane. Browse was not significant on these islands. Lower average water depths (below 8 cm [3.15 inches]) and the presence of preferred aquatics probably account for this difference.

The magnitude of damage to the Stairsteps tree islands, the importance of the islands to deer, and potential problems resulting from high water led to the closing of the eastern portion of the Stairsteps unit. In addition, the adjacent Everglades wildlife management area was closed because of high water. These closed areas should be evaluated periodically and when conditions improve they may be reopened. The status of adjacent areas and the availability of personnel should be evaluated before any areas are reopened.

Florida Panther

The Florida panther *(Felis concolor coryi)*, 1 of 30 named subspecies, is federally listed as endangered. Panthers probably do not now exist in the eastern United States except in Florida (L.E. Williams, in Layne 1978). Deer provide the main food source for the panther. The Florida panther has been intensively studied and monitored in South Florida for two decades. In Everglades, studies have documented the gradual disappearance of the species. In the mid-1980s, 7 animals in Everglades were being tracked with radio collars.

At the time of Hurricane Andrew, four radio-collared panthers were being monitored in national park system lands south of I-75 (Alligator Alley), and the only collared panther known to occupy territory in Everglades (#16) was in Big Cypress. The four panthers were located on Saturday, 22 August, before the hurricane and on Tuesday, 25 August, the day after the hurricane. Three (3) of the four panthers live north of

U.S. 41 in the Corn Dance and Turner River units of Big Cypress. The female, #23, whose two kittens had been removed 20 August to support the captive breeding program, was located on 25 August at a distance of 0.8 km (0.5 miles) from her 22 August site. The second female, #38, was located 4.8 km (3 miles) from her Saturday location. Male #42 made an extensive movement of 16 km (9.9 miles) during the 4 days. Aerial observations revealed minimal habitat damage (i.e., some downed hardwoods within hammocks) in the areas used by these three panthers. Their movements, therefore, were probably normal and driven by food and social needs.

The fourth monitored panther, #16, spends most of his time in the Loop and Stairsteps units of Big Cypress and is the only documented panther using Everglades. He crosses the park boundary and Shark River Slough several times a year and spends about 10 days in the Long Pine Key area of the park before returning to the preserve.

On 22 August and 25 August, #16 was located in a group of hammocks approximately 1.6 km (1 mile) southwest of U.S. 41, near the entrance to the jetport inside the Loop unit of the preserve. Moderate damage in the form of downed hardwood trees was observed from the air. Since then, #16 has traveled south through the Stairsteps area, where the hurricane extensively damaged tree islands and old-growth pinelands, and then returned to the Loop unit, exhibiting a normal movement pattern.

No other known panthers are in Everglades, although numerous unconfirmed sightings have been made recently.

In summary, Hurricane Andrew probably had no negative effect on the monitored panthers in the national park system units in South Florida.

Key Largo Woodrat and Cotton Mouse

The Key Largo woodrat *(Neotoma floridana smalli)* and Key Largo cotton mouse *(Peromyscus gossypinus allapaticola)* are federally listed as endangered species endemic to Key Largo (L.N. Brown, in Layne 1978) and may have in the past been found barely within the Everglades boundaries on Key Largo. The ranges of both species have contracted, however, and now include only the northern one-third to one-half of Key Largo. Because Key Largo lies to the south of the main impact area and was only minimally affected, the status of these two endangered species was not significantly jeopardized by the storm.

Florida Black Bear

The Florida black bear *(Ursus americanus floridanus)* is considered to be threatened (L.E. Williams in Layne 1978). Before the hurricane, 26 radio-collared animals were being studied. Of these, 25 were found north of the Tamiami Trail and outside the area of major hurricane effects. One (1) animal was found in the Everglades City area at the time the storm passed over. This animal moved from Everglades City into the Turner River area after the passage of Hurricane Andrew, but most likely this movement was not a direct result of the storm because damage in the Everglades City area was light. All 26 animals survived.

Bald Eagle

Bald eagles *(Haliaeetus leucocephalus)* nest throughout the coastal areas of southwestern Florida. Several agencies monitor different nests and some locations were not surveyed during the assessment, therefore the exact number of bald eagles in the hurricane path is not known. Based on available information, the team estimated that 12-15 eagle nests were in the storm path. Bald eagles generally begin nesting activity in mid-October. Nests are some-times blown out of trees or destroyed during the nonnesting season. Eagles will generally select another nearby site, if suitable nest trees are available.

Three southern territories of bald eagles are in Big Cypress, all south of U.S. 41 along the southwestern Stairsteps boundary. All three nests in the territories were affected by the hurricane. The Turner River territory was least affected because the location is the northernmost of the three. Although the nest tree, a slash pine, has been dead since monitoring began in 1981, the tree withstood the winds. The nest, itself, however, was disheveled and partially gone. On 27 August, an adult eagle was observed sitting in the tree next to the nest. The Sig Walker territory had a nest in a large cypress tree at the southwestern end of Sig Walker Strand. A flyover on 9 September revealed that the nest was gone, and observers were unable to identify the nest tree itself because of the extensive tree damage at the site. The Lostmans Pines territory had a nest tree in an old-growth pine tree in the southernmost red-cockaded woodpecker colony, north of Buttonwood Prairie. A ground inspection on 27 August revealed that the tree had been uprooted. Since then, Big Cypress field personnel have observed adult eagles in the vicinity several times. One observation was of aerial courtship.

None of the estimated 10-12 eagle nests in the mangroves in the hurricane path were surveyed. Based on the damage to the mangrove area, most of these nests were probably destroyed.

Wading Birds

Wading bird population estimates during the wet season are generally only 10-20% of the peak counts. Data are available for the southern portion of the survey area, including the major portion of the hurricane impact area. These population estimates cover most of mainland South Florida, west of Krome Avenue and south of U.S. 41 and Loop road. Population estimates (pre- and posthurricane) for major species and groups are presented in Table 6. The prehurricane survey was conducted on 3, 4, and 5 August whereas the poststorm survey was conducted on 8, 9, and 10 September. These surveys indicate that wading bird populations were similar before (20,793) and after (25,356) Hurricane Andrew. These numbers seem to be normal wet season counts for the survey and suggest that direct mortality of wading birds was minimal. The surge in water levels immediately after the storm may have displaced some birds, but environmental conditions, including restoration of shallow feeding, were stable by 8 September. In both surveys, white ibis accounted for one-half of all the birds observed (Fig. 8), whereas great egret accounted for one-third of the total population (Fig. 9). Wading bird distributions before and after

Table 6. Wading bird population estimates before and after Hurricane Andrew in southern Everglades National Park, Florida.

	Prehurricane 3 August 1992		Posthurricane 8 September 1992	
Species or Group	Population	Percent	Population	Percent
White Egret	6,680	32.1	8,752	34.5
White Ibis	10,287	49.5	12,865	50.7
Small White Heron	2,000	9.6	1,666	6.6
Small Dark Heron	1,093	5.3	1,200	4.7
Great Blue Heron	260	1.3	47	0.2
Great White Heron	173	0.8	153	0.6
Roseate Spoonbill	300	1.4	673	2.7
All Species Combined	20,793	100.0	25,356	100.0

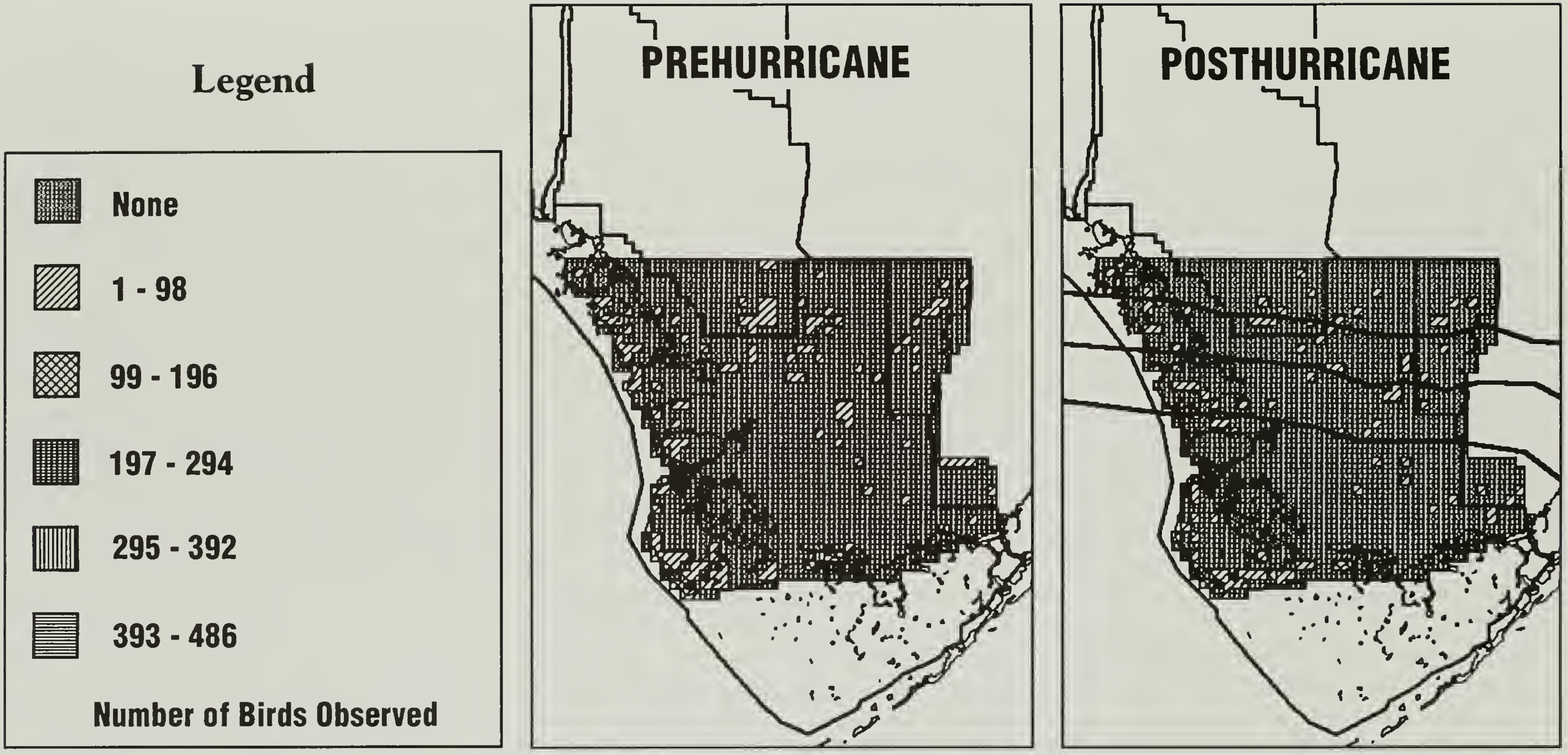

Figure 8. A comparison of the foraging distribution of the white ibis (Eudocimus albus) *before (3, 4, and 5 August) and after (8, 9, and 10 September 1992) Hurricane Andrew.*

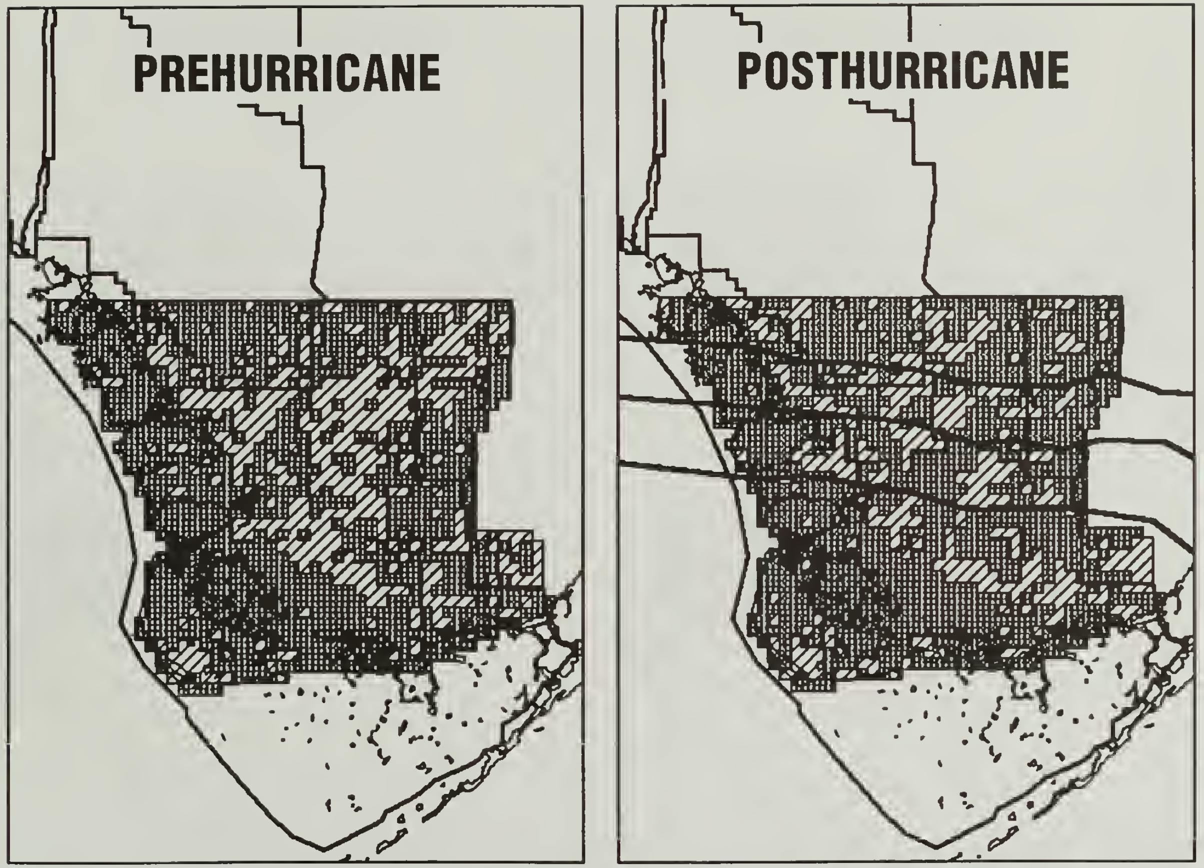

Figure 9. A comparison of the foraging distribution of the great egret (Casmerodius albus) *before (3, 4, and 5 August) and after (8, 9, and 10 September 1992) Hurricane Andrew.*

Hurricane Andrew are shown in Fig. 10. When compared to the Hydropattern maps (Fig. 11), they show expected distributions and feeding patterns.

Wading bird rookeries have been plotted for four South Florida counties (Dade, Monroe, Broward, and Collier) using data from Runde et al. (1991) and from NPS files. The location of these rookeries in relation to the path of Hurricane Andrew is shown in Fig. 12. We estimated that 16 of 160 rookeries (10%) were in the storm path. Nesting activity is low at that time of year, and many of these sites were unused when Hurricane Andrew struck. Some rookeries, such as Chicken Key, are also used as night roosts. A high number of deaths probably occurred where these roosts are surrounded by deep water.

The status of rookery habitat is unknown at this time. Rookeries in Biscayne Bay and the affected mangrove zone must have sustained severe damage. In these areas, most nest trees were probably damaged or destroyed.

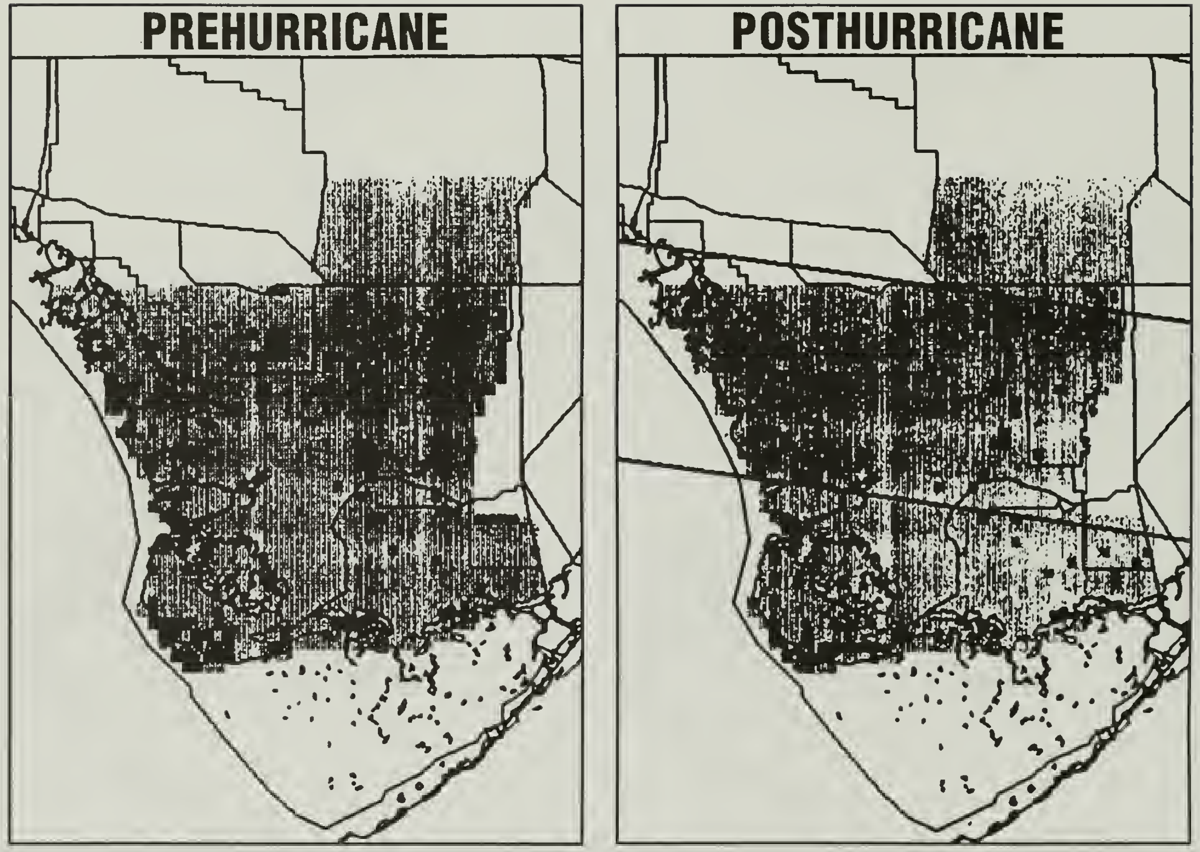

Figure 10. Distributions of wading birds (Ciconiformes) *before (3, 4, and 5 August) and after (8, 9, and 10 September 1992) Hurricane Andrew.*

Red-cockaded Woodpecker

The red-cockaded woodpecker *(Picoides borealis)*, federally listed as an endangered species, is endemic to coastal plain pinelands of the southeastern United States. This is one of the few species of birds that excavates its nesting and roosting cavities

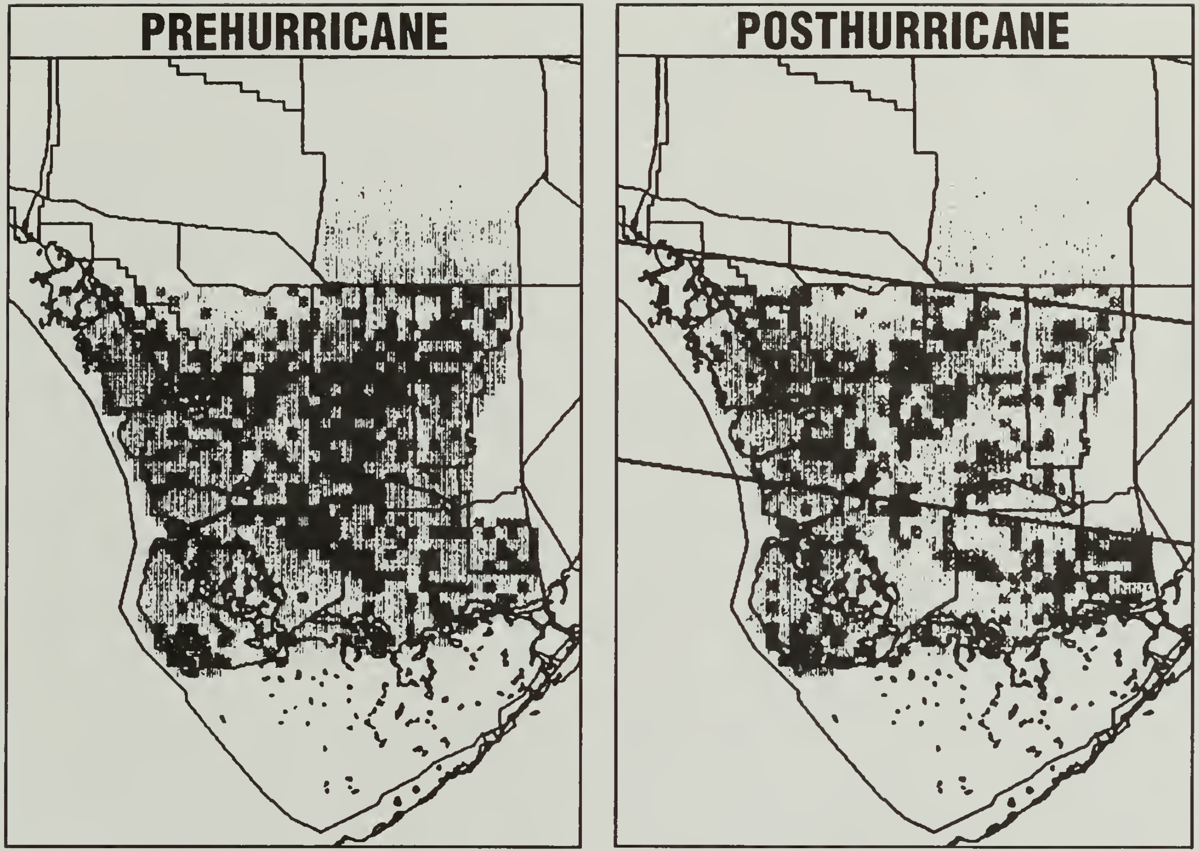

Figure 11. *Hydropatterns (water depth) in Everglades National Park, Florida, before and after Hurricane Andrew.*

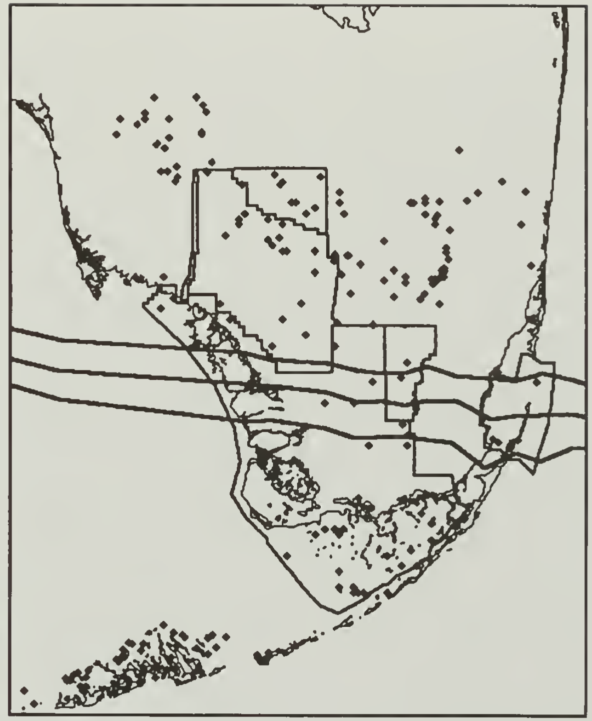

Figure 12. *Wading bird* (Ciconiformes) *rookeries in South Florida in the path of Hurricane Andrew.*

in living trees (W.W. Baker, in Kale 1978). The old-growth trees that are used are infected with the fungus *Fomes pini* that softens the heartwood. The species forms clans consisting of more than a pair (with 2-8 birds), with unmated birds acting as helpers during the nesting cycle. Roosting and nesting occur in the same trees year after year. Old-growth trees are essential to the species.

The red-cockaded woodpecker formerly occupied pinelands of the Miami rock ridge (including those of Everglades) but disappeared from that part of its range during the 1960s (Snyder et al. 1990). Populations are still present in Big Cypress (Patterson and Robertson 1981), mostly north of the Tamiami Trail. The species has been declining over the past several years, however, and its range has contracted.

Hurricane Andrew affected the Lostmans Pines area of old-growth pines in the central portion of the Stairsteps unit. Eight colonies of red-cockaded woodpeckers have been monitored in Lostmans Pines since the early 1980s. An apparent decline in the number of active colonies and nest attempts for the past 10 years prompted park personnel to intensively assess the red-cockaded woodpecker status in that area. A radio telemetry study in the area during summer 1991 revealed that only three colonies remained active and were composed of five adult birds—two pair, and one single male. The 1992 nesting season work confirmed that these five birds were still alive and that nesting was attempted in one colony.

Initial posthurricane assessment consisted of determining survival of known individuals, evaluating the status of cavity trees in the three active colonies, and plot sampling of all age-classes to determine varying levels of long-term impact.

We spent approximately 17 hours in the active red-cockaded woodpecker colonies while conducting vegetation sampling. During that time only one red-cockaded woodpecker was seen, a banded male from the only known nesting pair in Lostmans Pines. Taped calls failed to elicit a response from his mate. Because all of the time spent in the field was in the middle of the day, other red-cockaded woodpeckers may have survived but were foraging away from the areas we were assessing.

In the three active colonies, 33 of 36 known cavity trees, both active and inactive, were found and examined for hurricane impacts. Of the 33, 2 (6%) were uprooted, 7 (21%) were snapped at the base, 15 (45%) were snapped at the cavity, and 4 (12%) were intact. No active cavity trees remained standing.

Cape Sable Sparrow

The Cape Sable sparrow *(Ammospiza maritima mirabilis)*, endemic to South Florida, is federally listed as endangered. This species survives in three habitat areas, primarily in the national park system units of South Florida: (1) slightly brackish marshes on Cape Sable in Everglades, (2) slightly brackish and freshwater marshes in Big Cypress and Everglades, and (3) *Muhlenbergia*-saw grass prairie (freshwater) on the east side of Taylor Slough of Everglades (H.W. Werner, in Kale 1978). This bird is highly dependent on a regime of fire every 3-5 years. With accumulation of dead grass and sedge material, the birds cease to thrive (Kushlan et al. 1982). The subspecies was possibly favored by Hurricane Andrew through removing litter from its habitat, although physical damage to a small population of birds is also a likely result. The Taylor Slough population and the Big Cypress population were potentially affected. Assessing the status of the Cape Sable sparrow population is only possible during the spring breeding season. O.L. Bass (Everglades National Park and southern Big Cypress National Preserve, personal observation) surveyed the population in spring 1992. A similar survey needs to be conducted in spring 1993 to assess the population status.

Southern Hairy Woodpecker

The southern hairy woodpecker *(Picoides villosus auduboni)* is recognized as a species of special concern in Florida (O.T. Owre, in H.W. Kale 1978). Snyder et al. (1990) mentioned the hairy woodpecker as an example of pine forest bird species of northern derivation whose ranges have contracted in the period of historical record in patterns not wholly attributable to habitat disturbance. The hairy woodpecker barely persists in pinelands of Everglades, based on recent woodpecker surveys by Liz Lewis (Pinelands, Everglades National Park, personal observation). These surveys should be repeated during the 1993 breeding season to determine the status of the hairy woodpecker following Hurricane Andrew. According to W. Robertson (personal communication), hairy woodpecker populations may depend on food supplies. An increase may be anticipated, assuming that this bird can forage on insects associated with wind-broken pines. Alternatively, Hurricane Andrew could have had sufficient impact to extirpate the small population of the species in Everglades.

Snail Kite

Before Hurricane Andrew, 75 snail kites *(Rostrhamus sociabilis)* had been radio-tagged as part of a study on their survival and dispersal throughout Florida. Of these, at least 7 were in locations damaged by the hurricane. One (1) kite was in Lostmans Slough in the Stairsteps unit of Big Cypress, 1 in Everglades west of Shark Valley, and 5 in water conservation area 3-A. Although none of the radio-tagged kites was in the area hardest hit by the storm (e.g., Taylor Slough, kites have been reported using that area). The 7 kites were located just before the hurricane and 2 days after. All 7 survived and were in the same general location as before the storm.

Some anecdotal evidence suggests that the snail kites may have been affected in a minor way. A night roost at Forty-mile Bend was stripped of its foliage by the storm. Two radio-tagged kites had been using that roost. One stopped using it; the other is still roosting in the vicinity but may not be using the original roost trees. Several areas in Lostmans Slough had been used extensively by kites before the storm, but not at present. This shift may or may not have been in response to the hurricane.

Short-term changes in availability of snails because of changes in dissolved oxygen may also have occurred as well as some flooding of the apple snail egg clusters from increased water levels.

American Swallow-tailed Kite

South Florida serves as the center of abundance for breeding and premigration staging of the small remaining U.S. population of American swallow-tailed kites *(Elanoides forficatus)*. This species experienced a sharp reduction in range and numbers early in the 20th century. K.D. Meyer (1995) directed studies since 1988 on the breeding biology and habitat requirements of swallow-tailed kites that included data from 25 nesting attempts in Long Pine Key and the adjacent pine islands of Everglades, where 15 to 20 territories probably are active annually. These isolated pinelands, the largest surviving stands in the formerly expansive pine woods of the Miami rock ridge, support the highest density of nesting swallow-tailed kites remaining in southeastern Florida. Meyer's research documented the use of the tallest trees for nesting, selection of hammocks and other hardwood and shrub islands for foraging, and shifts in nest locations following prescribed burns, possibly because of the loss of moss and lichens that compose essential nesting material.

Because the kites had already migrated from South Florida before the arrival of the storm, the storm did not directly affect them. Because of the species' dependence on large trees for nesting sites and its use of forested areas for feeding, however, the effects will likely be evident in the next breeding season.

Alligator

Adult alligators *(Alligator mississippiensis)* were probably not affected by the hurricane. Alligator nests, however, are vulnerable to both high winds and water levels. Personnel of the Everglades National Park are engaged in ongoing alligator research throughout Shark River Slough. Nest locations for 1992 are shown in Fig. 13. One week before the storm, 43% of the eggs laid since the beginning of the nesting season had already been lost because of predation, flooding, and other egg mortality causes. Preliminary estimates indicate that an additional 8% were flooded as a result of posthurricane water levels.

Approximately 27% of the eggs were in nests that were assumed destroyed by the hurricane. Because the eggs were in the process of hatching, their fate is not known at this time. The remaining eggs (22%) probably hatched successfully based on both pre- and post-storm evaluations. Because of uncertainties concerning the fate of storm-damaged nests and eggs, success for 1992 may range from 22% to 49%.

Nesting success in the slough has averaged 74% (range, 44-85%) over the past 7 years. Whereas 1992 nesting success is low, antecedent high-water conditions and associated nest flooding account for a substantial portion of the eggs lost.

Eastern Indigo Snake

The eastern indigo snake *(Drymarchon corais couperi)* is federally listed as threatened and is endemic to Florida and southern Georgia (and formerly adjacent Alabama and South Carolina). Typical habitat of this large (to 2.6 m [8.5 feet]) snake in South Florida is pinelands and hammocks. This diurnal species preys on small mammals, birds, reptiles, and amphibians. This species is threatened primarily because of the interest to snake fanciers and dealers as a result of its large size and gentle nature (H.I. Kochman, in McDiarmid 1978, pp. 68-69). Negative impact is unlikely.

South Florida Tree Snail

The Florida tree snail *(Liguus fasciatus)* is endemic to Dade, Broward, Monroe, and Collier counties (where it inhabits tropical hardwood hammocks), plus Cuba and the Isle of Pines. Eight subspecies and numerous color forms have been recognized. Many color forms are highly local; some

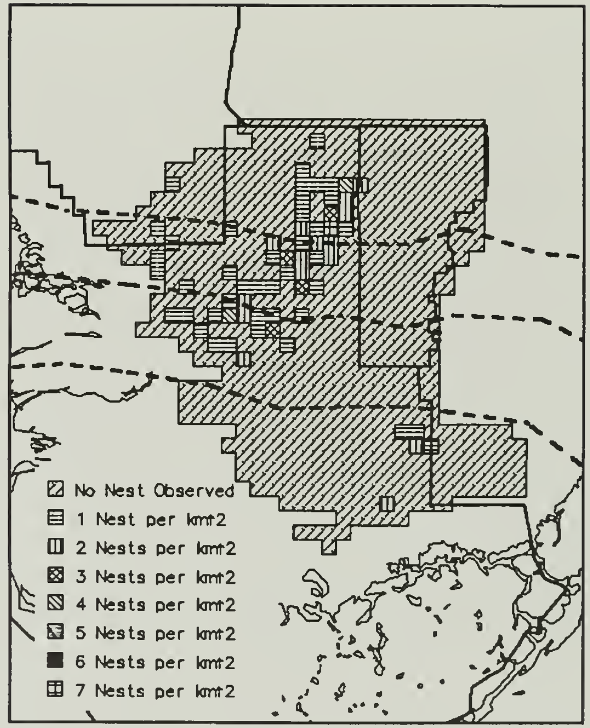

Figure 13. Distribution of alligator (Alligator mississippiensis) *nests, July 1992, in Everglades National Park, Florida*

have been extirpated (J.E. Deisler, in Franz 1982). Hurricane Andrew may have possibly provided the final blow to already depleted populations.

Because of the diversity of the color patterns on the shells, these snails have been the subject of numerous studies, although no recent quantitative work has been done on population dynamics. The following general observations are strictly qualitative, and must be followed up on using quantitative methods. During surveys of Osteen, Royal Palm, and Wild Lime hammocks in Everglades and Dr. Tiger and Pinecrest #40 hammocks in Big Cypress, *Liguus* were commonly seen. In fact, they were more conspicuous than usual because of the reduced foliage in the hammocks. No *Liguus* were seen in the survey of Elliott Key, but populations there have been small or lacking in recent years (J.E. Deisler, in Franz 1982). In mainland hammocks, only a few dead snails were seen. Some seemed to have been blown into the water and drowned, others were on the ground, apparently killed by exposure. Generally, Hurricane Andrew had little direct effect on the population. Future effects are more difficult to predict. Increased light may increase the food supply for *Liguus*, leading to a long-term population increase. *Liguus* feeds primarily on epiphytic algae and fungi and is usually most common in the areas of the hammocks with thinner canopies (A. Jones, Homestead, FL, personal communication). The lack of cover, however, will also leave the snails more susceptible to freezes and drought over the next few years. Also, the lack of cover may allow predators to find the snails more easily. Finally, severe fires in the hammocks could severely depress local *Liguus* populations. Given the absence of information on the importance of these various factors in the population dynamics of the species and the uncertainties associated with the long-term factors, no satisfactory prediction of future population trends can be made.

Butterflies

Adult butterflies were less common than normal in South Florida during the assessment surveys. Even in less affected areas, such as the Pinecrest hammocks, adults were infrequently seen, and they seemed to be newly emerged. Because plants are just now beginning to flower posthurricane, adults surviving the storm itself may have died before food resources became available. The long-term effects of a storm such as Hurricane Andrew can be substantial. Willig and Camillo (1991) studied the effects of Hurricane Hugo on six common invertebrate species in the Luquillo Forest of Puerto Rico. No specimens of three of the six species could be found 10-11 months after the storm. Four species of special interest in the national park system areas affected by Hurricane Andrew are discussed individually in the following sections.

Schaus' Swallowtail

Schaus' swallowtail *(Heraclides aristodemus ponceanus)* is a federally listed endangered subspecies, endemic to southeastern Florida, and now restricted to local colonies on Elliott Key and northern Key Largo. Its known habitat in hammocks of Elliott Key, in the Petrel Point area, was severely affected by Hurricane Andrew. Its larval food plants are torchwood (*Amyris elemifera*) and wild lime *(Zanthoxylum fagara)*. The adult flight period is from late-April to early-June. Females deposit eggs on the undersides of leaves of torchwood and wild lime (H.D. Baggett, in Franz 1982). Researchers from the University of Florida (R. Curry, personal communication) counted the Petrel Point population in May 1992. Our observations suggest that Hurricane Andrew defoliated both host plant species in the Petrel Point area, and it is likely that this Schaus' swallowtail population has been severely depleted.

Florida Atala Butterfly

The Florida atala butterfly *(Eumaeus atala florida)*, endemic to Dade and Broward counties, was reported in 1980 to have been reduced to a few isolated colonies in Dade County and believed to be on the verge of extinction (H.D. Baggett, in Franz 1982). This species was found to have a substantial population in the Long Pine Key area of Everglades during 1991 (A. Herndon, personal observation). The species was associated particularly with hardwood hammocks containing the larval food plant, coontie (*Zamia pumila*). No adults were seen during surveys of Osteen, Wild Lime, or Royal Palm hammocks. Coontie did not seem to suffer any direct wind damage during the storm, so larval and pupal populations may not have been greatly affected. Determining hurricane effects on this species will be complicated by the common occurrence of large year-to-year population fluctuations in the species.

Florida Leafwing

The Florida leafwing *(Anaea floridalis)* is endemic to South Florida, and a large part of the known prehurricane population was found in Long Pine Key (A. Herndon, personal observation). No adults were seen in the pinelands during the surveys of Osteen or Wild Lime hammocks, but they are more commonly seen during the winter months (A. Herndon, personal observation). The larval food plant, wooly croton (*Croton linearis;* H.D. Baggett, in Franz 1982), is common in the herbaceous layer of the Long Pine Key pinelands, where it may have escaped severe damage.

Florida Purplewing

The Florida purplewing *(Eunica tatila tatilista)* probably lost considerable population during the hurricane. This West Indian butterfly reaches its northern limits in the tropical hardwood hammocks of South Florida (H.D. Baggett, in Franz 1982). This species is normally found in the hammocks of Biscayne and in some hammocks in Long Pine Key in Everglades. The larval food plant is unknown (H.D. Baggett, in Franz 1982), but the population on Elliott Key was without doubt severely hurt because most plants in the hammocks seem to have been completely defoliated during the storm. One adult was observed in the less damaged hammock on Old Rhodes Key, so local survival seems ensured. Presumably, the Elliott Key population can be replenished easily by immigration from nearby keys. The future status of the Long Pine Key populations is more problematic. Defoliation was not complete in these hammocks, but was severe enough to depress larval populations. Also, adults of this species require considerable shade (H.D. Baggett, in Franz 1982) and how they will respond to the more open canopies in the hammock over the next 2-3 years is not clear. If the Long Pine Key populations are eliminated, reestablishment may take a long time because of no nearby colonies.

Freshwater Resources

Hydrology

Status of South Florida Hydrologic Network

The hurricane seriously damaged the Everglades hydrologic monitoring network. This network should be immediately restored. Of the more than 50 continuous recorders monitoring surface and groundwater in Everglades, 14 suffered damage to the instrumentation or support structures or both (Fig. 14). At least five stations that do not have continuous recorders installed have damaged support structures. The majority of the damaged stations are between the northern park boundary and the park road to Flamingo. In this region, the already sparse network sustained damage to 80% of the stations. Almost all the stations outside the heavily instrumented and relatively unaffected eastern panhandle region (Fig. 14), where a detailed study is taking place, have been disturbed. The data being collected there now are suspect. The elevations of the benchmarks on the platforms may have been altered. The discontinuous network of staff gauges has not yet been surveyed in detail, but spot checks in accessible locations indicate that most survived. Again, as with most stations, the staffs may have moved sufficiently that the gauge now has an unreliable reference to mean sea level. Most recording and staff gauges must be resurveyed.

Two (2) of the 10 continuous rainfall recorders continued to collect data through the entire storm. Only one anemometer exists in the network (located near Tamiami Trail, just north of the path that received the brunt of Hurricane Andrew). This recorder malfunctioned during the hurricane.

A large portion of the southern Dade County rainfall and water-level monitoring network was damaged or destroyed in the storm-affected area. Minor damage was observed at more that 15 other NPS stations. In addition, more than 30 stations that are monitored by the U.S. Geological Survey and the South Florida Water Management District, in and adjacent to Everglades and Biscayne national parks and Big Cypress, were also damaged or destroyed. Approximately eight of these sites were in East Everglades, and six more were in the Black Creek canal, monitoring inflows to Biscayne Bay. The U.S. Geological Survey and the South Florida Water Management District were able to restore nearly all of these stations in 2–3 weeks because they maintained an inventory of backup equipment.

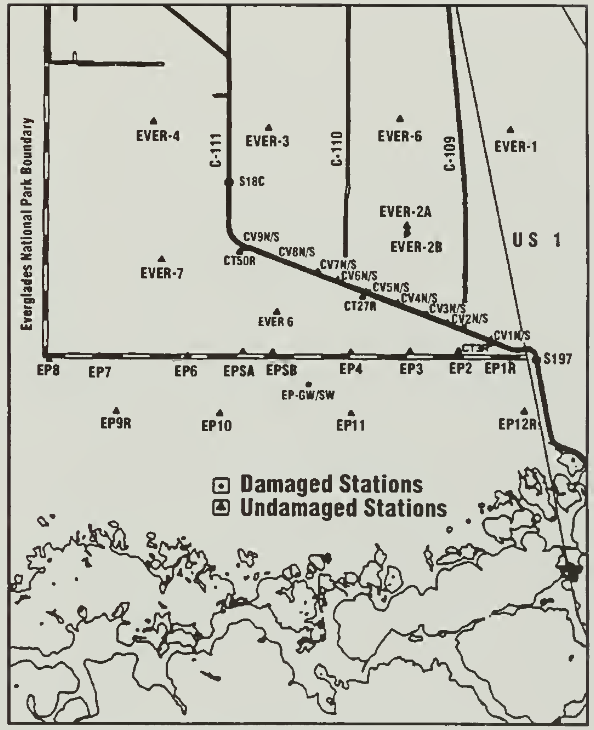

Figure 14. Status of hydrologic monitoring network in Everglades National Park, Florida.

A detailed assessment of how the hurricane affected the water management system is underway. Preliminary surveys indicate that a number of the water control structures in the storm path were damaged or flooded and inoperable following the storm. The high amount of rainfall for several days following the hurricane put pressure on the operation of these structures. In addition, many of the coastal and interior canals were eroded or blocked by debris, reducing their conveyance.

Most of the canals along the eastern portion of Everglades and those entering Biscayne Bay were blocked by storm debris following the storm. The majority of these canals were cleared and operational within 1 week after the storm. Three of the water-level recorders at the S-12 water delivery structures in the Shark Slough basin were damaged by the storm, but repairs have been completed. The two pumpstations that deliver water to the Taylor Slough and eastern panhandle basins of Everglades (S-331 and S-332) were badly damaged, and remain out of service (at the time of this writing). The 30-day experimental test in the Taylor Slough basin will most likely have to be postponed until the next wet season in 1993. In addition, damage to the control wells in East Everglades has temporarily suspended the experimental water delivery program in the northeast Shark Slough basin.

Hurricane Andrew was a fast moving storm, with relatively little rainfall over South Florida. The two surviving gauges in the Everglades network, stations P34 and P37, recorded totals of 4.37 and 5.8 cm (1.72 and 2.30 inches), respectively, on 24 August 1992. Generally, high winds caused rain gauges to record less rainfall than actually occurred, thus these values may be conservative. Even if adjusted, the rainfall values are not unusual for this area where local rainfall in excess of 12.7 cm (5 inches) is not rare. In the week before the storm, normal local thunderstorms occurred over the Everglades with less than 1.27 cm (0.5 inches) recorded at the rain gauges. The same pattern remained during the week following the storm (Fig. 15).

Surface and groundwater levels in Everglades responded as expected to the increase in rainfall and gate operations immediately after the storm. During the storm, large fluctuations in water levels took place at most stations in the affected area as illustrated by the hydrographs shown in Fig. 16. The lack of adequate spatial distribution of the stations precludes any formal analysis of the data. The graphs, however, do show the effects of some short-term wind driven build-up or pulse. The extended record indicates that these pulses are generally of the same order of magnitude as a normal increase in water level resulting from rainfall and gate operations.

Prestorm Hydrologic Conditions

Rainfall throughout South Florida was slightly above average for the 30-day period before Hurricane Andrew. Regional water levels were also higher than normal, and all of the water conservation areas

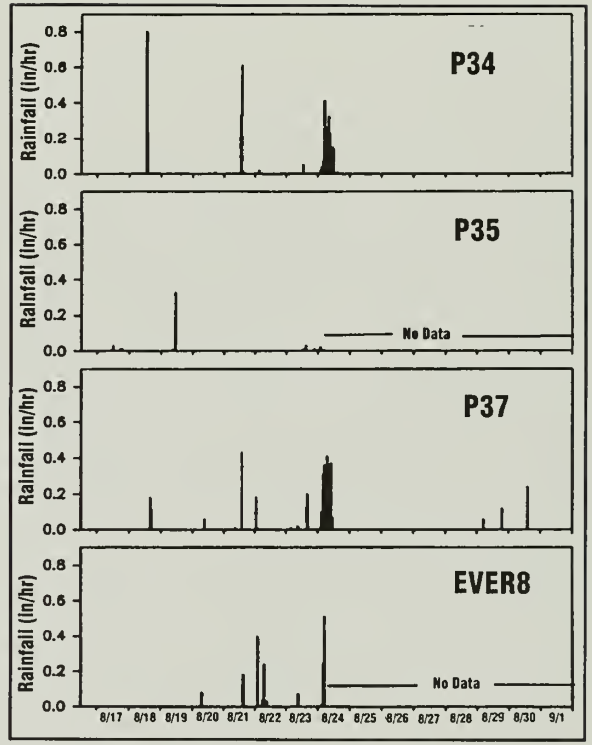

Figure 15. Rainfall rates at selected sites in Everglades National Park, Florida, from 17 August to September 1992.

were above their regulation schedules. Large water releases were being made from Lake Okeechobee into and through the water conservation areas and out to tidewater. Regulatory releases were being made from the water conservation areas into Everglades and the Big Cypress. The experimental water delivery program was in operation in Everglades. A 30-day test of

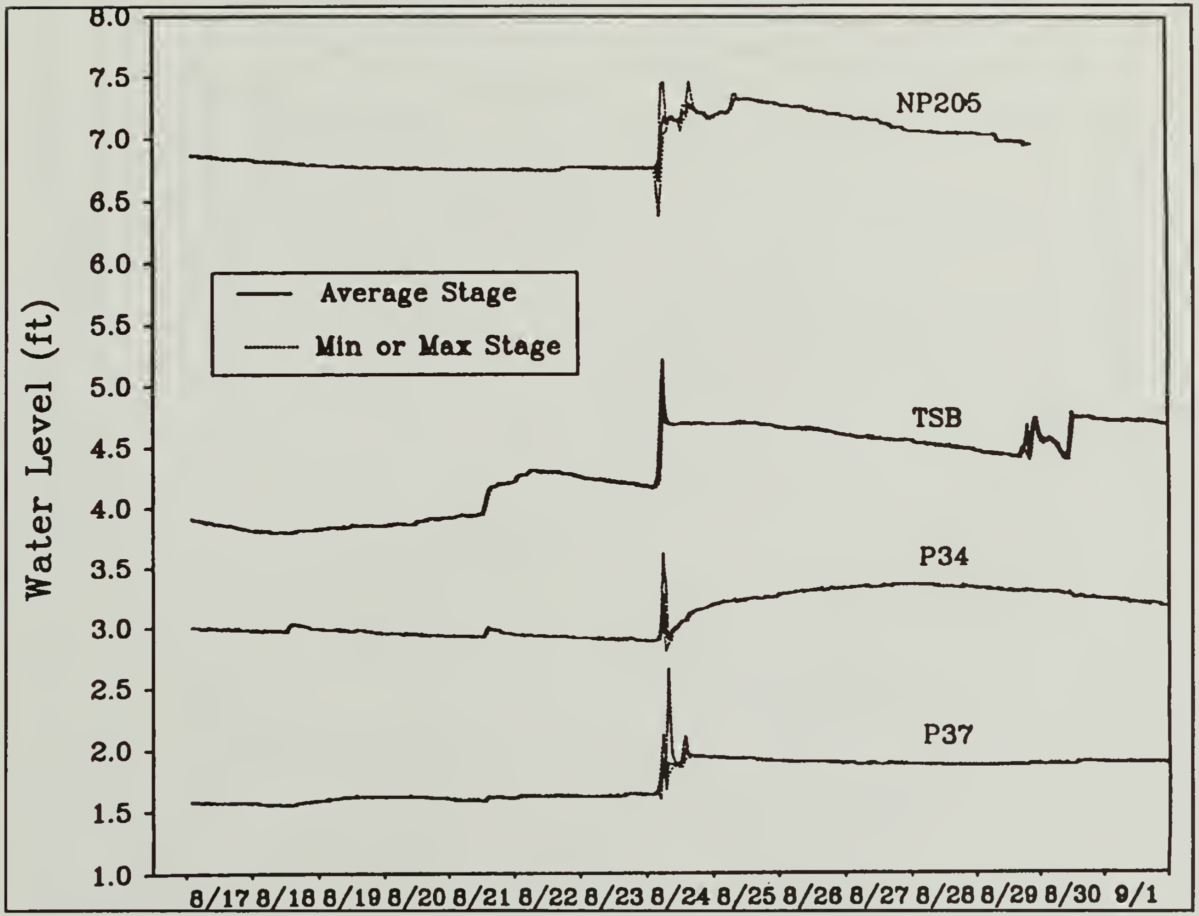

Figure 16. Water-level fluctuations after Hurricane Andrew at selected Everglades National Park, Florida, sites.

increased flows into the Taylor Slough basin was planned to commence on 1 October, to examine the effect on salinity conditions in the downstream areas of Florida Bay.

In the days just before the storm, the Army Corps of Engineers and the South Florida Water Management District were preparing to modify routine project operations as specified in their hurricane plan. The Army Corps of Engineers directed that the S-10, S-11, and S-12 structures (in the interior of the Everglades) be opened full, that the structures passing water from the Everglades to the Atlantic Coast be closed, and that control structures in the Everglades Agricultural Area (EAA) and the coastal areas be opened to lower the stages in the conveyance canals in anticipation of the storm.

Poststorm Hydrologic Conditions

Since the hurricane, water levels have increased throughout the lower east coast developed areas, the water conservation areas, and in Lake Okeechobee in response to above normal rainfall. All of these water storage basins have remained above their regulation levels, and large regulatory releases are being made throughout the South Florida area. Water deliveries to the Shark Slough and East Slough basins of Everglades and southern Big Cypress remain high in response to the increased regulatory releases from the upstream water conservation areas. Inflows into northeast Shark Slough are currently suspended, therefore, the water has been redirected through the S-12 structures. This redirection tends to create more rapid and pronounced water-level increases in the downstream wetlands of Shark Slough and southeastern Big Cypress. The loss of inflows into the northeast Shark Slough has the opposite effect, causing reductions in wetland water levels and more rapid drying of the marshes.

Because the two pumpstations along the eastern boundary of Everglades remain out of operation, water deliveries to the Taylor Slough and eastern panhandle basins are limited. The limited water supply has caused a rapid reduction in wetland water levels in these areas, and reduced inflows to the downstream Florida Bay estuary. Much of the water that would normally have been discharged into these basins is now being rerouted through the southern Dade County coastal canals and lost to tidewater. Water levels and surface water deliveries to these basins have been well below their historical levels for many years because of excessive drainage of the adjacent canal systems. If the southern Dade County water delivery operations are not restored soon, this situation could lead to more rapid drying of the eastern Everglades marshes, and a loss of persistent dry season flows, which would detrimentally affect salinities of Florida Bay.

Water Quality

Immediate and Short-term Observations

Water quality data have been collected monthly at four freshwater sites (P33, P35, P37, TSB) in Everglades at least since October 1985 and at the remaining five sites (EP, NE1, NP201, P34, and P36) since

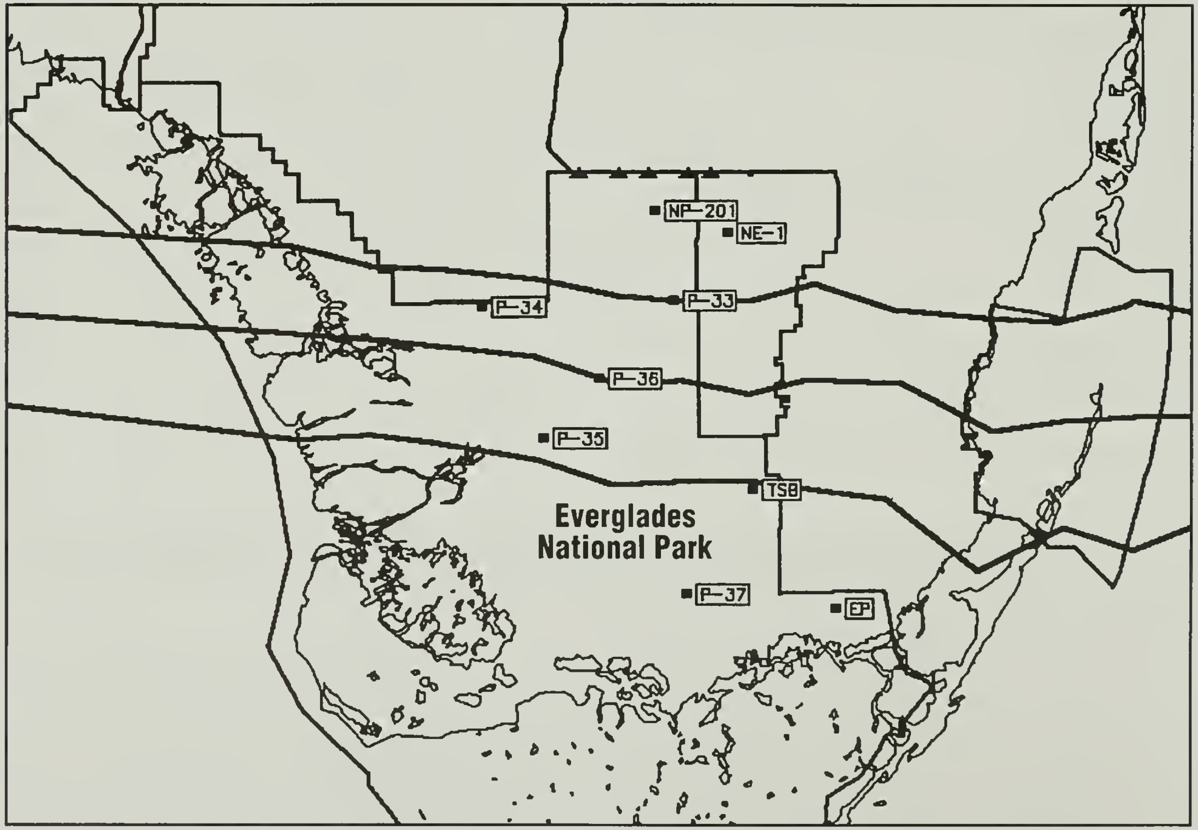

Figure 17. Interior water quality sampling sites, Everglades National Park, Florida.

1986 (Fig. 17). Earlier water quality data exist but are not considered here (South Florida Water Management District 1992) The sample record is not continuous at all sites, presumably because of the occasional occurrence of drought and equipment problems. The water quality assessment discussed here includes two poststorm data sets (28 August and 17 September 1992) compared to a 7-year historical database at nine interior sampling stations (NP201, NE1, P33, P34, P36, P35, P37, EP, and TSB 9). The South Florida Water Management District collected the samples by float helicopter and conducted the water quality analyses. Parameters that were measured and their units are listed in Table 7. Only those parameters for which poststorm results were available as of 22 September 1992 are considered.

The relationships between water levels and water quality and between water quality and sediment chemistry are important with regard to assessing potential hurricane impacts, but could not be considered because of time and data limitations. All data collected, both pre- and poststorm, may be obtained from the SFWMD water quality database (Department of Water Resources Evaluation, West Palm Beach, Florida).

Table 7. Water quality parameters routinely measured at freshwater water quality sampling stations in Everglades National Park, Florida.

Parameters Measured	Other Parameters Routinely Measured	
Temperature (°C)	NOX (mg N/L)	Total Fe (mg/L)
D.O. (mg/L)	NO_2 (mg N/L)	TKN-NH_4 (mg N/L)
Specific conductivity (μmhos/cm)	TKN (mg N/L)	Alk-$CaCO_3$ (mg/L)
pH	Na (mg/L)	NOX+NH_4 (mg N/L)
Turbidity (NTU)	K (mg/L)	Total Hg (μg/L)
Color	Ca (mg/L)	Total Cd (μg/L)
Total suspensed sediment (mg/L)	Mg (mg/L)	Total Cu (μg/L)
NH_4 (mg N/L)	Cl (mg/L)	Total Zn (μg/L)
OPO_4 (mg P/L)	SO_4 (mg/L)	Total As (μg/L)
TPO_4 (mg P/L)	Alkalinity (meq/L)	Total Pb (μg/L)
NO_3 (mg N/L)	Hardness (mg/L $CaCO_3$)	
Total N (mg N/L)		

Summary water quality statistics for selected parameters, including means, standard deviations, and maximum and minimum values, are presented in Table 10. Because of database problems, site NE1 is not included in this analysis. In general, the summary water quality data reflect a pristine wetland environment limited by phosphorus availability. Site P36 has unusually high nutrient concentrations because it is located in an alligator hole. This area remains wet even when surrounding areas are dry, and the higher nutrient concentrations may reflect the effects of evaporation and concentration or wildlife-related nutrient inputs (George Schardt, South Florida Research Center, Everglades National Park, personal communication).

Within the constraints of relatively limited grab-sample data, Hurricane Andrew seemed to have minimal impact on water quality in Everglades. When compared to the historical means, almost all of the poststorm parameters considered were within the range of values recorded between 1986 and July 1992. The exceptions were water temperature at sites P35 and P36 and color at site P36, 4 days after the storm.

Color of the water at site NP201, 4 days after the storm, was close to the maximum value observed before the storm, and may reflect the increased flow of water from water conservation area 3A into Everglades (see Hydrology section). The high value for color agrees with visual observations from helicopter flights, suggesting a more intense than normal tannin color in the water at WCA3A (Nicholas Aumen, personal observation). The lack of effect apparent from the water quality data also agrees with visual observations of a number of field personnel traveling throughout the Everglades interior in the days following the storm. No reports were made of unusually turbid water or of water colors suggesting algal blooms.

Short-term effects during the first 3 days following the storm (such as increased turbidity or suspended solids from wind-induced sediment resuspension) were possibly missed, and long-term effects may become apparent from future sampling. For limiting nutrients, such as phosphorus, any potential increases in water column concentrations would possibly have been rapidly taken up by physical or biological processes or both. No measurements of nutrient dynamics or biological processes are available to assess the aforementioned possibility. Finally, because of the relatively high lower detection limit for phosphorus analyses (0.004 mg P/L), a pulse of a magnitude lower than that would possibly have been undetected.

Because of the relatively high variation in some parameters, particularly those whose values approach analytical detection limits, a time series was viewed using only July, August, and September data. The high variation is from either the difficulties related to obtaining a representative sample during periods of low water, or other seasonal influences. Because the mean and standard deviation are too heavily influenced by outliers and occasional high values associated with low-stage conditions, nonparametric statistics (e.g., 25th, 50th, and 75th percentiles) would provide a more robust characterization of baseline water quality conditions.

Sites P37, P34, and NP201 are generally considered the most representative water quality sites for Shark River Slough. Figure 18 illustrates July, August, and September data (when available) for selected water quality parameters, and includes 6 July 1992 data collected before (48 days) the storm. Almost all poststorm parameters are within the July-September prestorm database ranges. The exceptions are temperature 4 days after the storm, which slightly exceeded poststorm values, and dissolved oxygen 4 days after the storm, which also exceeded prestorm values (Fig. 18).

Because of the possibility of nutrient-related effecting phytoplankton, water samples for chlorophyll analysis were collected at the sites previously described during the 24-day poststorm sampling. Chlorophyll is not a parameter measured during the regular monthly sampling, so no prestorm data are available with which

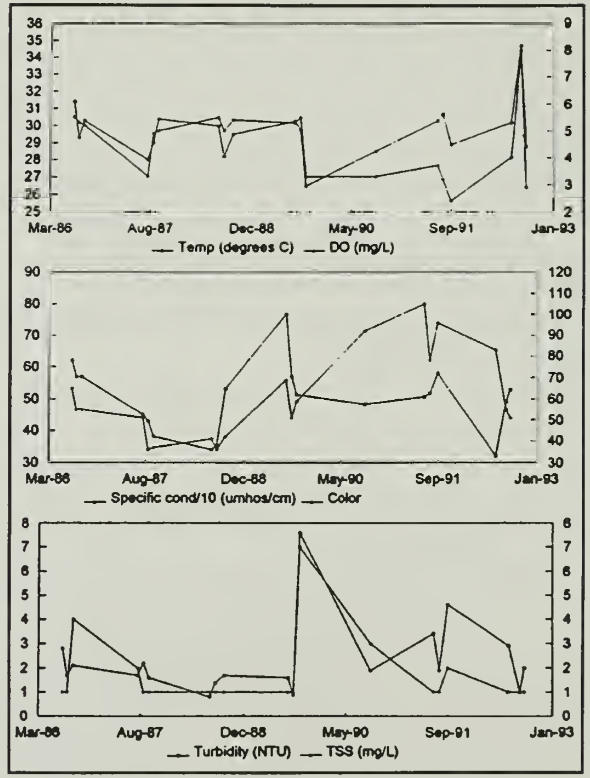

Figure 18. Summary of late-summer water quality parameters at station P-33, Shark Slough, Everglades National Park, 1986-1992.

to compare poststorm data. Poststorm chlorophyll values were low, reflecting the oligotrophic nature of wetland environments in Everglades (Table 8).

In addition to the interior stations previously discussed, water quality data have also been collected at weekly to monthly intervals at many locations representing inflow points to Everglades or adjacent to Everglades (Germain and Shaw 1988). Sampling frequency depends on whether or not discharge from the structures is occurring. For this assessment, total phosphorus data were examined from four inflow structures having high discharge potential into Shark River Slough: S12A, S12B, S12C, and S12D (Fig. 19). These structures were completely open before the storm, and have remained open since the storm (see Hydrology section). The South Florida Water Management District collected grab samples from road access and conducted water quality analyses. Parameters that were measured and their units are listed in Table 7. Because this assessment was prepared quickly, phosphorus-loading estimates could not be calculated. Because the gates were completely open before and after the storm, any changes in concentration would be reflected by corresponding changes in sediment-loading to Everglades. All data that were collected, both pre- and post-storm, may be obtained from the water quality database (Department of Water Resources Evaluation, West Palm Beach, Florida).

Total phosphorus concentrations at the four inflow structures were measured in 1991 and 1992 (Fig. 19). As with the interior site, results and the limited grab sample data, poststorm concentrations did not differ greatly from prestorm concentrations. The same limitations with respect to assessing storm-related effects that were applicable to the interior water quality analyses also apply to this analyses. These limitations include the possibilities of (1) missing immediate poststorm effects (hours), (2) increased nutrient levels in water conservation area 3A resulting from the storm might have been sequestered before reaching the S12 structures, and (3) low-level impacts may not be detectable

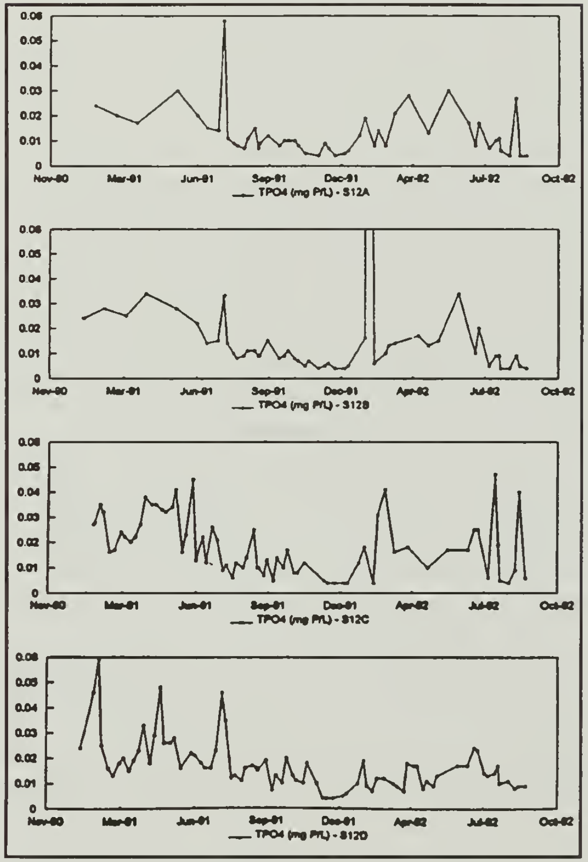

Figure 19. Total phosphorus at four S-12 inflow structures along the Tamiami Trail, just north of the Everglades National Park boundary, in 1991 and 1992.

Table 8. Chlorophyll concentrations measured at Everglades National Park, Florida, freshwater sites from 19 September 1992 sampling.

Site	Chl a (mg/L)	Site	Chl a (mg/L)
P33	3.2	NE1	5.1
P34	3.7	NP201	2.1
P35	8.3	EP	2.7
P36	2.9	TSB	1.3
P37	1.6		

given the relatively high lower detection limit. The potential for longer-term effects must be assessed by continued monitoring and by experimental research.

Poststorm Detrital Pulse

More than 3 weeks following the hurricane, observing green woody plant leaves within saw grass communities was interesting. Dead woody leaves were also observed, and it seemed that they were recently introduced into the aquatic system; yet, this situation could not be confirmed. Observations suggest that these leaves were locally distributed in the vicinity of tree islands. This could be confirmed with a systematic sampling program. The density of woody leaves in the aquatic saw grass community was variable, ranging from 0-3 leaves/m^2, for both live and dead leaves (based on just three 1-m^2 samples in Shark River Slough). The ultimate fate of this organic material deserves further investigation (see Recommendations section).

Wrack deposits or windrows of emergent herbaceous vegetation (predominantly saw grass) were particularly evident from helicopter surveys in the upper Shark River Slough and southern end of water conservation area 3A, areas characterized by a long hydroperiod. In other portions of the Shark River Slough and Taylor Slough, and especially in short-hydroperiod marshes, wrack deposits were observed, but were much less evident. Generally, these wrack deposits were along the east or southeast sides of tree islands. Field surveys in Shark River Slough revealed that the wrack consisted of decaying herbaceous plant material, dominated by saw grass. The windrows were often high (up to 0.75 m, [2.5 feet]), ranged from <1 m to over 3 m (9.8 feet) wide, and often extended up to 50 m (164 feet) or more along the edge of tree islands. Following hurricanes Donna (1960) and Betsy (1965), similar wracklines were observed on the eastern edges of tree islands and hammocks (Craighead and Gilbert 1962; Alexander 1967).

In central Shark Slough, the storm may have disrupted the characteristic mat complex of periphyton and *Utricularia* spp. and contributed to detrital pools (see next section on fish habitat). A short-term investigation to determine the quantity and distribution of this storm-generated detritus in the park is recommended (see Recommendations section). Further, studies to evaluate the role of this apparent pulse of organic material into the aquatic system is warranted.

Fish and Macroinvertebrates

Speculation on the role of freshwater fishes and macroinvertebrates in the Everglades ecosystem has figured prominently in recent public debates on water and wildlife management. These organisms have become the focus of interest because of their use as forage for wading birds, their role in nutrient cycling, and their potential role in the bioaccumulation of mercury (accumulation of mercury within the living organism). In each instance, however, the biological details remain to be worked out. For example, a link between fish and macroinvertebrate abundance and wading bird nesting success remains to be made, although this link seems likely. Water management practices have been shown to influence the abundance and community composition of both fish and invertebrate taxa (Kushlan 1976, Loftus et al. 1986), but food availability has not been shown to limit wading bird nesting success. Similarly, the role of fish and macroinvertebrate community dynamics in nutrient flux has not been studied in sufficient detail (Rader and Richardson 1992).

Nonnative fishes have become an abundant component of the Everglades fish fauna and probably are important prey for wading birds. Walking catfish, for example, are commonly taken by great egrets along the canals lining the Tamiami Trail. The expansion of these fishes into pristine Everglades habitat is not welcomed, and the factors influencing their expansion remain to be explored in-depth. The recent drought of 1989-91 seems to have promoted the penetration of nonnative fishes into new areas throughout the park (Loftus 1991). Hurricanes may also serve to disperse fishes and permit colonization of new areas (Hubbs 1962), suggesting that nonnative fishes may display further range expansion following Andrew.

Hurricane Andrew could potentially affect fish and macroinvertebrate communities in all aspects previously described. The hurricane could have altered the food-web dynamics and nutrient flow patterns if detrital, algal, or macrophyte distribution or abundance was altered by the storm. This may be manifested by changing fish and invertebrate distribution and abundance, which could influence prey availability for wading birds. Wind-driven perturbation of sediments may have released methyl-mercury into the water column or have exposed mercury-laden detrital materials that could enter the food web. Finally, any changes in the native fish community may provide new opportunities for nonnative species to further expand their current distributions or increase their population sizes. During the survey these topics were addressed by qualitative surveys of old and new sampling sites, coupled with quantitative assessment of active long-term monitoring sites

The freshwater resources team visited several sites to examine the abundance of fishes and to evaluate the possible effects of Hurricane Andrew on their communities. Six sites were sampled using a 1-m^2 (10.8-$foot^2$) throw trap to provide quantitative data comparable to those obtained from ongoing sampling efforts in the area. Seven samples were taken at each site. Four of the sites represent short-hydroperiod areas and two represent long-hydroperiod areas. Also, several other sites were sampled qualitatively by visual survey, electroshocking, seining, and dip netting. Three sites had been sampled monthly by seining for the year before the storm (Fig. 20). (See Loftus et al. 1986 for more information on sampling techniques.) No effort was made to sample mercury at this time because of the laboratory time required.

Prior Knowledge

Long-term data sets on fish and macroinvertebrate density, with sampling up to the time of Hurricane Andrew, are available for 11 sites. These data indicate extensive annual variation in fish and macroinvertebrate abundance at all sites, probably related to changes in rainfall and water management activities (Fig. 21). Two general patterns can be discerned from previous data collections. The first is that fish density is cyclical, reaching minima during winter and maxima during summer and fall. The dates of maximum and minimum fish densities are variable among years, however. Second, short-hydroperiod areas have lower fish abundance than longer hydroperiod areas in Shark Slough (Loftus et al. 1986)

One possible source of information for evaluating the effect of Hurricane Andrew is to examine the history of effects and recovery from Hurricane Donna. Donna hit the Everglades in September 1960. Unfortunately, we are not aware of any data on the effect of Hurricane Donna on the freshwater fishes or invertebrate communities of the Everglades. Tabb and Jones (1962) observed high mortality of fishes in the saline marshes north of Flamingo caused by saltwater flooding inland and stranding marine organisms or by anoxia resulting from decomposition of plant matter accumulated after the storm. Breder (1962) observed that Hurricane Donna dispersed fishes in Lemon Bay on the west coast of Florida. We hope that more is learned from Hurricane Andrew in anticipation of future storm events.

We have divided our analysis of the effect of Hurricane Andrew according to the length of inundation of marsh areas. Fish and prawn densities are generally lower in short-hydroperiod areas than in long-hydroperiod ones, whereas crayfish densities display the opposite pattern (Loftus et al. 1986; W.F. Loftus, Everglades National Park, personal communication). Nonnative fishes have been abundant in Shark Slough since 1989 and continue to expand their ranges. At least one nonnative species has been collected at all sampling stations in the park (W.F. Loftus, Everglades National Park, personal communication).

Effect of Storm

No evidence of an immediate effect of Hurricane Andrew on aquatic animal communities was observed by our survey with the possible exception of the central Shark Slough site. Dense periphyton, which normally characterizes this long-hydroperiod site, was absent when we visited (Table 9). A similar observation was reported by Reark (1961) who noted that *Utricularia purpurea* mats were blown into windrows by Hurricane Donna. Craighead and Gilbert (1961) also noted vegetative debris from freshwater habitats accumulated into windrows by Donna. Fishes are closely associated with *Utricularia* mats and use them both for foraging and as refuges from predators. Thus, if Hurricane Andrew were responsible for the loss of the periphyton layer, that fish have abandoned this site for the present is not surprising.

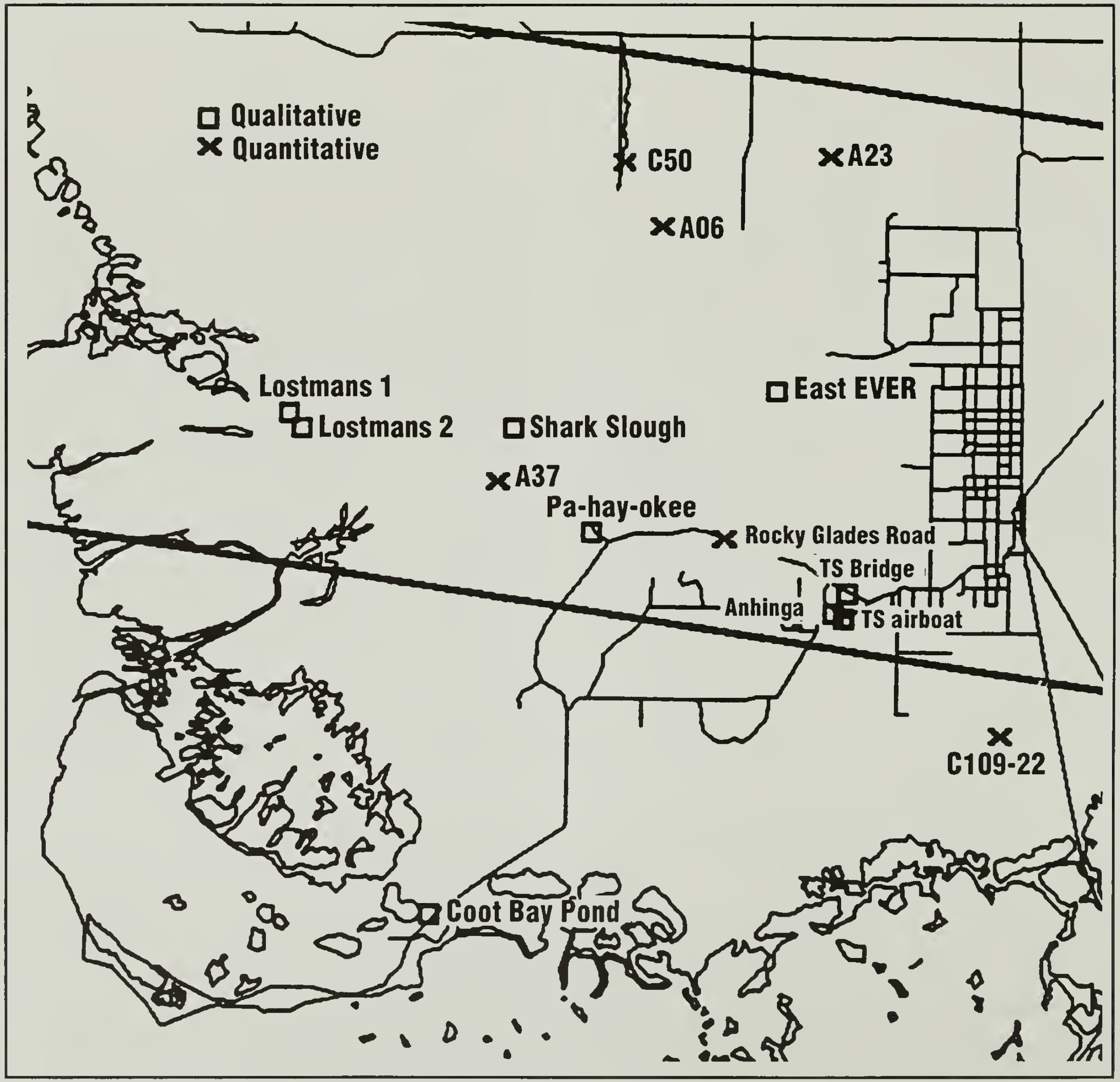

Figure 20. Freshwater fish sampling sites, Everglades National Park, Florida, and environs.

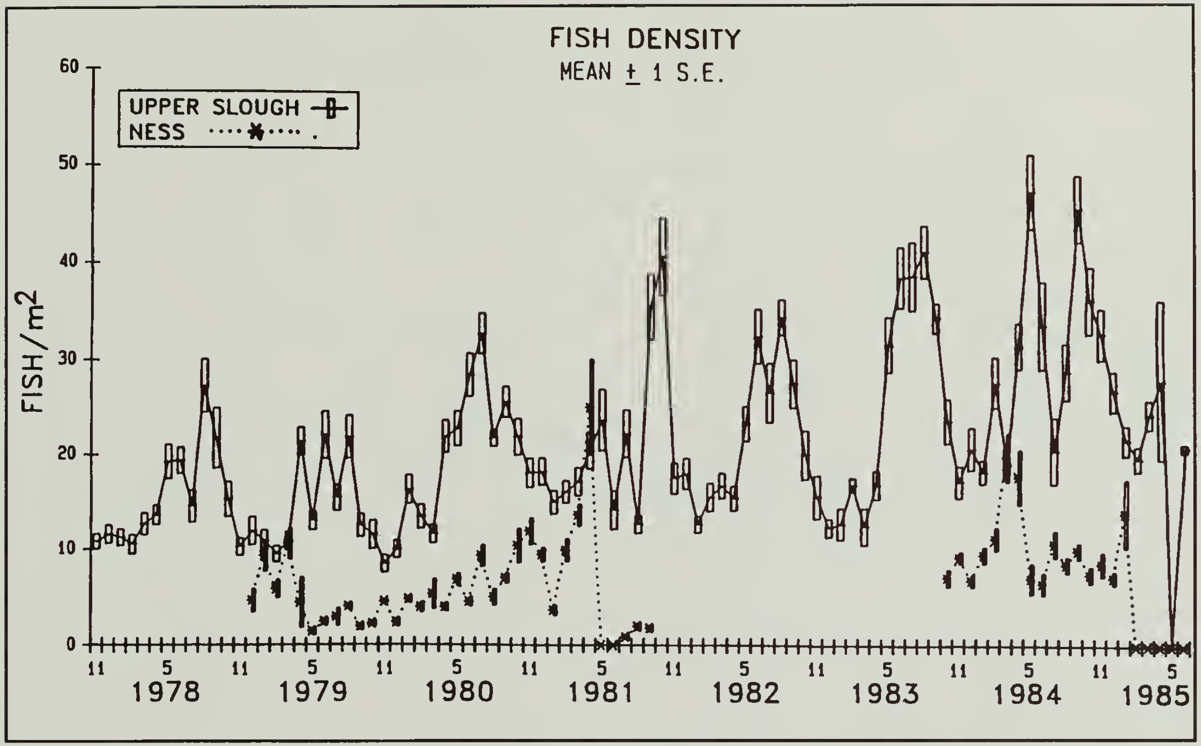

Figure 21. Change in fish density at a long (upper slough) and short (northeast Shark Slough) hydroperiod site in Shark Slough, Everglades National Park, Florida, and environs.

Our estimated fish density was substantially below that estimated in July 1992 and below that estimated for October 1991 (Table 9; no sample was taken in September 1991). Our data from Rookery Branch indicated much lower densities than at the same season in the mid-1980s, the last time when data were collected. Unfortunately, a shortage of funding caused this site to be dropped from the monitoring effort in 1986, so it is not clear if the large change observed there is storm-related.

We anticipate that fishes will return to the central Shark Slough area when the periphyton-*Utricularia* mat is reestablished. No evidence exists that the fishes died, although this is possible. The small size of the fishes would lead to rapid decay, leaving no evidence. We believe most fishes have moved temporarily to another area of the marsh with denser cover.

We observed a second site with an absence of periphyton that had a similar bottom consistency as the central Shark Slough site (Fig. 21, Shark Slough qualitative site). The Rookery Branch site, near the Shark Slough qualitative site, also lacked a *Utricularia*-periphyton mat. Historical records of this site indicate a limited mat years before the storm, but no data from immediately before the storm are available. Thus, the geographic extent of the periphyton loss may be great. The absence of prestorm data on periphyton distribution and bottom sediments prevents us from drawing any firm conclusions on this potentially significant effect of Hurricane Andrew.

Outside of areas where the periphyton mat may have been affected by Hurricane Andrew, there is little evidence of alteration of the fish fauna. Sites at Shark Valley, northeast Shark Slough, the Rocky Glades, and near the C-111 canal do not seem at this time to have been affected directly by Hurricane Andrew (Table 9). Also, sites sampled qualitatively along the road to Flamingo and elsewhere did not seem affected by the storm. If the hurricane results in altered aquatic food-web dynamics, however, we would anticipate an

Table 9. Plant and periphyton cover, fish, prawn, and crayfish density at selected sites in southern Everglades National Park, Florida.[a]

Location	Date	Plant Cover (%)	Periphyton (ml)	Fish (#/m^2)	Prawn (#/m^2)	Crayfish (#/m^2)
Rocky Glades	9/92	37 (22.6)	100 (191)	0.3 (0.8)	0.1 (0.4)	5.6 (5.7)
C-111	9/92	21 (20.7)	4300 (3084)	3.7 (3.0)	0	0.1 (0.4)
NE Shark Slough	9/92	43 (13.8)	<200	9 (4.5)	3 (3.3)	0.1 (0.4)
NE Shark Slough	7/92	38.6 (21.4)	<200	3.7 (2.1)	0	1.3 (1.0)
NE Shark Slough	10/91		1521 (1256)	3.7 (4.1)	0.1 (0.4)	1.1 (2.2)
NE Shark Slough	7/91	10.6 (5.1)	<200	2.3 (2.3)	0	3.0 (1.6)
Rookery Branch	9/92	42 (13.8)	0	9 (4.5)	3 (3.3)	0.1 (0.4)
Rookery Branch	9/85	77 (12.2)	129 (197)	53.6 (104)	13.7 (3.9)	1.6 (0.8)
Rookery Branch	9/84	55 (19.7)	266 (270)	58.3 (19.2)	24.4 (9.2)	1.8 (1.4)
Central Shark Slough	9/92	26 (4.8)	0	1.6 (1.5)	0.7 (1.5)	0.4 (0.8)
Central Shark Slough	7/92	29 (22.2)	2171 (2274)	16.3 (5.0)	2.3 (2.1)	2.4 (2.1)
Central Shark Slough	10/91	6.6 (3.9)	4443 (1474)	16.4 (5.5)	17.4 (7.4)	1.7 (0.8)
Central Shark Slough	7/91	23.7 (16.4)	1700	7.1 (3.7)	7.6 (5.3)	7.0 (4.2)
Central Shark Slough	10/85	18.2 (10.3)		16.7 (6.9)	6.8 (4.9)	1.0 (1.4)
Central Shark Slough	9/84	20 (14.2)	2183 (709)	46.1 (9.4)	22.3 (10.6)	0.6 (0.8)
Shark Valley	9/92	31 (10.7)	993 (430)	2.7 (3.1)	0	0.3 (0.8)
Shark Valley	7/92	15.1 (17.0)	<200	1.7 (1.5)	0	0.3 (0.8)
Shark Valley	10/91	8.0 (5.8)	3071 (3236)	0.6 (0.8)	0	0.7 (1.1)
Shark Valley	7/91	9.6 (9.5)		3.1 (1.9)	0	1.6 (1.1)

[a] Means of information gathered from seven quadrats are reported, numbers in parentheses are sample standard deviations. Rocky Glades, C-111, and NE Shark Slough and short hydroperiod sites and Rookery Branch, Central Shark Slough, and Shark Valley are long hydroperiod sites. When available, prestorm and previous year data are presented. September 1992 samples were collected on 17 and 18 September 1992.

influence on the macroinvertebrates and fishes. Monitoring over the next year will be required to identify such possible storm effects.

We observed no evidence that the distribution of nonnative fishes in the park was altered by the storm, although the abundance of the Mayan cichlid at several sites was unusually high. Nonnative fishes may possibly increase in abundance following recovery from the loss of periphyton. Few data exist on which to base predictions regarding the response of these species to hurricane impacts.

Marine Resources

Water Quality

Hurricane Andrew had a significant impact on the water quality in the marine areas of South Florida. Turbidity, nutrient-loading, and dissolved organic carbon increased both inside and outside the areas of direct impact of the storm.

Effects in Florida Bay and along the west coast, on the southern edge of the impacted area, include increases in dissolved phosphate and ammonium. Dissolved phosphate is normally less than 4 ppb in this region, but has recently been measured as high as 60 ppb at some stations. In addition, dissolved organic carbon has increased from 4 ppm to 40 ppm, suggesting an input from an upland source.

Increased nutrient-loading (carbon, nitrogen, and phosphorus) measured along the southwestern coast is believed to be leaching from the massive amounts of downed vegetation or sediment disturbance associated with the storm. This increase in nutrients should affect the carbon, nitrogen, and phosphorus cycles of the marine resources. Although the increased dissolved organic carbon and nutrients measured are already demonstrating significant impact through plankton blooms and increased turbidity, the greatest impact is expected in the future (from 6 months to 5 years).

Short-term Effects on Light, Nutrients, and Oxygen in Biscayne Bay

Dissolved oxygen levels were nearing zero on 25 and 26 August due to mass quantities of particulates along eastern Biscayne Bay and in the adjacent canal areas. Large schools of fish, particularly black mullet, were seen frequently on the surface getting oxygen.

On 27 August, large numbers of lobsters were observed along canal walls at Gables by the Sea, climbing up the walls to the surface to obtain oxygen. We hypothesize that their actions were due to oxygen depletion because of the heavy concentrations of particulates in the water column.

Long-term Effects in Biscayne Bay

The huge pulse of organic and nutrient input to the bays and the Continental Shelf might cause a prolonged planktonic bloom that will reduce ambient bottom light and deplete oxygen in the lower water column. This planktonic bloom may have severe consequences for the sea grass and hard-bottom communities in Biscayne Bay and the outer shelf on the east coast, and should be of primary concern. On the west coast, sea grasses were restricted to shallow waters because of relatively high ambient turbidity. Decay of the wetland and upland vegetation killed by the storm provides a further time release mechanism for introducing nutrients and organics.

High nutrient release during and following this storm has a strong probability of moving seaward and southward from Biscayne Bay and southward from the west coast and influencing the coral reef system.

Pollutant Inputs

On 24 and 25 August, we observed Dinner Key marina in Coconut Grove from the shore and by boat. We could see and smell large quantities of petroleum floating on the surface as well as onshore.

To the south, we noticed similar situations at Matheson Hammock park and marina. There were also large quantities of diesel and gasoline fuel being released from sunken and demolished boats in the bay. Not until Wednesday, 2 September, a week after the storm, did the marina place a containment boom in operation. Fuel discharge was heavy on the surface and along the mangrove fringe.

On 27 August, at Black Point marina, large quantities of fuel were in the water and no containment boom was in place. We spoke with the dockmaster and were told that the fire marshall recommended that they let the gasoline flow out with the tides to decrease the hazards of mass fires. We also noticed fuel in the water along the severely damaged mangrove coastline. Our overflight on 19 September revealed a continued heavy plume of fuel discharging into Biscayne Bay from the area of the collapsed dry storage building (this was 27 days after the storm).

Sediment, Erosion, and Deposition

Before the arrival of this rapidly moving storm, intense north-south currents set up strong north to south currents on the reef tract shelf: in Biscayne Bay and along the barrier islands, the coral islands of the northern Keys, along the mainland shore of Biscayne Bay, along the western shore south of Chatham River, and on the marine environment to the west of the Chatham River to Cape Sable shore. This situation was described by one observer as the Gulf Stream moving southward along the Key Biscayne shore. This phase of the storm moved large volumes of water into southern Biscayne Bay, building tide levels and initiating the expected storm discharge out of Caesar Creek.

The rapid forward speed of the storm seems to have severely limited the normal period of prolonged wave attack that a coastline receives before a storm reaches land. The intense winds of the storm moved into the Straits of Florida less than 2 hours before landfall on the eastern shores. As a result, wave attack of the shores was minimal and wave scour of the sand, mud, and sea grass bottoms of the reef tract, Biscayne Bay, and the west coast marine environments was minimal. Rather, these shore and marine environments were dominated by brief but extremely strong unidirectional currents and onshore surges. The effects of this storm were different from those that have occurred with slower moving hurricanes.

Although the storm moved across South Florida at an extremely rapid forward velocity (measured at 50 km/hr [32 mph] by Dr. D. Churchill at the University of Miami), the effective winds on the southern side of the storm seem to have been as strong and effective as those on the northern side. Another peculiarity of the storm is that the winds did not seem to have diminished as the storm crossed the peninsula. The wind damage to the coastal mangrove forests on the west coast was as severe, possibly more severe, than observed on the east coast.

Coastal Modification

Strong onshore surges occurred on the east coast islands from central Key Biscayne south well down the coast of Elliott Key. On the mainland coast of Biscayne Bay, strong onshore surges occurred between Rickenbacker Causeway and Turkey Point, with a peak height occurring in the Burger King to Black Point area. Pronounced flooding occurred to the south because of water buildup from the northerly winds before the storm. On the west coast, strong along shore transport occurred south to the Lostmans River area. Southward, a strong onshore surge occurred along Highland Beach (water levels reaching to 2.6 m [8.5 feet] above poststorm high-water marks), up the Broad River 2 m (6.5 feet) at the mouth, decreasing inward), and decreasing southward to Ponce de Leon Bay +1.2-1.5 m (+4-5 feet). On Cape Sable the water levels were about +1.2 m (+4 feet) in the north decreasing to 0.6 m (+2 feet) in the south. The wash across Cape Sable did not produce high water levels in the area behind. These surges were relatively short and were preceded by only a very brief period of normal wave attack. The onshore surge current was the primary influence of this storm on the coastline.

Beaches

On southern Key Biscayne, in the northern eye wall of Hurricane Andrew, the filled shoreline was reshaped into a very straight, very gently seaward-sloping beach in which the crest was over 2.1 m (7 feet) above poststorm high-water mark. This reprofiling by the surge scoured portions of dune vegetation and dunes, and partly to completely filled swales. The position of the beach high waterline shifted very little, but over one-half of the volume of sand in the front 25 m (82 feet) was swept landward. Some channels were cut in the beach as floodwaters poured out of the island interior in the late stages of the storm. Poor water clarity has left unresolved how much the quartz-carbonate sand shoal extending southeastward from Cape Florida has moved or been modified during the storm.

The exposed northeastern sandy margin of Boca Chita Key was significantly scoured, leaving a scarp. The sandy beaches on northern Elliott Key were shifted, and one northern beach was breached by a post-storm discharge of impounded water eastward.

Large volumes of the quartz sand that formed beaches and shoals on the mainland shore were moved landward (e.g., Matheson Hammock).

On the west coast, Highland Beach received a major onshore surge causing inundation and extending sand and shell lobes 3.0-12.1 m (10-40 feet) landward across the mangrove swamps. Numerous sand and shell deltas formed as the flood surge waters moved back seaward. All of these channels are now largely filled.

On Cape Sable, initial winds caused a strong north to south current, causing some erosion to the west-facing shores. The flood levels occurred from the west and then from the south. West-facing beaches have a distinct onshore inundation pattern with lobes extending the beach ridge 3.0-12.2 (10-40 feet) landward. On south-facing beaches, an erosional phase presumably resulted from the westerly winds. Southerly waves caused a final burst of beach ridge growth. Plugs placed in the mouths of three Cape Sable canals in the 1970s failed. Tidal exchange was occurring at the east Cape canal, Ingraham canal, House ditch, and Slagles ditch.

On the sloping beaches of Key Biscayne, Highland Beach, and Cape Sable, the lower half of the beach slope was erosional commonly down-cutting 30-100 cm (11.8-39.4 inches). Lateral erosion of the shoreline was less than 10 m (32.8 feet) in all areas, because of the lack of prolonged wave attack and the relatively brief duration of the surge. On the upper half of the beach, a mixture of deposition, erosion, and bypassing occurred with deposition rarely being greater than 30 cm (11.8 inches). The exception is the central and southern Cape Sable beaches that appear to have built a new beach ridge against the shore crest after a phase of significant erosion. This has resulted in 50-80 cm (19.7-31.5 inches) of deposition. The beach-dune crest was bypassing, having less than 10 cm (3.9 inches) of new sediment. Landward wash-over lobes have extended the shore as much as 10 m (32.8 feet) landward and are 30-100 cm (11.8-39.4 inches) in thickness. These beach modifications are minor compared to the effects of slower-moving historical hurricanes.

Sea turtles nests on the upper beach have a moderate to good chance for survival, except on middle to south Cape Sable where significant erosion occurred. One hatch was observed on Key Biscayne following the storm.

Peat and Marl Coastlines

The brief surge itself caused little shore erosion to the peat and marl coastlines or channel margins. Storm winds and the storm surge, however, uprooted many trees at the shoreline. These uprooted trees have created a rough and unstable shoreline that is being reprofiled by waves and currents. This process will release large volumes of organics into the coastal bays for several years. Trees at the onshore surge coastline are commonly flattened and uprooted. Most of the destruction of mangrove inlands was the result of wind, not storm surge. Mangroves along channel margins generally survived much better than those away from the channel margin. Mangroves in a leeward (primarily northern) shore or channel-margin setting commonly lay down in the water and remained green through the storm.

Rocky Shorelines

The gently seaward-sloping rocky shorelines from Soldier Key through Elliott Key received an onshore surge that had no effect on the limestone surface but stripped away the shore vegetation and any other objects. (The house on the seaward side of northern Elliott Key was reduced to rubble and deposited several hundred feet west of its origin.)

Storm Sediment Layer

The sedimentary deposits resulting from the storm represent the nature of the material eroded and transported during the storm, and much of the storm-deposited material will be reworked by prevailing and winter-storm processes. The thickness and distribution of the storm layer will determine the turbidity, water clarity, and oxygen levels in marine environments for the next several years. Subtidal observations were made 3-4 weeks after the storm so that the highly ephemeral materials had possibly moved on.

In Biscayne Bay, a tan to brownish sediment layer to 50 cm (19.7 inches) in thickness is present in depressions in the western bay and in some channels. This layer is composed of mud and organic material. The general rocky-bottom environment has little sediment. We have not yet dived the deeper portions of north-central Biscayne Bay but expect a significant layer there. On the seaward side of Biscayne Bay, there is a grayish mud layer to 50 cm (19.7 inches) in thickness in depressions in the mudbanks. On the reef-tract shelf, the deeper blowouts in the sea grass contain a thick wrack deposit of sea grass blades and other storm-eroded material. There is no widespread subtidal storm mud layer.

On the west coast, the interior bays have a grayish mud layer 20-50 cm (7.9-19.7 inches) in thickness. This gray mud layer is also found offshore in protected depressions. These bottoms released numerous bubbles as we motored through the bays. The broad intertidal to shallow subtidal banks seaward of Harney River, Broad River, and Lostmans River contain a patchy to widespread layer of mud to muddy sand to 50 cm (19.7 inches) in thickness. No significant muddy storm deposits were in the channels or on the seaward deepening offshore slope (to the Everglades boundary). The subtidal storm layer present does contain some organic material and leaves and twigs, but the grey to light grey color (quartz and calcium carbonate material) is surprisingly light compared to the large volumes of dark organic matter released by the storm.

Ebb-flow deltas have formed both along the coast and along penetrating tidal channels. These formed after the storm surge as waters were receding out of the mangrove swamp. On the shore of Highland Beach there are numerous breaches. A few of these cut through the island to several feet below sea level; most breached the sand-shell beach ridge but did not cut to normal high water level. Each shore ebb delta created a seaward lobe or spits of sand and shell extending 10-50 m (32.8-164 feet) seaward of the shore. Only a few deltas formed on Cape Sable. The ebb deltas caused more destruction to the inshore sea grass beds than the storm waves and currents.

In Broad River, several ebb deltas formed during the storm and built well out into the main channel. These deltas are built of a soft, grey mud. These deposits are 1-3 m (3.3-9.8 feet) in thickness. Prevailing tidal currents are gradually modifying these intrusions into the channels.

One ebb sand delta is present on the eastern side of Elliott Key about 3 km (1.86 miles) from the north end of the island. The beach on Key Biscayne has numerous small channels on the beach. The most pronounced were on the north and the south sides of the Towers of Key Biscayne where the flood surge scoured in association with gaps in the shore structures. Poor water visibility has inhibited assessment of such features on the mainland shore of Biscayne Bay.

The surface of the broad mangrove swamp between Lostmans River and Broad River on the west coast was covered by a grey mud layer 1-10 cm (0.39-3.9 inches) in thickness. The layer is sandy within 100 m (328 feet) of the coastline, is exposed at low tide, and has become firm and resistant to erosion. The grey mud layer decreases in importance inland. Adjacent to the Harney and Shark rivers, this layer rapidly decreases in thickness inland and is not present adjacent to Tarpon Bay.

The mangrove swamps adjacent to eastern, western, and southern Biscayne Bay received a new layer of grey to tan sediment. We observed this from the air but have not yet sampled it from the surface.

The mangrove wetlands that were severely damaged contain large volumes of dead leaves, twigs, and trees. In addition, the uprooted trees have created a highly irregular topography and exposed the substrate to erosion.

Suspended Sediment

Following the severe sediment resuspensions or the storm proper, several coastal and nearshore areas of southeastern and southwestern Florida have retained high turbidity levels. Some areas remain high because of continued reworking of storm deposits; others, because of the plankton blooms that have been triggered by the pulse of nutrients and organics provided by the storm.

Reworked Storm Deposits and Scour

The landward half of Biscayne Bay has maintained high turbidity levels relative to prestorm ambient. The brownish color indicates much is related to resuspension of storm-released coastal peats. The deep central portion of central Biscayne Bay north of Featherbed Bank has evolved to moderate to high levels of green turbidity caused by a major poststorm plankton bloom.

Seaward of southern Key Biscayne, and the northern Safety Valve, persisting high turbidity levels that are whitish in color represent continued reworking of storm mud layers and of scour areas on the seaward flanks of the island and banks. Waters on and seaward of the Safety Valve from Soldier Key south cleared within a week of the storm and have remained clear (except when intruded by ebb waters from the inner bay) indicating the lack of subtidal erosion or storm deposition in the area. The inner portion of the reef tract from Elliott south has retained high whitish turbidity reflecting continued reworking of storm mud deposits and of storm scour areas.

The west coast of Florida between Cape Sable and Chatham River normally had high turbidity levels along the coast before the storm. In addition, the inner channels and bays had reduced visibility because of tannin-rich waters. Following the storm, the Chatham River had returned to tannin-rich waters with low particulate turbidity by our 31 August overflight. To the south, however, the bays and channels associated with Lostmans River, Broad River, and Harney River retained comparatively high particulate levels. The ebb tidewaters from the Broad River area maintained high particulate levels through 20 September (but somewhat lower than the visits on 12 September). The high turbidity levels are brownish—quite different than the grey mud layer deposited. Ebb and flood currents along the Broad River are scouring and introducing brown to tan to grey turbidity into the channel waters.

Sea Grass Beds

Two major questions were addressed with respect to the potential impact of Hurricane Andrew on the sea grass bed communities of Everglades and Biscayne national parks: what changes occurred in sea grass community distribution and what changes occurred in blade density, standing crop, and community structure?

Biscayne Bay

From the air, the sea grass and shallow marine communities appeared to be remarkably untouched by the storm. This was most dramatic off Elliott Key, Boca Chita Key, and the Ragged Keys. Here the terrestrial communities were leveled on the islands, while 10 m (32.8 feet) offshore, sea grasses, *Sargassum*, and gorgonians could be seen from the air, apparently untouched. Concern had been expressed about propeller cuts in grass beds acting as erosional foci and allowing the beds to be torn from within. This did not happen with Hurricane Andrew. Throughout the tidal banks off the northern Florida Keys, the propeller scars seemed unaffected. Later, as viewed in the water, a few centimeters of sediments were eroded from the sides of the cuts and from the bottom, but that rhizophytic algae, including *Halimeda*, and *Penicillus*, were still firmly attached.

Sea grass blowouts are common in numerous areas. Most of those observed were unaltered, as evidenced by the presence of fixed algae or gorgonians growing in or adjacent to them.

The only suggestion of possible new or very enlarged features was the northerly most lobe of the Safety Valve, just south of Key Biscayne. Only the seaward flank of the northern Safety Valve displayed extensive sea grass loss by the onshore storm surge. This surge cut elongated scour patterns 50-100 cm (19.7-39.4 inches) deep into the sea grass bed surface. On the crest of the Safety Valve and on the Featherbed Bank, however, almost no sea grass erosion occurred. This is in sharp contrast to Hurricane Betsy (1965) and other storms that caused extensive destruction to the sea grass bed surface.

Although water clarity is still poor in the deeper, central portions of central Biscayne Bay, the sea grass beds in the bay appear to have not suffered direct storm damage. The patches of sea grass on the rocky bottom of the landward portions of Biscayne Bay appear moderately damaged, and the veneer of sand has been largely swept out of the area.

Seaward of the Keys, sea grasses show only minor modification on the sea grass platforms seaward of southern Key Biscayne and seaward of Caesar Creek. Little visible modification has occurred to the sea grass bottom of the inner portion of the outer shelf along the length of Biscayne. This bottom is generally a mixed muddy sand and not quickly remobilized. One of the patch reef areas seaward of northern Elliott Key had a north to south scour channel formed between two reef patches. This channel seems to be another display of the strong north to south current that developed as the hurricane approached. The channel had a pronounced sand delta that extended across the sea grass bed to the south. The rigid reef patches provided constriction to flow initiating the channel scour.

The sandy bottom of the outer portion of the reef-tract shelf showed greater modifications from the storm. Most characteristic is a crescentic lobe of sand deposited on the sea grass to the south of bare sand areas. These are seen both south of blowouts in the sea grass beds and south of the bare sand halo around reef patches. We observed these by air as far south as Carysfort Reef. These present a clear record of the shelfwide north to south current that extended well south of the southern eye wall. In addition, the sea grass beds were subjected to blowout enlargement towards the shelf margin and were cut by linear scours in some midshelf areas. Historically, hurricanes have dramatically modified and set back the sea grasses of the outer shelf. This storm appears to have caused less modifications than did Betsy or Donna (1960).

An analysis of sea grass plant and blade density at three of Dade County Department of Environmental Resources Management long-term monitoring stations following the storm is presented in Fig. 22. These data (Appendix A) indicate that

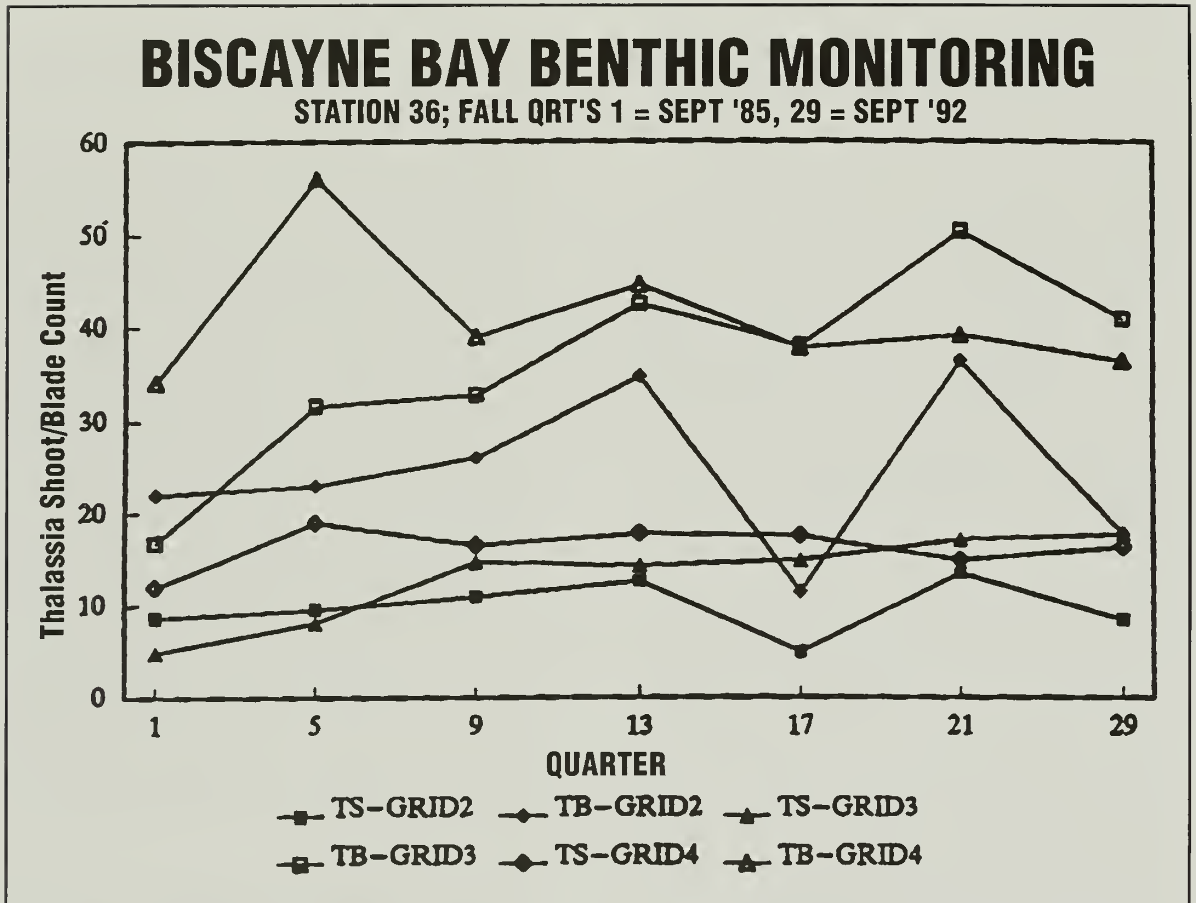

Figure 22. Turtle grass (Thalassia testudinum) *blade counts in Biscayne Bay, Florida, before and after Hurricane Andrew.*

blade density is currently well within the normal ranges measured before the storm, and that no significant change has occurred in the grass bed standing crop.

Hard-bottom Communities

What changes occurred to sponges and other rock reef or hard-bottom community organisms in the shallow water areas of Biscayne?

As with the other underwater marine resources in Biscayne and Everglades national parks, the hard-bottom communities in Biscayne Bay and the areas immediately seaward of the keys are believed to have been only moderately affected. In most areas, little change to these resources is discernable with casual visual observations. Typical hard-bottom community components such as the sea plumes (*Plexaura*, *Pterogorgia*, and *Pseudopterogorgia*), calcarious algae (*Halimeda*, *Penicillus*, *Udotea*, and *Rhipocephalus*) and stony corals (*Siderastrea*, *Porites*, and *Manicina*) appeared virtually undisturbed. Occasional uprooted sea plumes were encountered, but these were not frequent or excessive.

The shallow rocky ramp seaward of Soldier Key retained many of its sponges and sea fans and sea whips, but a number of the isolated head corals were ripped loose and tumbled landward. Similar survival of sponges, sea fans, and sea whips was observed in eastern and western southern Biscayne Bay. The veneer of sand has been swept from many of these areas.

The sponges were the most impacted component of the hard-bottom communities. Underwater surveys at a location approximately 1.6 km (1 mile) south and west of the Pelican Bank west marker in Biscayne Bay (near the site of Biscayne's previously established Pelican Bank sponge monitoring plot) revealed that a relatively heavy layer of fine flocculent silty marl sediment has been deposited over the bottom. This material averaged 1-2 cm (0.39-0.78 inches) deep at this location. The deposition seems to have resulted in the smothering and death of most sponges encountered. The only species for which live specimens were encountered at this location was the loggerhead sponge *(Speciospongia vesparium)*. Several dead specimens of the genera *Spongia*, *Hippiospongia*, *Ircinia*, *Verongia*, and *Haliclonia* were encountered during a 30-minute survey period. The skeletal remains of these sponges fell apart readily when handled. The sediment-loading did not appear to have a significant impact on stony corals, sea plumes, algae, or sea grasses. Although a buoy previously marking the location of the Pelican Bank sponge study plots was located, we were unable to find the established monitoring plots and therefore did not obtain quantitative data on specific changes at this location.

The sponge component of the hard-bottom community was also found to be significantly altered near Elliott Key (Billys Point sponge monitoring plots). Stakes and lines marking Biscayne monitoring plots were located at this site, and a count of all commercial sponges remaining within the plots was conducted. The count revealed that less than 140 remained of the 282 commercial sponges marked and mapped within these plots before the storm. All sponges and other organisms that remained on the plot seemed healthy and were present in a variety of sizes. Changes in the substrate characteristics at this site during the storm seemed to be one of minor sediment loss and scouring as opposed to any accumulation. None of the fine flocculent material so pronounced at stations visited on the western side of the bay was evident at Billys Point. Resource management staff at Biscayne reported visiting this location on 5 September 1992 (10 days after the storm) and finding essentially no loose sediments at the site. Upon the team's visit on 21 September, they felt some sediment had accumulated.

The importance of the prior monitoring data cannot be overemphasized in this case. The impression one gets from any casual observation at the Billy Point location is that the community was probably little changed during the storm. A large number of commercial sponges and other sponge species of all sizes and age groups were observed and all appeared healthy, as did the corals, algae, and other community components.

We visited a third hard-bottom location near the Biscayne sponge monitoring plots directly east of Black Ledge in mid-Biscayne Bay. Again, although the buoy previously marking the monitoring plots was found, the markers and line locating the plot were not found. Therefore, observations at this site were only qualitative. As at the Pelican Bank site, some deposition of an extremely fine flocculent marl sediment was evident, but to a much lesser degree than at Pelican Bank. Most sponges encountered during the survey were alive and appeared to be relatively healthy. Most other community organisms appeared to be largely unchanged. Some gorgonians were encountered that had been uprooted and were lying flat on the bottom. These may either have been from the site or transported to the site from other areas. A number of echinoderm tests were encountered while surveying this site but no live specimens. The Biscayne park staff reports that sea urchins were common in the area before the storm.

Although only qualitative data are available for the hard-bottom communities seaward of the Keys, the communities appeared to be relatively undisturbed. No evidence of mass destruction or loss of organisms were evident during flights or during transects by boat over several of these areas.

Coral Reefs

What changes in coral community structure, density, and species composition occurred on the bank reef areas? Was there evidence of deep water wave surge impact to Biscayne reefs?

Aerial observations indicated that Hurricane Andrew caused significant smothering and sand blasting to certain reef areas and left others relatively undamaged. The strong north to south current along the shelf seems to have dominated the stress and to have been responsible for transporting large volumes of mud in suspension south of the main storm area.

The major types of damage observed to corals were detachment and overturning (both small and large heads), and breakage of branching species. Abrasion and gouges were also evident on some corals. Damage to soft corals and sponges, two of the major community components on Biscayne reefs, consisted mainly of detachment and burial, and partial breakage (chunks missing). Damage severity varied greatly among and within reefs, with more severe damage to corals and soft corals observed on Bache Shoals and to sponges on the deeper offshore reefs. A brief description of each reef visited (from south to north) follows.

Ball Buoy (midshore)

This reef is dominated by large stands of the elkhorn coral *Acropora palmata*, a species known to be sensitive to storm damage. Some colonies had broken off and were laying amidst large colonies of this species. Some colonies had abraded fronds. Recently exposed skeletons (where branches were broken off or tissues were abraded) of *A. palmata* were covered with a green filamentous alga, possibly *Cladophora*. Older lesions on the same or adjacent colonies had a totally different algal colonization. This infection with the filamentous green algae was not observed on any of the other reefs investigated. Roughly 10-20% of the elkhorn colonies had breakage at this reef. Soft corals, sponges, and other reef organisms showed no sign of recent damage. Overall, coral community impacts were slight and were concentrated on one major species. The fate of broken elkhorn with the green algal infestation should be monitored.

Rubicon (midshore)

This reef is characterized by a large rubble field on the reef flat with few large corals. The rubble field had large numbers of recently broken and killed corals (cobbles with some tissue remaining), mostly elkhorn but also some head corals, and generally looked disturbed. A grass bed on the southern side of the reef was undercut, but grasses just south of this feature did not appear to be affected or buried. Overall, damage was moderate, and the source of fresh rubble was not apparent. This reef should be surveyed more extensively.

Elkhorn (midshore)

This reef has dense patches of elkhorn on the northeastern quadrant, much of which were broken up; large colonies were overturned, and many of the smaller pieces were reduced to rubble. Other colonies, however, were not impacted physically. Interestingly, the broken and abraded elkhorn pieces showed no evidence of the filamentous green alga observed on Ball Buoy Reef. Head corals on the eastern side of the reef showed minimal signs of damage. The reef flat looked abraded and disturbed. Overall, the damage was moderate to the elkhorn and slight to moderate to the remaining reef organisms. The reef should be surveyed in more detail.

Ajax (offshore)

The area visited was at 24.4 m (80 feet) where there was some deep spur and groove. The area was characterized by small colonies of the star coral *Montastrea annularis* (morph type III), and *M. cavernosa*, the barrel sponge *Xestspongia*, and smaller colonies of other corals (*Siderastrea, Stephanocoenia, Agaricia* spp.). Much of the deep reef and coral was covered by silt, but some corals that had previously been partially covered by silt appear to have been exposed during or following the storm. This was shown by dead white area in and along the edge or middle of a colony, usually in a depression. Other colonies with silt on them had similar dead white areas under accumulations of silt. Some of the *Xestospongia* colonies had upper portions missing, especially on their seaward sides; these upper portions were in the process of healing. These light-colored lesions were similar in shape to older totally healed lesions on some of the colonies. A few gorgonians and tube sponges were totally detached and had accumulated in reef depressions. Whether the silty condition of this reef is normal or related to the storm is unknown. The bottom around and seaward of the deep reef was composed of fine rich sediments that had burrows and algal films. Thus, if the deep sediments were disturbed by the storm, they had returned to some degree of normalcy. Even though there was a strong current at the surface, the deeper water was calm, possibly allowing for the accumulation of silt.

Alinas (midshore)

This reef has many large head corals, especially *M. annularis* and *Diplora* spp., but little elkhorn. Several of the large coral heads on the reef flat, especially toward the middle and south of the reef, were dislodged and overturned; examination of the exposed attachment sides indicates that the colonies that overturned were heavily bioeroded. Other large and better attached coral heads were not affected. Many detached soft corals were on the back (western) side of the reef, lodged in depressions among the large star corals. The northern end of the reef appeared unaffected, as did parts of the southern end. Overall, damage was slight to moderate. Recruitment to the newly exposed coral framework and the fate of the overturned corals should be monitored.

Long Reef (offshore)

We examined a deep spur that ranged from 15.2 to 24.3 m (50-80 feet) deep. A strong current was at the surface, but no current occurred below the surface. The reef was silty and had a low coverage by hard corals. As on Ajax, many of the barrel sponges had pieces missing from their seaward sides, but little evidence of damage was seen to the hard or soft corals. Some corals showed evidence of detachment from earlier storms. Many heavy ropes (lobster pots) were draped over the sponges and corals; some of these animals showed evidence of abrasion from these lines. We recommend that these lines be removed to prevent further damage to the reef fauna. Overall, storm damage was minimal.

Ledges (offshore)

This small formation at 6.1 to 12.2 m (20 to 40 feet) has high topography filled with schools of fish. The benthic community is characterized by a dense soft coral community, with some head corals. On the seaward side of the formation, a few overturned corals were partially buried in the sand, as were a few detached soft corals. Overall, however, only slight evidence was seen of hurricane damage. This site has a fair number of recruits of *M. cavernosa* that could serve as a resource for a study of juvenile coral survival.

Triumph (deep offshore)

We examined a deep reef at a depth of 24.3 m (80 feet). A strong current was at the surface and a slight current was present at depth. This reef was less silty than either Ajax or Long reefs. Little hard coral was seen at this site, similar to the aforementioned reefs. Large pieces of barrel sponges were missing. Large masses of sponges of numerous species had accumulated in depressions at the base of the reef ridges; some large soft corals were mixed in with the sponges. There were a few overturned pieces of coral rock along the margin of the reef, and coral blocks seemed to have been overturned during previous storms. The sediment around the reef looked undisturbed. Overall, there was significant damage to the sponge community, but it was not clear whether the sponge accumulations derived from the shallower reef inshore of the deep reef or from sponge populations further offshore. The source of the damaged sponges should be determined.

Triumph (shallow offshore)

At the southern end of Triumph Reef, Dr. James Porter (University of Georgia) has a photographic documentation site that he and his team have been sampling for the past several years. Dr. Porter and park personnel have visited the site annually every 3 weeks to deploy and recover a Hydrolab DataSonde water quality monitoring unit that measures dissolved oxygen, pH, salinity, conductivity, and temperature at hourly intervals. The unit was in place and running during the storm. The unit was collected 3 weeks after the storm, and the data collected during the storm will be made available. Early reports by Porter and the park staff indicated that the reef was destroyed. In reality, some minor damage occurred and a large coral head (approximately 2 m [6.6 feet] in diameter) was displaced several hundred feet from Porter's study site. The clearest indication of the passing of the storm over this reef was the large accumulation of broken lobster traps, sea fans, plumes, rope, and other debris in hollows and other protected areas of the reef complex. No evidence was seen of abrasion, breakage, or excessive siltation.

Bache (midshore)

On the western side of the coral reef is a small complex of reefs (5) known as Bache Shoals. The area is a popular snorkeling and recreational site because of the high faunal diversity and the availability of mooring buoys. Early reports indicated severe damage to the reefs in the complex. Although no mooring buoys were lost, a significant amount of damage was done to this reef. A number of heads of *Montastrea annularis* were displaced, dislodged, and buried, and many sponges had nicks and cuts resulting from impacts with moving debris. The pavement rock of the reef appeared to be broken compared to the highly cemented and smooth pavement extant before the storm. The process that would cause this type of damage without the total loss of the benthic community is unknown. About 30% of the benthic community was lost by displacement, covering, and breakage. No evidence was seen of tissue abrasion (sand blasting), excessive siltation, or any development of rubble piles.

Kavorkian (northern and eastern boundary)

The Kavorkian wreck was a 22.9-m (75-foot) coastal fishing vessel that was sunk adjacent seaward of the national park boundary as an artificial reef memorial to a local dive shop operator. The vessel was originally placed in 20.7 m (68 feet) of water and showed little deterioration since it was sunk in 1984. The wreck was located about 70 m (230 feet) from a healthy natural reef. Park personnel had last evaluated the vessel approximately 1 week before the storm. The poststorm evaluation confirmed reports that the vessel was completely destroyed and thrown against the nearby natural reef located with the park boundary. The total relief of the vessel after the storm was less than 1-1.5 m (3.3-4.9 feet) compared to its 5 m (16.4 feet) profile before Hurricane Andrew. The wreck was turned almost inside out, and the wreckage was reshaped to conform to the shape of the reef. A survey of the natural reef at this location indicated little evident damage to the rock substrate. The reef was almost totally devoid of macrofauna and probably died long before the storm. The sediment around the site was a fine, easily disturbed marl but little deposition of this material was on the wreck itself or in the numerous depressions on the reef. At the time of the survey, a noticeable current, sufficient to scour areas of high relief such as the reef and wreck, was evident.

Biscayne National Park

The team visited 11 sites on foot or by boat in Biscayne. These sites included the south side of the entrance to Mowry canal; just east of the L-31E canal and one-half mile north of the Mowry canal; both the north and south sides of the entrance to the Military canal; south side of the entrance to the Princeton canal; both to the south and the northeast of the Black Point marina; the east and northeast sides of West Arsenicker Key; the north side of East Arsenicker Key; Mangrove Point; and a site at the south entrance to Midnight Pass on the mainland side.

The areas of severe mangrove destruction were Soldier Key to Caesar Creek on the eastern islands; south of Matheson Hammock to northern Card Sound on the mainland Biscayne Bay shore, and the mangrove belt between North Ponce de Leon Bay and Chatham River on the west coast. The northern and southern portions of these areas generally had less complete destruction than the middle. The mangroves in the vicinity of Highland Beach, for example, are 80-95% destroyed. This destruction is by both trunk snapping and by uprooting. This type of destruction resulted from wind rather than storm surge as the effect extends well inland from the coast. Areas of less than 75% tree destruction are commonly in elongate bands less than a few hundred meters wide. In these areas, the community of uprooted mangroves will have to recolonize by seedling to reestablish a viable mangrove community. In areas of extensive destruction, there does not seem to be selective survival of the taller red, white, and black mangroves. The extensive uprooting of the larger trees has left an extremely irregular swamp surface with more than 1 m (3.3 feet) of relief and extensive areas that seem to be too low or too high for effective mangrove recolonization. In some areas, red and black mangrove seedlings were deposited in the wrack by the storm and are already beginning to grow.

The tall fringing forests on the western side of Biscayne Bay were devastated by Hurricane Andrew, from Mangrove Point in the south to the park northern boundary (DC4). Many areas of almost total blowdown (DC5) can be found within the forest. These areas are to the northeast and south of Black Point marina, the north and south sides of Military canal, south of the Mowry canal and at Mangrove Point. East and west Arsenicker Keys also suffered severe storm damage (DC4).

All of these taller fringing forests had moderate to large numbers of saplings and seedlings that survived the storm. These forests should provide an adequate seed pool for regeneration. Standing stems, however, seemed to be well behind other species (e.g., gumbo limbo) in leafing out. A few white and black mangroves were found that had begun to develop adventitious branches. Most standing, defoliated mangroves, however, had not begun this process.

In the southern portion of the park and on the outer keys, the shorter fringing forests seemed relatively healthy. These shorter trees were most likely covered by the storm surge and thus escaped damage from high winds. The interior forests on Elliott, Adams, Totten, and Old Rhodes keys all suffered severe damage (DC4). The aerial survey was not adequate to judge the abundance of seedlings or saplings in these forests or to assess whether there was sediment accretion or loss.

Dwarf mangrove forests dominated by the red mangrove are also found along the western shore of Biscayne Bay. These "forests" are landward of the tall fringing forests. They also appear healthy at present. In these dwarf forests, however, some 5-20 cm (2.0-7.9 inches) of marl and organic detrital material were deposited by the storm surge. This material released copious amounts of H_2S when stepped on. If this leads to lower redox potentials, these healthy looking dwarf trees could die over the long-term. Lesser amounts of this marl and detrital stew were deposited in the taller fringe. Also of concern is the long-term release of nutrients to the bay as this material decomposes.

Because of the relatively short north to south span of Biscayne, no gradients in damage were detectable. The seaward to landward gradients damaged are previously described .

Everglades National Park

In Everglades the following areas were surveyed by boat: Cormorant Pass; Shark River, from the mouth to hydrologic station P35; Shark Point; the Broad River, from the Gulf to Broad River Bay; Highland Point; Lostmans River, from Onion Key Bay to the Gulf; Johnson Mound Creek (a small creek to the south of First Bay at the Lostmans mouth); Chatham River, from the Gulf up through the back bays and out the Lopez River; and Clam Key.

A distinct gradient in damage was observed from northwest of Everglades City to Whitewater Bay. A peak in damage (DC4-5) was found from Shark Point to the Lopez River. Damage then quickly decreases from lower Shark River (DC3) to Cormorant Pass (DC2). Little damage was observed from northern Whitewater Bay south (DC0). To the north of Lopez River, locally severe damage can be found all the way to Rookery Bay National Estuarine Research Reserve (just south of Naples).

Seedlings and saplings were found in all of the heavily damaged forests, but their abundance varied widely. For example, in a forest immediately north of the Lostmans ranger station, seedling density was less than $1/m^2$ ($1/10.8\ ft^2$). In the upper Broad River there were less than 10 seedlings/m^2. Significant amounts of sediment and mangrove detrital material were deposited in many forests in this region. As much as 25 cm (9.8 inches) of material was found along the Broad River and behind Highland Point. The influence of this material on the seedlings, saplings, and trees that survived Hurricane Andrew is unknown. Data collected following Hurricane Donna indicated that tree mortality could occur 6-12 months after the storm due to sediment deposition.

Little refoliation was observed on trees that remained standing. New leaves were observed on a few white and black mangroves. Many of the standing mangroves showed signs of stem damage (cracks, splits, broken bark). These trees are alive at present but may die in the coming months.

Due to logistical constraints, the team was not able to sample along the mangrove marsh interface by foot. Aerial surveys indicate that large numbers of trees are either down or are totally defoliated along this interface from the upper Shark River to the Chatham River (DC4-5). Large amounts of Brazilian pepper are mixed in with the mangroves in this region. Most of the Brazilian pepper appears to have been knocked over and defoliated. Unfortunately, observations on Brazilian pepper in other habitats indicate that it is leafing out at a rate much faster than are the mangroves.

Interior marsh areas (predominantly *Spartina bakeri*) that are scattered through the mangrove forest along the west coast of Everglades seem to have escaped major damage from the storm, based on aerial surveys. Numerous small coastal marshes, dominated by *S. alterniflora*, are found in this region. Many of these also seem to have survived the storm.

Marine Fish Populations

Biscayne National Park

Fish populations appeared to be healthy in all locations investigated. During a 30-minute dive off Ajax Reef in 21.3 m (70 feet) of water, 22 species were recorded and, although quantitative estimates of abundance were not possible, populations appeared normal. Along the outer reef edge near the northern boundary of the park, over 15 species were encountered during a 16-minute dive in relatively low visibility conditions. During investigations on several patch reefs in 6.0 to 9.1 m (20-30 feet) of water, the reef fish observed seemed relatively undisturbed. Some individuals were seen with tattered fins and body scrapes suggesting that they had been battered about by heavy wave surge. At Elkhorn Reef, where relatively heavy coral damage occurred on the upper reef surface, fish typically seen over the reef flat were still present in large numbers. The loss of much of the *Acropora palmata* forest on the top of Elkhorn Reef resulted in an unusual open aggregation of glassy sweepers, Spanish grunts, and other species that are usually seen in more protective habitat. In this situation, these species seemed to be displaced from their normal habitat and may not have yet located new areas of suitable cover.

Dr. Michael Schmale of the University of Miami Rosenstiel School of Marine and Atmospheric Sciences has been conducting fish studies in the vicinity of Caesar Creek over the past several years. He reported that since the storm he has observed several of his previously tagged fish remaining in the Caesar Creek area. Although some individuals were observed with minor body damages, losses are not likely to have been significant. Several small snappers and grunts were observed during visual observations in the mangrove creeks and prop-root systems, suggesting that the juvenile fish typically occurring in these habitats may have been little impacted.

The Biscayne staff has received several reports of excellent sportfishing since the storm. Bay shrimpers returning to trawling since the storm have also reported that catches have greatly exceeded those typically found this time of year.

Other incidental observations also suggest that fish are relatively abundant since the storm. While surveying sea grass beds near the Featherbed Banks, large numbers of juvenile snappers were observed and while investigating hard-bottom areas east of Black Ledge in middle Biscayne Bay, several large schools (numbering 15-30 individuals) of pinfish were encountered.

Everglades National Park (west coast)

Information on fishes from the impacted regions of the west coast is largely anecdotal. In the first several weeks following the storm, the park and the Florida Department of Natural Resources received several reports of massive fish kills in the mangrove zone. Several reports were also received of an extremely strong smell of hydrogen sulfide over the entire west coast region. These factors suggest that a significant amount of mortality may have occurred, either during the storm or in relation to depleted oxygen levels associated with organic-loading.

During our investigations of the west coast areas, 4 weeks following the storm, no evidence of large fish kills was encountered. A single dead and floating fish (probably *Bardiella spp.*) was observed during the investigation of mangroves along the Broad River.

The Florida Department of Natural Resources sent an investigative team from Everglades City on 3 September 1992 to document water quality conditions and the extent of the reported kills. Results of their water quality observations from 10 sites in the Ten Thousand Islands region are presented in Table 10. This team did not

Table 10. Water quality data from eight sites in the Ten Thousand Islands region of Everglades National Park, Florida.

SITE		TEMP C	DO mg/L	COND unhos/cm	TURB NTU	COLOR	TSS mg/L	NH4 mg/L	OPO4 mg/L	TPO4 mg/L	C1 mg/L
EP	Mean	25.5	6.3	1189	2	29	32.2	0.168	0.005	0.008	292.5
	Std	5.2	2.2	693	1	10	183.6	0.329	0.002	0.007	255.8
	Max	35.7	12.5	3150	5	70	1149.0	1.570	0.014	0.034	920.7
	Min	12.8	2.8	550	0	11	1.0	0.010	0.004	0.002	55.9
	Poststorm (4 d)	33.4	6.7	544	1	38	1.0	0.010	0.007	0.004	64.7
	Poststorm (24 d)	34.5	9.9	559	2	26	1.0	0.010	0.004	0.006	76.9
NP201	Mean	24.3	5.8	491	2	37	3.6	0.061	0.005	0.008	51.7
	Std	4.1	1.4	159	3	11	7.2	0.149	0.003	0.007	24.8
	Max	31.0	8.7	888	22	71	44.0	0.980	0.022	0.031	131.7
	Min	15.4	1.0	292	0	17	1.0	0.010	0.004	0.003	16.0
	Poststorm(4 d)	36.0	7.6	501	1	70	1.0	0.010	0.007	0.005	49.5
	Poststorm (24 d)	29.3	5.7	563	1	51	1.0	0.010	0.004	0.005	71.6
P33	Mean	24.8	5.2	569	4	53	5.3	0.186	0.005	0.017	65.8
	Std	4.5	1.5	132	13	16	22.3	0.796	0.003	0.067	25.5
	Max	36.5	9.3	1011	106	105	180.0	6.210	0.020	0.546	145.2
	Min	15.7	2.4	280	0	28	1.0	0.010	0.004	0.003	15.1
	Poststorm (4 d)	34.7	8.0	491	1	55	1.0	0.010	0.007	0.004	58.1
	Poststorm (24 d)	28.8	2.9	529	2	51	1.0	0.012	0.004	0.004	69.4
P34	Mean	26.0	6.2	362	1	26	1.4	0.022	0.005	0.008	28.0
	Std	4.2	1.4	87	1	7	0.9	0.028	0.003	0.006	12.7
	Max	31.7	9.6	610	5	44	5.0	0.160	0.015	0.029	57.0
	Min	17.4	3.3	243	0	12	1.0	0.010	0.004	0.004	8.7
	Poststorm (4 d)	-	-	-	-	-	-	-	-	-	-
	Poststorm (24 d)	30.2	6.5	285	1	26	1.0	0.010	0.004	0.007	15.6
P35	Mean	22.9	4.3	767	3	68	5.6	0.069	0.005	0.019	166.1
	Std	4.4	1.5	659	8	35	22.7	0.161	0.008	0.025	249.0
	Max	31.2	8.0	3400	63	174	168.0	1.070	0.063	0.137	1313.5
	Min	12.9	1.6	0	0	26	1.0	0.010	0.004	0.003	21.7
	Poststorm (4 d)	32.9	4.8	404	0	48	1.0	0.010	0.006	0.004	57.9
	Poststorm (24 d)	30.4	5.2	496	2	76	1.0	0.010	0.005	0.008	67.6
P36	Mean	23.9	3.7	559	6	52	10.3	0.332	0.006	0.065	72.2
	Std	4.26	1.36	166	10	24	21.9	0.680	0.006	0.168	32.0
	Max	30.3	7.9	914	51	119	118.0	4.280	0.046	1.137	146.1
	Min	15.0	1.2	295	0	58	1.0	0.010	0.004	0.003	19.6
	Poststorm (4 d)	32.7	6.2	401	1	50	1.0	0.010	0.004	0.004	55.4
	Poststorm (24 d)	29.7	6.1	488	3	64	1.0	0.024	0.004	0.005	58.9
P37	Mean	23.9	5.1	387	3	21	3.2	0.095	0.005	0.009	39.4
	Std	4.9	1.7	119	3	15	4.8	0.172	0.002	0.012	17.3
	Max	35.2	10.3	790	18	91	30.0	0.820	0.014	0.074	102.0
	Min	12.5	2.0	255	0	18	1.0	0.010	0.004	0.004	15.3
	Poststorm (4 d)	34.5	7.5	194	0	14	1.0	0.010	0.007	0.004	14.9
	Poststorm (24 d)	32.9	10.2	220	1	13	1.0	0.010	0.010	0.007	18.3
TSB	Mean	24.9	5.1	462	2	26	2.2	0.093	0.006	0.016	37.2
	Std	4.9	1.8	94	2	16	2.4	0.149	0.008	0.022	14.6
	Max	34.5	11.1	754	11	131	13.0	0.640	0.052	0.133	84.7
	Min	13.7	1.6	259	0	11	1.0	0.010	0.004	0.001	7.4
	Poststorm (4 d)	32.1	7.1	227	0	26	1.0	0.010	0.005	0.004	14.3
	Poststorm (24 d)	31.8	10.0	442	1	22	1.0	0.010	0.004	0.007	45.9

encounter any dead fish during their survey, although they were unable to get into the upper (more inland) mangrove areas. They reported that local fisherman indicated that dead mullet, catfish, snook, mangrove snapper, sand perch, pinfish, and blue crab had been observed around the Barron River. Evidence of other mortality was found at Pavilion Key during their investigation. They reported finding a large number of mollusks (mostly quahog and horse conch) and horseshoe crab washed onshore, but did not report signs of fish skeletal remains. Ten raccoons were feeding on the shore when they approached the island. As with the fishermen in Biscayne, the park has received numerous reports that sportfishing has been excellent along the park west coast since the storm. Fishermen out of Everglades City and those coming up from the Keys report good catches of snook, redfish, seatrout, and tarpon. Those investigating the mangrove areas have also reported frequently seeing feeding tarpon.

Wildlife

What changes occurred in the abundance or nest site availability of wildlife species of special concern?

Sea Turtles

Before Hurricane Andrew, the more than 57 km (35.4 miles) of beaches in Everglades provided significant suitable nesting habitat for loggerhead sea turtles. The approximately 19 km (11.8 miles) of marl, shell, and quartz sand beaches of the Cape Sable region provided the largest nesting rookery in the park, with the remainder of the nesting occurring on Highland Beach to the north, and on the spits and crescent beaches of numerous islands west and south of Everglades City (e.g., Pavilion Key, Jewell Key, Kingston Key, Indian Key, Picnic Key, Tiger Key, etc.). The estimated nesting activity over the years for all of Everglades ranges from 817 to 1,644 nests. Slightly less than 90% of the nesting activity took place on the Cape Sable beaches. Based on nesting frequencies from past studies and the minimal monitoring efforts of the last 3 years, approximately 40-50% of Cape Sable nests and about 25% of the nests in the Everglades City area would have hatched before Hurricane Andrew.

To assess the impact of Hurricane Andrew on the sea turtle nesting beaches, visual observations were made by boat and on foot in comparison with personally known preexisting conditions from this season's nesting surveys. Seven (7) km (4.3 miles) of the Cape Sable rookery from east Cape Dock to the middle Cape spit, and the nesting beaches of Pavilion Key, Jewell Key, Kingston Key, Indian Key, Picnic Key, and Tiger Key were included in the visual survey. Highland Beach was surveyed from the air. This assessment was conducted on 18 and 21 September 1992. None of the markers from this year's nesting surveys was relocated, so we are unable to confirm any hatching post-Hurricane Andrew.

In Biscayne, large numbers of the sea jellyfish *Aurellia* sp. have been seen since hurricane Andrew in the offshore reef area. Jellyfish represent a highly used food resource of sea turtles, and turtle sightings have been numerous over the reef tract during our surveys. Before Hurricane Andrew, sea turtles nested annually in Biscayne, but suitable nesting habitat was limited. Small stretches of sandy beaches on Boca Chita, Sands Key, and Elliott Key were used. Overall changes to Biscayne beaches were minimal, and turtle nesting habitat may have been improved at several locations.

Boca Chita Key—northern shoreline along the cut between the island and Ragged Key 5: There was considerable erosion of the area south of the old seawall. The former grassy-sandy area was washed out about 15 m (49.2 feet) south and sand was deposited. This area may have been improved for nesting, and access is easier because the wall is now covered with sand, but there is little area not subject to saltwater inundation during high tides or future storms.

Northeast shoreline oceanside—This small (access limited to about a 20 m [65.6 feet] break in the mangroves fronting the shoreline) but popular area now has access blocked by downed trees. The berm was eroded to a lower profile, but the same sandy area is available for nesting. *Casuarina* was removed in this location, and now the soil has eroded and exposed root systems. Minimal work to clear the shoreline debris and *Casuarina* stumps and roots would put this site back to its former state.

Sands Key—Storm surge has washed sand up beyond the former beaches approximately 25 m (84 feet) enhancing nesting habitat. Vegetation was blown towards the interior of the island and poses no problem to access. Before the hurricane, this shoreline was heavily covered with trash and now much of it was blown or carried by storm surge further inland, thus improving access and habitat. Much of the Sands Key Beach is fronted by mangroves, and they remained virtually intact—suffering only some broken branches and lost leaves.

Elliott Key—Known nesting sites on Elliott Key included Tannehill Beach, Sea Grape Point, Sawyers Cove, and Petrel Point. Impact was essentially the same on Elliott as Sands Key. Sand built up and deposited further inland, downed vegetation was blown towards the interior, and trash was removed from the shoreline. Habitat for turtle nesting is unaffected or improved.

Everglades National Park—All of the nesting habitat surveyed along the west coast had been affected by onshore surge causing inundation and extending sand and shell lobes (3.0-12.2 m [10-40 feet]) inland across and beyond the preferred nesting habitat. The depth of new material deposition ranged from 10 to 120 cm (3.9 to 47.2 inches) and ranged widely in degree of compaction. The degree of compaction is thought to be more important to the emergence of hatchlings than the depth of the material (B. Schroeder, personal communication, Florida Marine Research Institute, Department of Natural Resources). The duration of these surges or the residency of floodwaters over nests is thought to have been relatively short and of minimal consequence to viable nests. All of the beaches surveyed had vegetation and debris cleared from the beach and blown or washed landward towards the interior of the mainland or island. Debris on nesting habitat, which might present an obstacle to nesting females or emerging hatchlings, is not a problem. Only Jewell Key had a significant quantity of sizable worm rock deposited on the beach, but removal is not recommended.

Overall the preliminary assessment of the impact of Hurricane Andrew on sea turtle nesting habitat in Everglades is considered minimal and perhaps even improved. Regarding the current years reproductive effort, it is estimated that approximately 50-60% of the season's remaining nests to hatch after 24 August, will fail, due to compacted overburden, or were eroded out before inundation and redeposition. Sea turtles are long-lived iteroparus animals and in the long-term this event is insignificant.

No evidence of any nest loss from the past nesting season was observed on any of the beaches surveyed.

Manatees

Manatees were found throughout the entire mangrove and coastal zones of Everglades in virtually every waterway surveyed. Marked spatial and temporal patterns exist to their distribution, however. Their distribution and relative abundance varies from season to season. To document and describe the spatial, temporal, and behavioral patterns of the endangered Florida manatee (*Trichechus manatus latirostris*) in Everglades, monthly aerial surveys have been conducted since March 1990. Survey data from March 1990 through February 1992 have been reported in Snow (1991, 1992).

To make a preliminary assessment of the impact of Hurricane Andrew on manatees in Everglades, aerial surveys were conducted following the same methods as described in Snow (1991). The study area includes the entire mangrove coastline of Everglades and some adjacent coastline, from Card Sound road to the park boundary north of Everglades City. Surveys were conducted from a Cessna 172 high-wing aircraft, at an altitude of approximately 213 m (700 feet) and at an airspeed of approximately 148 km/hr (80 knots). Three flights, over 3 consecutive days were required to cover the survey zones. Zone 7 was flown on 15 September; zones 1, 2, and 3 on 16 September; and zones 4, 5, and 6 on 17 September. Overall survey conditions were good to very good, with water surface conditions excellent and water clarity good to very good offshore, and fair to very poor in the back bays and rivers.

One-hundred five (105) groups of manatees, totaling 209 manatee observations, were observed during 9.55 survey hours (does not include any nonsurvey or aircraft ferry time). This survey represents the highest monthly count since the study began in March 1990. Before this posthurricane September survey, the highest monthly count (181) was in August 1991. The monthly average for the past survey year (March 1991 to February 1992) was 120.9 manatees. Calves made up 9.6% (20 of 209) of total manatees observed during the posthurricane survey. Two (2) of the calves observed were exceptionally small. During the past survey year, the percentage of calves observed per month varied from 6.4 to 14.0%.

Manatees were observed in all aerial survey zones during the survey. More than 60% (128) of all the observations were made in the offshore shoals, channels, and river mouths, primarily associated with beds of benthic vegetation, in zone 1 (Everglades City and Ten Thousand Islands), zone 2 (Chatham and Hueston rivers), and zone 3 (Lostmans River). This distribution is expected for this time of year. About 15% (31) of the observations were made in zone 6 (Cape Sable). This number is more than four times the number of manatees recorded in this zone during past surveys conducted in the same season. Interestingly, these animals were in relatively large (>8 manatees) feeding groups. During the posthurricane survey, approximately 10% (21) of the observations were in zone 7 (northern Florida Bay to Card Sound road). This figure is more than twice the number of manatees expected based on past surveys. Some of this increase is possibly a result of manatees from Biscayne Bay and Miami moving south in some response to Hurricane Andrew.

Of the total number of manatees observed during the survey, 111 (53%) were recorded as feeding, 50 (24%) were traveling, 31 (15%) were resting, and 17 (8%) were cavorting. Sightings of feeding manatees are expected to comprise the greatest percentage of observations from June through November, based on past surveys. Overall, except for slightly elevated numbers, the distribution and behavior recorded are what would be expected for this time of year based on the previous 2 years of survey data.

No manatee deaths were observed during the posthurricane aerial survey, and none was reported for our area by the Florida Department of Natural Resources carcass salvage staff on either coast (Pete Nabor and Sharon Tyson, Florida Marine Research Institute, Department of Natural Resources, personal communication). One report of a dead manatee in the C-111 canal remains unverified and as yet not recovered. A badly decomposed dolphin was reported on 19 September, high and dry in the mangrove shoreline of Hueston Cove (behind Duck Rock). The skull is being retrieved for species identification. The stranding will be reported to the Marine Mammal Stranding Network. On 3 September a manatee was sighted by a DNR fish biologist traveling in low areas around Chokoloskee Bay and Everglades City (Doug Haymans, personal communication).

Regarding the impact of Hurricane Andrew on a specific manatee, the following account is of interest: On 18 December 1991, a 330-cm (10.8-foot) female manatee named Zephyr was caught and radio-tagged by Florida Department of Natural Resources at the Apollo Beach power plant, Tampa Bay. By the end of March 1992, Zephyr moved to Charlotte Harbor and Peace River. Zephyr left Charlotte Harbor about 24 July and by 29 July was located in Everglades in the Turner River. This movement involves a straight line distance of over 250 km (155.3 miles). Zephyr weathered Hurricane Andrew in Chokoloskee Bay near the mouth of the Turner River. The day after the storm, 25 August, she was north of Rabbit Key Pass. On 27 August Zephyr was still in the storm-affected area, in Chokoloskee Bay. By 8 September, Zephyr had moved north to the Caloosahatchee River and by 16 September she was back at the Peace River (Florida Marine Research Institute, Department of Natural Resources, personal communication).

Crocodiles

Most crocodiles and all of those known nesting in Everglades occur from Long Sound near U.S. 1 to Cape Sable. Irregular, scattered sightings of crocodiles have been made in the west coast river system. A preliminary assessment of the effects of Hurricane Andrew on crocodile habitat was made during a fixed-wing aircraft survey on 18 September 1992 of the entire coastal mangrove fringe from Long Sound to Everglades City, and during a boat survey of the core crocodile habitat and nesting area in northeastern Florida Bay (Trout Cove to Madeira Beach, including Joe Bay, Mud Bay, and Taylor River).

Except for the mangrove destruction in the west coast river system where Hurricane Andrew left the peninsula, little damage (confined to broken branches and a few uprooted trees) was observed. No soil erosion occurred at nest sites that we observed.

We could not assess direct damage to crocodiles in the Everglades from the storm. Deaths of crocodiles were unlikely, however, unless they were directly in the storm path. On 26 August, one dead crocodile was observed along the roadside of U.S. 1 approximately 2.4 km (1.5 miles) north of the Jewfish Creek bridge, the victim of impact with a motor vehicle (M. Fleming, personal communication). Storm displacement of crocodiles may have occurred, however. Storm displacement has been hypothesized to be the cause of wandering crocodiles in the west coast river system after Hurricane Donna in 1960 and to have caused the disappearance of hatchling crocodiles from northeastern Florida Bay after Hurricane David (1979) and Tropical Storm Dennis (1981). Approximately 3-4 days after Hurricane Andrew, two adult crocodiles were observed in the mouth of the Shark River, traveling upstream (M. Fleming, personal communication).

Other Species

Other observations include a hasty assessment of mortality in the storm debris line on Pavilion Key. On 21 September three 1 m x 1 m plots were randomly thrown on the debris along the 2,400 m (1.5 miles) of beach. The width of the debris line ranged from 1 to 3 m (3.2 to 9.8 feet). The casualties were sorted into like items and tallied. An average of 3 horseshoe crabs, 9 sea stars, 8 mollusks (mostly quahog and horse conch), and 37 pieces of sponge, coral, and colonial anemone, were observed per 1 m x 1 m. Two healthy raccoons and one near death draped on a mangrove branch were observed. One medium-sized alligator was observed floating dead in Halfway Creek. And on 18 September one small monkey was observed walking along the shore 274 m (300 yards) north of the East Cape dock.

Special Resource Issues

Air Resources

Storm damage to facilities and structures was especially severe in a 427/km^2 (165 mi^2) area extending for 32 km (20 miles) south of U.S. 41 and for a distance of 24 km (15 miles) inland. Areas of Cutler Ridge, Homestead, and Florida City were largely devastated by the storm, generating millions of tons of debris from ruined homes, commercial and industrial establishments, and agricultural activities, and extensive areas of downed vegetation were created.

Estimates of storm-related debris from the hurricane exceed 3.716 million m^3(40 million yd^3). This debris consists of trees and shrubs (73%), building debris (24%), damaged highway debris (2%), and general household debris (1%). As residents dug out in the early days following the storm, debris types were mixed, and generally piled in front of homes, in vacant lots, and in rights-of-way. Only recently, as a more normal infrastructure began to emerge, have guidelines been established to separate debris into five categories, including (1) burnable yard trash (trees, bushes, shrubs, tree limbs, and brush); (2) burnable construction material (nontreated lumber, wood products, wood furniture, clothes, etc.); (3) nonburnable construction demolition debris (sheetrock, treated lumber, asphalt shingles, bricks, insulation, appliances, metal, and tires); (4) hazardous waste (paint, solvents, gasoline, aerosol spray cans, insecticides, cleaning supplies, batteries, etc.); and (5) recyclable materials (metal, glass, plastics, and Styrofoam).

Following the hurricane, the state of Florida Department of Environmental Regulation (FDER) issued an Emergency Final Order (dated 26 August 1992) providing certain relief with respect to regulatory environmental protection programs. In the Findings of Fact supporting the state emergency order, the Florida Department of Environmental Regulation states that "the hurricane has... created a risk of further substantial impact on the environment," in addition to the devastating impacts caused directly by the storm. Among other provisions, the emergency order specifies the following:

> The Department authorizes (only at locations designated by local government officials) the open burning of hurricane-generated yard trash and construction and demolition debris in areas remote from habitation, as well as the burning of yard trash and construction and demolition debris in air-curtain incinerators anywhere in the emergency area. Within thirty days of commencing any such burning, however, the permittee shall notify the Department in writing, describing the general nature of the materials to be burned, stating the location and method of burning, and providing the name, address, and telephone number of the representative of the permittee concerning the work. Permittees should note that other waste materials must be disposed of in a department-permitted facility.

Primary consideration in issuing this emergency order was given to the expediency of debris removal from populated areas to protect the public health, safety, and welfare, and "to avoid having to issue a potentially large number of approvals on a case-by-case basis and squander the agency resources during the time of emergency." This extensive removal and disposal effort has, however, created the potential for impacting the surrounding environment and the general public, and posing a threat to the integrity of air and water resources of Everglades, as well as a possible risk to the health of park employees and visitors.

Disposal Site Status

As of 22 September 1992, Dade County Department of Environmental Resources Management authorities had authorized the operation of 81 dump sites for receiving storm-related debris. Figure 23 provides the location of the permitted burn sites in southern Dade County as of 14 September 1992. Countless, smaller backyard fires were observed in the disaster area where

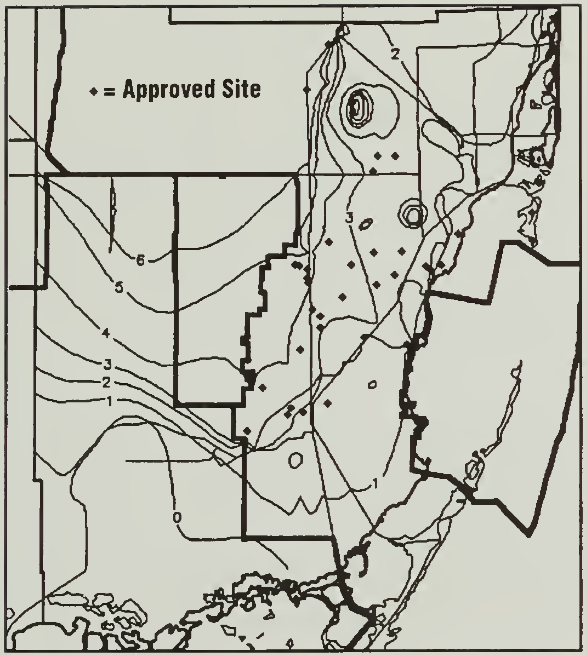

Figure 23. Approved hurricane debris disposal sites in Dade County, Florida, and underlying water resources.

residents have attempted their own clean-up, but these fires were not permitted or tracked, and were usually of short duration.

Disposal of debris at the permitted sites is presently being undertaken largely by burning. While the use of air-curtain incinerators is specified at the majority of the sites, the design, installation, operation, and maintenance of these systems is highly variable. Because of the uncertain nature of the materials being burned and the lack of strict enforcement of proper design and operation of these facilities, the effectiveness of these systems in controlling air emissions and preventing potential groundwater contamination is suspect.

Cursory site inspections of several burn pit and disposal sites from 17 to 21 September 1992 revealed that while attempts were being made to separate burnable materials from nonburnable materials, the effectiveness of these efforts varied from site to site. An estimated 1-2% of the materials placed into the burn pits was nonburnable, including construction debris (shingles, treated wood products, insulation, etc.), household debris (plastics, cleaning supplies, yard pesticides and fertilizers, used motor oil, tires, etc.) and recyclable materials (plastics, metal, Styrofoam, etc.). These nonburnable materials might contain a variety of inorganic and organic contaminants.

It is anticipated that over the next few weeks approximately 100 disposal sites will be authorized (Ken McFarland, Dade County Department of Environmental Resources Management, personal communication). While the alternatives for debris disposal are limited, a number of environmental groups and others have expressed concern that the virtually unregulated burning at these dump sites constitutes a significant concern (Miami Herald, 8 September 1992) and that "the expediency of the moment is going to cost dearly if it is not dealt with properly."

Everglades is one of 48 national park system units nationwide that is designated class I by the Clean Air Act as amended in 1977, and the only national park system class I area in the state of Florida. This designation provides the highest degree of air quality protection afforded by the Clean Air Act, including special protection for the visual resources of the park. The Clean Air Act also charges the federal land managers of class I areas with the affirmative responsibility of protecting air quality related values (e.g., visibility, vegetation, wildlife, water, soils, etc.) from adverse impacts due to man-made air pollution. Additionally, the National Park Service Organic Act of 1916 charges the National Park Service to provide for visitor enjoyment of all areas under its jurisdiction. Clean air and good visibility are important resources that visitors enjoy in the Everglades.

The National Park Service has previously tried to work with the Florida Department of Environmental Resources, the Florida Department of Forestry, and the Dade County environmental protection officials on problems related to open-burning practices on agricultural lands known as the Frog Pond area, which is adjacent to the eastern boundary of Everglades. Major park concerns have included protecting visibility and the potential for toxic emission effects on the park, park visitors, and park personnel due to the burning of waste from farming operations, including black plastic mulching. Other waste materials (some of which are prohibited from open burning under state and local rules) have also been disposed of by open burning practices near the eastern park boundary.

Photographic evidence and personal observations have documented visible smoke impacts on the park from these agricultural burning practices. A number of park incident reports and public nuisance complaints have been filed concerning smoke intrusions into populated regions of the park (i.e., park employee housing, and visitation areas near park headquarters).

Impacts along the eastern park boundary are especially of concern because the main park interpretive corridor and port-of-entry to the park passes through this area. About 80% of the park annual 1 million visitors enters the park on this road, and park headquarters, maintenance facilities, visitor centers, and park employee residences are located nearby. Several of the permitted open-burning disposal sites are located in proximity to the Everglades eastern boundary, including one site in the Frog Pond area. Burning at these sites, and possibly more distant sites depending on meteorological conditions, poses a threat to the class I airshed of the park and may potentially have adverse effects on sensitive vegetative species, aquatic resources, visibility, and human health. Also, the emissions caused by the transport of debris to these disposal sites by thousands of trucks daily, most of which have dirtier burning diesel engines, also add to the pollution-loading potentially affecting the park.

As of 21 September 1992, smoke intrusions from burning at nearby disposal sites were already observed inside the park and have affected both developed and wildland areas of the park. To properly assess the potential air impacts of the debris disposal operations on Everglades, several actions are recommended, including monitoring at the source, monitoring ambient air and visibility, monitoring meteorological criteria, and modeling air quality. Because none of the existing air monitoring at the park (discussed later) is operational or ideally located for determining maximum impacts from debris burning operations related to the hurricane, new monitoring efforts will be needed in addition to reestablishing the background monitoring sites that were damaged by the storm.

Existing Air Monitoring

Before Hurricane Andrew, Everglades routinely monitored several air quality and meteorological parameters in the area of the park research center, about 11.2 km (7 miles) west of the park main entrance. The monitoring program consisted of collecting data on particulate concentrations, ozone levels, wetfall and dryfall, wind speed, wind direction, air temperature, and dew point. Subsequent to the storm, no monitoring equipment has been operational.

Aerosol Monitoring

Beginning in 1988, the National Park Service initiated routine aerosol (i.e., particulate matter) monitoring in Everglades. Until September 1991, monitoring was accomplished with an array of three fine particle samplers (i.e., PM-2.5 - particulate matter with an aerometric diameter less than 2.5 micrometers) and one course mass sampler (i.e., PM-10). Different filter media are used in each sampler to allow for special analysis techniques on each sample. This type of monitoring setup is commonly called an Interagency Monitoring for Protected Visual Environments (IMPROVE) protocol sampler, named for the federal interagency program that established this type of aerosol sampling as standard procedure in selected class I areas across the nation. Though not an official IMPROVE site, the Everglades site was similarly designed until funding resources diminished in fiscal year 1992, necessitating the elimination of all but one of the PM-2.5 samplers. This site suffered some damage during the hurricane, and attempts to operate the equipment with generator-supplied power have failed.

Meteorological Monitoring

The meteorological monitoring tower located near the research center was blown down by the hurricane, and instrumentation on the tower has not yet been located. Even if found, the equipment more likely will not be serviceable. Parameters measured at the site included wind speed, wind direction, air temperature, and dew point. This site was not properly located (i.e., did not meet siting criteria) and a new station should be reestablished locally at a site that conforms to siting criteria.

Wet and dry Deposition

This station is located at the research center. The equipment at the site was damaged during the storm and will need repair or replacement.

Ozone

The storm damaged the instruments' intake system outside the building in which it is located. While housed inside a temperature- and humidity-controlled room at the center, the instruments (monitor and calibrator) will need to serviced by the NPS contractor before operation is resumed.

Water Resources

While air quality degradation is perhaps the most visible environmental concern relating to the open burning of the debris, degradation of water may also occur. Potential transport pathways for the movement of contaminants from the debris burning pits and temporary disposal sites into the aquatic environment include surface runoff, leaching, and atmospheric deposition. Because of the flat topography, high porosity associated with the limestone substrate, shallow depth to groundwater, and prevailing precipitation and wind patterns, atmospheric deposition and leaching are considered the most likely pathways for potential water resource contamination. The potential for direct contamination from surface runoff seems limited, due to the flat topography and levees adjacent to many of the canals. Direct contamination of nearby canals could occur by wind deposition from nearby ash piles, however, if proper on-site containment measures are not undertaken.

Atmospheric Deposition

Atmospheric deposition is perhaps the most significant pathway by which contaminants from burn pit sites can enter the aquatic ecosystem. As emissions from the burn sites emanate from the source, they will be dispersed along gradients determined by prevailing meteorological conditions. Eventually some of the contaminants will be deposited into the Everglades aquatic ecosystem, primarily during rainfalls.

Source monitoring, air quality modeling, and ambient atmospheric deposition monitoring are important initial activities that are necessary to assess the types and amounts of contaminants associated with atmospheric deposition. Once these are known, appropriate second-phase studies can be designed to determine the fate and effects of these contaminants on the aquatic ecosystem.

Groundwater Contamination

The soil and surficial geology of southern Dade County is characterized by extremely shallow soils overlying a porous limestone substrate. The watertable is generally high, with depth from surface to watertable commonly less than 0.91 m (3 feet). The shallow aquifer is also hydrologically connected to an extensive canal system, part of which conveys water to Everglades.

While the Army Corps of Engineers schematic cross-sectional burn pit plan recommends a minimum of a 30.4 cm (1-foot) impervious layer beneath each pit, impervious bottom liners were not being constructed at the sites inspected. The Army Corps of Engineers confirmed that the construction of an impervious base was not widely practiced at this time, though they recommended this design feature, and were attempting to encourage it in future burn pit construction.

As materials are burned at the disposal site, the residual ash is typically removed from the pit through a front-end loader, and stored in open piles pending removal to a permanent disposal site. Currently, the Dade County Department of Environmental Resources Management and the Army Corps of Engineers are determining the testing procedures (TCLP, metals, and others) for alternatives in waste characterization and for evaluating disposal. Alternatives presently under consideration include agricultural land application, industrial use, and export to appropriate landfills.

At the present time, it seems likely that large quantities of ash will be stored onsite for an undetermined length of time awaiting removal and disposal. At inspected sites, residual ash was being stored in open piles, subject to both wind dispersal and leaching.

From the standpoint of groundwater contamination, the sites of greatest concern to the National Park Service are those located within 0.8 km (one-half mile) of the canals delivering water to Everglades (L-31N, L-31W, C-111). Of 60 burn pit sites approved by 14 September 1992, 4 are within 0.8 km of these canals. These sites include the following:

- Site 13: SW 360th Street (Frog Pond), West of C111
- Site 22: SW 136th St and SW 187th Avenue, East of L31N
- Site 30: SW 133th St and SW 193rd Avenue, West of L31N
- Site 42: Homestead General Airport, East of L-31N

In addition, Department of Environmental Resources Management has designated a large number of temporary transfer sites for the storage of nonburnable debris. The locations of these sites were not available at the time of this report.

Surface Runoff

Because of the relatively flat topography, surface runoff is not expected to be a significant mechanism of transport from the burn pit and temporary disposal sites into the aquatic ecosystem. Wind dispersal and the direct deposition of ash into nearby surface waters could occur, however, if adequate measures to prevent wind dispersal of ash are not undertaken.

Biscayne Bay Canals

Under the current Biscayne Bay Surface Water Improvement and Management Plan, the Dade County Department of Environmental Resources Management monitors water quality at monthly intervals for approximately 90 canal and bay locations throughout Dade County. Of these, nine are located in the lower canals or near the mouths (bay side) of Black Creek, Goulds canal, Princeton canal, or Mowry canal (Appendix B).

In addition, Biscayne had conducted extensive water quality monitoring throughout these systems, both at the sites previously listed and other important locations. Constituents monitored included the common field parameters (water temperature, salinity, conductivity, and dissolved oxygen) and nutrient parameters. Data collected from this program were saved, but are currently in storage and not available for this report (Richard Curry, Biscayne, personal communication). Thus, prestorm and poststorm comparisons are possible at this time only for DERM-monitored sites.

Following Hurricane Andrew, the South Florida Water Management District, the Dade County Department of Environmental Resources Management, and the National Park Service all recognized the need for poststorm damage assessment and water quality monitoring. On 16 September 1992, DERM personnel, accompanied by a SFWMD representative, conducted a water quality monitoring survey in southern Biscayne Bay (from Black Point and the Featherbed Bank to Barnes Sound and Manatee Bay). Sampling also occurred on this day in the upland canals discharging into the southern bay.

Observations made during this trip noted a decrease in water clarity and possible algal blooming in several parts of the southern Biscayne Bay, including the western side of the bay from Convoy Point northward (Rick Alleman, South Florida Water Management District, personal communication).

While the water quality in the Mowry canal and Princeton canal did not appear to vary much from that observed after normal storms, the water quality in Black Creek and Goulds canals appeared to be severely degraded. The water discharging into Biscayne from Black Creek had a black color and water in the Goulds canal was a deep brown (Rick Alleman, memorandum dated 17 September 1992, South Florida Water Management District).

The color tinting of the water in the Goulds canal has been found to be correlated to the quantity of leachate migrating from the southern Dade County landfill, which contains high concentrations of ammonia. Based on past studies, the amount of leachate discharging into the bay on this day probably contained ammonia in concentrations lethal to fish. In addition, the leachate may also contain a number of other toxins (Rick Alleman, memorandum dated 17 September 1992, South Florida Water Management District).

FIU personnel from the Drinking Water Laboratory again sampled the nine site locations previously listed on 19 September 1992. Observations made during this trip were similar to those reported on 16 September 1992. Water color in Black Creek continued to range from dark brown to black, while water color in the Goulds canal remained a dark brown. Field measurements were taken at the sites (water temperature, salinity, pH, dissolved oxygen, and conductivity) and samples returned to the laboratory for further analyses (turbidity, NO_2, NO_3, NH_4, total nitrogen, soluble reactive phosphorus, total organic carbon, chlorophyll a, and alkaline phosphatase).

An analysis of salinity data collected on 16 September 1992 indicated that low salinity (0.5-4‰) waters overlaid higher salinity (15-19‰) bottom waters in canal mouth waters below the control structures indicating the occurrence of considerable discharge from the upland canals to the bay. A preliminary evaluation of field measurements made during these site visits indicates that pH levels (Table 11) appeared depressed on 16 September, with pH levels ranging from 0.3 to 0.7 pH units below the historical median (1987-91). The pH data recorded at the same sites on 19 September, however, were closer to the historical medians.

Dissolved oxygen concentrations (Table 12) also appeared depressed from historical data (1987-91), with dissolved oxygen concentrations below 3 mg/L at BL-01, BL-02, BL-03, and GL-02 on both 16 September

Table 11. Posthurricane and historical field pH measurements for surface waters in Black Creek (C1), Goulds Canal, Princeton Canal (C102), and Mowry Canal (C103).

Station	87-92 Median[1]	09-16-92[1]	09-19-92[2]
Upland/Lower Canal			
BL03	7.6	6.9	7.5
GL03	7.6	7.1	7.5
PR03	7.3	6.7	7.2
MW04	7.5	7.1	7.5
Canal Mouth/Bayside			
BL01	7.8	7.2	8.4
BL02	7.7	7.1	8.2
GL02	7.6	7.3	7.3
PR01	7.5	7.2	7.4
MW01	7.9	7.2	8.1

[1] Dade County Department of Environmental Resources Management.
[2] Florida International University.

and 19 September. While depressed well below historical medians, Richard Curry (Biscayne) states that dissolved oxygen levels have been low all year.

Final bacteriological data were not available at the time of the report. Preliminary estimates, however, indicate that fecal coliform bacteria and total coliform bacteria are significantly higher than the historical medians at most sites (Cecelia Weaver, Dade County Department of Environmental Resources Management, personal communication). It is probable that these waters were affected by sewage contamination during and after the storm. Further analysis of this issue is pending, however, awaiting the final laboratory results.

Table 13 presents the completed laboratory analyses (turbidity, ammonium, nitrate, nitrite, soluble reactive phosphorus, total organic carbon, chlorophyll a, and alkaline phosphatase) available as of 21 September 1992, for sites sampled on 19 September 1992. While historical information for these constituents was not available at the time of this report, a cursory examination of the data indicates very high concentrations of ammonium and total organic carbon, and elevated chlorophyll a and alkaline phosphatase levels in the Goulds canal in the vicinity of the southern Dade County landfill. In addition, water quality conditions in Black Creek were degraded, in relation to the Mowry and Princeton canals.

Their close proximity to the southern Dade County landfill and the Miami-Dade Water and Sewer Authority southern Dade County regional wastewater treatment facility has created long-standing, unresolved chronic water quality degradation in Black Creek and the Goulds canal. The effects of Hurricane Andrew on these sites cannot be fully evaluated until all laboratory results are available. Conditions surrounding the storm, however, may have temporarily increased landfill and, possibly, wastewater leachate into the system. The effects of this on adjacent bay waters cannot be evaluated at this time.

Preliminary analyses of available information indicate that the hurricane did not appear to initially degrade water quality in the Princeton and Mowry canals any more than might be expected from storm-water runoff after any major storm. Additional effects on nearby bay environments are not known.

Table 12. Posthurricane and historical field dissolved oxygen measurements for surface waters in Black Creek (C1), Goulds Canal, Princeton Canal (C102), and Mowry Canal (C103).

Station	87-92 Median[1] (mg/L)	09-16-92[1] (mg/L)	09-19-92[2] (mg/L)
Upland/Lower Canal			
BL03	6.6	2.3	1.1
GL03	7.9	5.4	5.0
PR03	4.8	3.1	3.1
MW04	4.9	6.4	4.7
Canal Mouth/Bayside			
BL01	4.9	2.2	1.6
BL02	4.9	1.3	1.1
GL02	3.0	2.7	1.4
PR01	5.6	4.2	3.4
MW01	5.5	5.0	4.4

[1] Dade County Department of Environmental Resources Management.
[2] Florida International University.

Table 13. Posthurricane, 19 September 1992, water quality analyses for selected water quality constituents in Black Creek (C-1), Goulds Canal, Princeton Canal (C-102), and Mowry Canal (C-103).

SITE	ALK PHOS (μM/h)	CHL a (μg/L)	NO_2+NO_3 (μM)	NO_2 (μM)	NH_4 (μM)	SRP (μM)	TOC (μM)	TURB (NTU)	TN (μM)	TP (μM)
MW-01	0.765	3.84	94.46	4.11	27.35	0.02	165	7.30	120.14	0.46
BL-011	0.659	2.77	20.22	3.59	38.73	0.03	805	3.12	84.87	0.99
BL-02	0.587	2.30	21.56	4.11	38.83	0.04	849	3.36	91.13	1.29
GL-02	0.895	5.30	13.14	3.84	132.91	0.06	1143	5.65	177.93	0.86
PR-01	0.377	1.34	271.22	7.24	35.75	0.00	154	1.94	296.23	0.24
MW-04	0.199	2.04	147.23	5.21	24.92	0.00	187	2.41	191.58	0.41
GL-03	0.770	7.72	115.05	20.90	74.21	0.03	384	11.20	208.03	0.79
BL-03	0.499	2.80	21.56	4.33	58.24	0.04	897	3.03	100.56	1.40
PR-03	0.106	0.80	289.56	5.91	92.03	0.01	201	2.87	332.53	0.20

Legend:

ALK PHOS = Alkaline Phosphotase
CHL a = Chlorophyll a
NO_2 + NO_3 = Nitrite + Nitrate
NH_4 = Ammonia
SRP = Soluble Reactive Phosphorus
TOC = Total Organic Carbon
TURB = Turbidity
TN = Total Nitrogen
TP = Total Phosphorus

Archeological Resources

Shark River Slough Area Hammocks

Overall, the damage to hammock sites in the Shark River Slough area appears to be relatively light. Of the 11 hammock sites that received onsite visitations (Table 14), 8 (78%) were found to have tree-fall disturbances affecting less than 5.0% of their total site areas. Inspections made from helicopters of other hammock sites in the area showed similar low numbers of fallen trees.

The location of hammock sites relative to the centerline of the hurricane seems to correlate with the amount of damage that each site suffered. The sites with the greatest amount of damage, Everglades NP-21, Everglades NP-24, and Everglades NP-19, are located 17.2, 16.6, and 11.9 km (10.7, 10.3, and 7.4 miles) north of the centerline. Apparently, sites located outside a path covering roughly 9.6 to 17.1 km (6 to 11 miles) north of the centerline suffered much lower levels of damage due to uprooting of trees. This path of greatest tree uprooting roughly corresponds with the location of the northern edge of the cloudwall of the hurricane eye, the point where hurricane winds are typically their greatest.

An apparent correlation appears with the tree species present on a hammock and the amount of damage that it incurred. Three species of trees represented 78% of the total number of uprooted trees recorded at the hammock sites. These were gumbo limbo (24%), palm (21%), and strangler fig (33%). Of these, strangler fig represents the largest proportion in terms of numbers (33% of all hammock site fallen trees) and of the total disturbed area (47%). This tree species is typically tall enough to catch the brunt of the hurricane winds and tends to have shallow roots systems. When strangler figs are uprooted they pull up soil from only 30 cm (11.8 inches) below the ground level. Although easily uprooted, the amount of ground disturbance tends to be minimal.

Table 14. Shark River Slough archeological sites receiving onsite inspection.

Site Number	Rank	Site Type	Impacted	Size	Center
Big Cypress NP-58	2	Dirt Midden, Camp	1.75	1.0 ha	11.6 mi. N
Everglades NP-21	1	Habitation Midden, Dirt Midden, Camp	21.40	.05 ha	10.7 mi. N
Everglades NP-24	1	Habitation Midden, Agricultural, Camp	9.50	.02 ha	10.3 mi. N
Everglades NP-19	1	Habitation Midden, Dirt Midden, Burial	10.00	.12 ha	7.7 mi. N
Everglades NP-15	1	Habitation Midden, Dirt Midden, Burial	4.83	.06 ha	5.9 mi. N
Everglades NP-110	1	Habitation Midden, Dirt Midden, Habitation	4.69	.69 ha	3.6 mi. N
Everglades NP-119	1	Habitation Midden, Dirt Midden, Habitation	2.20	.15 ha	0.4 mi. N
Everglades NP-101	1	Dirt Midden, Habitation	3.70	.30 ha	2.3 mi. S
Everglades NP-102	1	Dirt Midden, Agricultural	0.40	.09 ha	3.5 mi. S
Everglades NP-186	1	Habitation Midden, Dirt Midden, Camp	4.00	.12 ha	5.9 mi. S
Everglades NP-188	1	Habitation, Recreation	3.75	.02 ha	9.4 mi. S

Time limitations, the current lack of adequate vegetational coverage data, and the immediate unavailability of hurricane data gathered by the Incident Command System (ICS) natural researchers, currently limits our ability to provide more than a general prediction of those sites that probably suffered the greatest damage. Sites occurring near the northern edge of the hurricane cloudwall, when large trees are present, are expected to receive the greatest amount of fallen tree damage. We would expect the amount of subsurface ground damage to range somewhere from 10 to 20% of the total site area for sites located in this path. Outside this path, total site ground disturbance is expected to be less than 5%. When the stemfall data and hurricane winds data are refined and made available in GRASS format, the development of a more refined model predicting the amount of damage expected to occur for the remainder of the sites in the parks should be possible.

Ten Thousand Islands Archeological District

Generally, the damage to sites in the Ten Thousand Islands archeological district seems to be relatively light. Of the 11 sites that received onsite visitation (Table 15), 9 (81%) were found to have tree-fall disturbances affecting less that 10% of their total site area. Inspections accomplished by using helicopters showed similar low numbers of fallen trees.

Five (5) of the 11 (45%) sites that received onsite visitation showed evidence of a strong storm surge. This surge deposited up to 30.4 cm (1 foot) of shell material on the beach sites and pushed trees along the shoreline inward. In the beach areas, 15-40% of the trees are estimated to be uprooted. Determining the damage that occurred before the surge is not possible without more work.

The location of the sites relative to the centerline of the hurricane does not correlate with the amount of damage each site suffered. Preliminary data indicate that the greatest effect from fallen trees was on the northern edge of the storm. By the time the storm edge reached the Ten Thousand Islands area, however, the effect was significantly reduced.

Table 15. Ten Thousand Islands archeological sites receiving onsite inspection.

Site Number	Rank	Site Type	Percent Impacted	Size	Disturbance Center
Everglades NP-49	1	Shell Midden, Habitation Midden, Agricultural	Surge	9.00 ha	15.5 mi. N
Everglades NP-36	1	Shell Midden, Habitation Midden, Agricultural	1.00	9.00 ha	12.8 mi. N
Everglades NP-4	3	Habitation Midden, Agricultural, House	8.88	11.40 ha	8.7 mi. N
Everglades NP-140	1	Burial Midden	0.0	.01 ha	8.1 mi. N
Everglades NP-151	1	Shell Midden	Surge	.40 ha	7.9 mi. N
Everglades NP-3	1	Shell Midden, Habitation Midden, Shell Work	1.0	1.08 ha	7.6 mi. N
Everglades NP-143	1	Artifact Scatter	Surge	-	5.8 mi. N
Everglades NP-90	1	Artifact Scatter	Surge	2.0 ha	0.2 mi. S
Everglades NP-91	1	Habitation	1.0	-	4.2 mi. S
Everglades NP-89	1	Habitation Midden	0.2	.10 ha	1.1 mi.
Everglades NP-144	1	Burial	Surge	-	8.1 mi.

An apparent correlation exists with the tree species present on the nonbeach sites and the amount of damage that was incurred. Three species of trees represented 56% of the total number of uprooted trees recorded at the inland sites. These were gumbo limbo (27%), palm (8%), and black mangrove (21%).

Of these, gumbo limbos represent the largest proportion in terms of numbers (27% of all fallen trees on nonisland sites) and of the total disturbed area (39%). This tree species is generally tall enough to catch the brunt of the hurricane winds and tends to have shallow roots systems. It is also relatively rare that they pull up subsoil more than 30 cm (11.8 inches) below the ground level, so although this species is easily uprooted, the amount of ground disturbance tends to be minimal.

Time limitations, the current lack of adequate vegetational data for the Ten Thousand Islands archeological district, and the immediate unavailability of hurricane data gathered by the ICS natural researchers, limits our present ability to provide more than a general level of predicted impact. Nonisland, inland sites were relatively unaffected by the hurricane. Sites that were located on open water keys and on the western shoreline were impacted by the storm surge. We would expect the amount of damage to range somewhere from 0 to 1% for fallen tree damage and 15 to 40% for surge damage across the path of the storm. When the stemfall data and hurricane winds data are refined and made available in GRASS format, the development of a more refined model predicting the amount of damage expected to occur for the remainder of the sites in the park should be possible.

Submerged Sites in Biscayne National Park

Sites visited (from south to north) were Pillar Dollar, Capt. Eds wreck, Black wreck, Populo, Pacific Reef wreck, Morgans wreck, Hubbard and Ledbury, Alicia, Mandalay, Lugano, Brick, Fowey, Safety Valve Barge, and Bell wreck.

Sites listed in west to east order were Hubbard, Capt. Eds, Black wreck, Pillar Dollar, Safety Valve Barge, Populo, Morgans wreck, Pacific Reef wreck, Alicia, Fowey, Brick wreck, Mandalay, Lugano, and Bell.

Overall, damage was much less in all environments than expected. Fowey and Safety Valve sites showed most damage. Safety Valve barge was the most shallow site, constructed and exposed to the most surge, which broke up the structure. The Brick wreck site demonstrated concreted site features displacement. The Pillar Dollar site had depressions on the wreckage. All affected sites except the Safety Valve barge demonstrated human impact antecedent to the storm that contributed directly to storm impact.

The site of the Fowey, an historic 1748 shipwreck site (which was the focus of intense archeological evaluation in 1983), showed severe effects of overburden displacement. Much of the hull structure, which had previously been under 22.8 to 45.7 cm (9 to 18 inches) of sand, were now uncovered—with many loose artifacts in evidence. These loose artifacts and the exposure of the site to both human and biological threats require immediate action for site stabilization and preservation.

Recommendations

Short-term Recommendations

The resource assessment team made recommendations for short- and long-term projects, with estimates of cost and project duration. The highest priority, most urgent, short-term projects are summarized in Table 16. The next most urgent projects are listed in Table 17, and the third-order priority projects are in Table 18. For most of the recommended short-term projects, the purpose and approach of each project are discussed following the tables.

Environmental Monitoring

The Everglades hydrologic and marine water quality monitoring networks, the NPS air quality monitoring capabilities, and the Biscayne water quality laboratory must be restored to continue the long-term environmental monitoring capability of the South Florida national parks. The hydrologic monitoring, research, and modeling and the ongoing and future environmental and ecological monitoring and research are highly dependent on the monitoring networks.

An immediate goal should be to reestablish the long-term monitoring stations that were destroyed during the storm. To restore the Everglades hydrologic monitoring network, the damaged instrumentation should be replaced, the new platforms and stilling wells, which have disappeared, installed, and the platforms and stilling wells straightened wherever possible. The following resources would reinstall only the stage and rainfall network and restore the Everglades hydrologic network to a minimal functioning state that existed before Hurricane Andrew:

- Instrumentation (for 12 stations) $32,000
- Support structures (for 20 stations) $ 8,500
- Staff (150 days @ $8.50/hr) $10,200
- Helicopter $10,000
- Surveying (50 stations @ $300/station) $15,000

Hurricane Andrew caused significant damage to some of the air quality monitoring equipment at Biscayne and Everglades and destroyed the Biscayne water quality laboratory and the water quality network of Biscayne and Everglades. The monitoring capabilities of these stations should be restored as soon as possible.

Close cooperation among the National Park Service, the Dade County Department of Environmental Resources Management, the South Florida Water Management District, and local universities was evidenced by the quick response of these organizations to the storm event. With the loss of the laboratory facilities at Biscayne, an in-house response to monitoring post-storm events would probably not have been possible without the cooperation of these organizations.

Archeological Material

The Fowey shipwreck is in immediate need of mitigation and should be considered the top priority for the submerged sites in Biscayne National Park. The Fowey site should be documented to HABS/HAER (Historic American Building Survey/Historic American Engineering Record) standards, which would include mapping, photographing, videotaping, and recovering specific fragile artifacts that were exposed. These artifacts should be stabilized, conserved, and provided long-term curation.

The effects of lobstering were observed on most sites. Because commercial lobstering in Biscayne National Park is incompatible with long-term site preservation, this activity should be eliminated in the impacted site areas (without inadvertently exposing shipwreck locations). Law enforcement efforts should be significantly increased on submerged sites. Most storm effects on historic wrecks had an antecedent human component that contributed to damage. Park managers must take an active and supportive role in cultural resource protection.

Table 16. Recommendations for the highest priority short-term projects.

Projects	Project Duration	Cost Estimates
Restore environmental monitoring capability	2 months	$579+k
1. Restore Everglades hydrologic network	1 month	$76K
2. Restore marine water quality network	1 month	$300K
3. Reestablish air quality network (no estimate) and Biscayne water quality laboratory		$203
Protect exposed archeological material on shipwrecks	1 year	$82K
1. Document Fowey shipwreck and evaluate preservation options	1 year	$45K
2. Stabilize Fowey shipwreck and institute monitoring program	6 months	$12K
3. Increase site protection and surveillance	1 year	$25K
Remove all nonnative animals introduced by storm	6 months	$25K
1. Increase backcountry patrol		
2. Evaluate removal strategies		
3. Coordinate with other agencies and private organizations		
Determine ecological effects of Hurricane Andrew	3 years	$1775k
1. Analyze historical plant data	2 months	$40K
2. Analyze forest canopy trees in major plant communities	1.5 years	$436K
3. Analyze impacts of storm surge on inundated upland forest	1.5 years	$50K
4. Determine storm-generated herbaceous detritus in Everglades	2 months	$30K
5. Determine role of detritus in wetland food webs	1 year	$70K
6. Survey storm effects on marsh fishes and plants	1 year	$175K
7. Resurvey fish tissues for storm-mobilized mercury	3 months	$10K
8. Analyze mercury in marsh food web	1 year	$50K
9. Establish marsh primary production protocol	2 year	$120K
10. Determine storm-induced mangrove litter contributions to coastal nutrient cycles	1 year	$50K
11. Monitor distribution of subtidal storm sediments	1 year	$50K
12. Determine changes in sea grass beds	1 year	$80K
13. Determine storm effects on lobster recruitment	1 year	$50K
14. Determine storm effects on sportfish catch rates	1 year	$45K
15. Determine storm effects on heavy metal concentrations in hardwood hammocks	3 years	$117K
16. Determine storm effects on coral reefs	2 years	$100K
17. Compare mangrove and Schinus litter dynamics	2 years	$160K
18. Include global change mangrove forest model	2 years	$120K
19. Survey marine water quality from Biscayne Bay canals	3 months	$20K
20. Determine historical hurricane frequency	3 years	$155K
21. Determine spatial variability of Hurricane Andrew	2 years	$54K
22. Establish woody debris study plots	1 year	$53K
23. Establish herbaceous subcanopy plots	1 year	$90K
24. Establish tree recruitment plots	1 year	$50K
25. Replace manatee warning signs destroyed by storm	1 month	$2K

Table 17. Recommendations for the second highest priority short-term projects.

Projects	Project Duration	Cost Estimates
Determine plant population status	**1 year**	**$160k**
1. Assess current status of selected rare plants	1 year	$80K
2. Monitor spread of melaleuca	1 year	$20K
3. Assess nonnative plants		$50K
Biscayne National Park	1 year	$10K
Everglades National Park	1 year	$40K
4. Determine status of mangrove forests	1 year	$10K
Determine wildlife and fish population status	**2 years**	**$886k**
1. Expand wading bird and rookery survey	1 year	$50K
2. Conduct eagle and osprey breeding surveys	2 years	$40K
3. Determine alligator hatchling survival	1 year	$24K
4. Monitor white-tailed deer habitat use	9 months	$25K
5. Conduct white-tailed deer survey	1 year	$18K
6. Survey red-cockcaded woodpeckers and habitat	1 year	$50K
7. Monitor Cape Sable seaside sparrow	9 months	$35K
8. Assess swallow-tailed kite	3 years	$195K
9. Study the effects on pineland breeding birds	3 years	$177K
10. Evaluate tree snails	2 years	$80K
11. Assess Schaus' swallowtail	1 year	$30K
12. Resample Biscayne sponge monitoring plots	2 months	$20K
13. Determine effects on coral reef fishes	6 months	$15K
14. Survey sea turtle nesting (Biscayne Everglades	1 year	$30K
15. Continue manatee survey	1 year	$17K
16. Determine status of crocodile population	1 year	$80K
17. Compare mangrove faunal dynamics	3 years	$900K
Improve environmental monitoring networks	**1 year**	**$700K**
1. Improve Everglades hydrologic monitoring network to withstand major storm events and fire	1 year	$240K
2. Assess historic data to design sampling strategy	1 year	$50K
3. Include Everglades inflow and estuaries and add Big Cypress to link freshwater and marine systems		$50K
4. Add west coast to marine water quality network		$150K
5. Analyze existing marine water quality data	2 months	$40K
6. Increase marine water quality monitoring	1 year	$120K
7. Monitor marine turbidity and chlorophyll	1 year	$50K
Limit urban debris disposal impacts on park resources	**1 year (0.25 FTE)**	
1. Encourage efficient fixed incinerators		
2. Request COE and DERM proper air curtain design		
3. Request DERM monitor contaminants		
4. Encourage COE and DERM to contain and stabilize ash		
5. Encourage COE and DERM to enforce burning regulations		

Table 18. Recommendations for the third highest priority short-term projects.

Projects	Project Duration	Cost Estimates
Survey archeological resources	**3 years**	**$560K**
1. Big Cypress National Preserve		$185K
2. Biscayne National Park		$125K
3. Everglades National Park		$250K
Monitor damage to archeological sites from disposal facilities	**1 year**	**$75K**
Remove artificial reef debris (Kevorkian) from reefs	**1 year**	**$20k**
1. Request reef owners to remove		$0
2. Document reef damage and monitor recovery after removal		$20K
Restore integrity of coastal marshes at Cape Sable	**2 months**	**$75K**
1. Repair east Cape Canal plug		
2. Repair Ingraham Canal plug		
3. Repair plugs in House and Slagel ditches		
Protect resources threatened by cleanup activities	**3 years**	**$67K**
1. Evaluate cleanup activities regarding rare plants and storm interpretive opportunities	6 months	$20K
2. Verify fire management practices	3 years	$40K
Evaluate management practices changed by storm	**2 years**	**$29K**
1. Document effect of hurricane-induced fuel heterogeneity on understory	2 years	$25K
2. Complete manatee protection plan to ensure facilities restoration is compatible	1 month	$4K
3. Delay changes in access to NE Florida Bay until crocodile status is determined		$0
Determine impacts of debris disposal on parks	**1 year**	**$361K**
1. Characterize emissions from debris burning		
2. Model air quality and visibility		
3. Monitor air quality, visibility, and meteorology at 2 sites		

Effective law enforcement, site evaluation, and monitoring programs are fundamentally dependent on predictable and accurate site location. A differential global positioning system (GPS) should be set up in the park and park vessels equipped with real-time receivers and electronic charts.

At least one additional FTE, a patrol vessel, and positioning and accessory equipment dedicated to patrolling cultural resources for ARPA (Archeological Resources Protection Act) violations should be provided.

Nonnative Animals

To remove nonnative animals that were introduced by the storm, backcountry patrols should be increased, removal strategies evaluated, and removal activities coordinated with other agencies.

Ecological Effects of Hurricane Andrew

In recent years, an awareness has been increasing on the role that natural perturbations play in ecosystem dynamics. The concept that nature, undisturbed by humans, is maintained in an equilibrium condition is being replaced with the concept that ecosystems are unstable, and different portions of them are changing at different rates under the influence of one or more types of disturbance. Major perturbations can in a matter of hours or weeks produce more change in an ecosystem than would occur during normal everyday processes over periods of decades or even centuries. Documenting how these events interact with other natural processes to produce the earth's varied landscapes is critical to the understanding of how existing ecosystems have come into being and are likely to change in the future.

Hurricanes represent one type of severe perturbation that produces major changes in natural landscapes. They are regular storm events in the southeastern United States, although many years may occur between these storms.

Diversity in forests is perpetuated by factors that produce major changes in the structure or result in the death of older trees. These changes allow younger individuals to enter into the canopy on a variety of temporal and spatial scales. These changes can be isolated phenomena affecting individuals and creating small gaps in the canopy or cause severe perturbation affecting many individuals. These extremes can produce different responses in the understory, shrub, subcanopy, and canopy populations.

Knowing how forests are affected by severe hurricanes is critical to land management in hurricane-prone areas, and managers should determine whether changes are part of a natural process, or whether they are caused by anthropogenic alterations to the system. If these patterns can be separated, natural processes can be recognized and managers will avoid spending time and money trying to fix something that is not broken. Recognizing anthropogenic changes allows managers to take appropriate remedial actions to compensate for undesirable effects.

The following projects, listed in Table 19, provide a basis for describing the composition and structure of major forest communities in the South Florida national parks as they existed before the hurricane and as they currently exist. This basis also provides an understanding of why these changes have occurred, as well as a critical baseline for evaluating future recovery of the communities.

Historical Plant Data

The first step in documenting impacts on plant communities should be developing an inventory of vegetation plots that have been studied in the past, including information on location, when sampled, types of information collected, where the information currently resides and what form it is in, and if the plots were marked in a way that would allow them to be relocated. This effort would require examining published and unpublished reports, and discussing and possibly visiting study

Table 19. Questions that should be quantitatively evaluated in analyzing pre- and post-hurricane characteristics of forest canopy trees in major plant communities at sites exhibiting different degrees of impacts.

Were major community types affected differently?
- Document community structure in each community type before and after hurricane in terms of: density, basal area, crown size, and height.
- Document mortality in different community types.
- Document types of damage in different community types.

Were different species affected differently?
- Document structural characteristics of individuals of each species before and after hurricane in terms of: basal area, crown size, height (including vertical and bole length).
- Document survival and mortality in different species.
- Document frequency of damage types in different species.
- Determine how different species are resprouting in terms of numbers of individuals resprouting and density and location on tree of resprouting.

Were effects caused by nearby falling trees different from effects resulting directly with hurricane winds?
- Determine by inspection of each individual tree and others around it whether damage it sustained could have been caused by adjacent trees rather than wind.

What were the major types of damage and what are the characteristics of this damage?
- Evaluate types of damage for each individual in terms of:
  - Broken bole: diameter at break, height of break, weakness at break, and direction of fall.
  - Uprooted: root ball exposure, angle of bole, supported by another tree, direction of fall.
  - Bent stem: angle of stem top from vertical, direction of bend.
  - Major branch loss: number of major branches lost and remaining, diameter of branches lost at break, diameter of remaining branches near main stem, percent crown loss.

Were certain types of damage more lethal?
- Evaluate mortality in terms of:
  - Type of damage.
  - Severity of damage: e.g., height of stem break, diameter at stem break, amount of root exposure, angle of bole (degrees from vertical), percent of major branches broken, percent crown loss due to loss of major branches.

What were the directions of fall in the study area to assess whether sustained winds or merely gusts were involved?
- Determine the direction of lean or fall for each individual.

In areas where the hurricane eye crossed, were effects more associated with the front or back portion of the storm, i.e. were edges created by the leading edge of the storm that resulted in more severe damage by the following edge of the storm?
- Determine the vertical position within debris piles of each individual relative to others to assess damage due to winds preceding or following the hurricane eye.

What is the relationship between tree size and hurricane effects?
- Measure or estimate stem diameter (dbh), height, and crown size of each individual and analyze size distribution by species and major community type in relation to: type of damage, degree of damage, and mortality.

Is a tree's susceptibility to damage influenced by site location within the local and regional landscape, i.e. natural or human-caused variations in topography, past or present land use, etc.? Alternately, how important are isolated strong wind gusts in producing more severe localized impacts?
- Assess the location of each site in terms of proximity to: edge of forested area, various types of land use alteration, other study sites, etc.

Can survival from previous disturbances be detected by looking for pre-Hurricane Andrew damage on individual trees? Are trees on certain sites or of certain species more likely to survive major disturbances?
- Determine occurrence of previous damage and relate frequency of damage types to: species, community type, site characteristics, site location, and tree size.
- Describe how previous damage compares with effects produced by Hurricane Andrew in terms of: mortality and type of damage, such as broken bole and major branch loss combined, uprooted, or bent.

sites with individuals who have conducted past research in the parks. Verifying the relocatability of sites in the field could be quite time-consuming.

An important consideration, when resampling these plots, is that as the time period since they were last sampled lengthens, our ability to associate changes in the sites to Hurricane Andrew will decrease, because other environmental factors will also have been influencing the character of these sites over the years. Any information that documents these other influences will greatly enhance our ability to interpret the results of these studies.

Resampling previously studied sites has the potential for producing some of the most valuable data on Hurricane Andrew effects on natural ecosystems. Resampling should be supplemented by additional study sites to ensure an adequate representation of the spectrum of community types that exist in the parks and the variation in levels of impact that have occurred in different areas. Evaluating storm impacts must include minimally impacted sites as well. A collection of sites can be selected based on aerial photography and reconnaissance, but final selection should require ground truth measurements of the individual sites.

Using geographical information system (GIS) technology should facilitate selecting previously sampled and new sites to assess the degree of storm effects in relation to availability of representative communities and possibly previous disturbance histories in different areas of the park.

Forest Canopy Trees

The forest canopy effectively determines environmental conditions for most plants and animals existing on a site. Thus, a major effort should be made to document the current status, and to construct the prehurricane status, of the forest canopy in representative replicate (at least 3) sites in all major forested communities in severely, moderately, and relatively unaffected areas. Sites should be elongated rectangles to minimize clumping effects. A minimum tree size must be established for all plots, in combination with a standard plot size that allows reasonable representation of all major species, without taking excessive amounts of time at any one site. All trees above the minimum size should be permanently tagged. This field effort could take 9 months, followed by approximately 9 months for data compilation, analyses, and writeup. The work must begin by November 1992, since there is a window of only about a year after the hurricane to acquire this information. After that, regrowth of living vegetation and deterioration of killed vegetation would make this assessment much more difficult and in some communities virtually impossible. Questions that should be quantitatively evaluated, along with recommended approaches for addressing these questions, are in Table 19.

Upland Forests

Some coastal upland forests were inundated by the storm surge, while others were not. In South Carolina, salts added to the soil profile as a result of the Hurricane Hugo storm surge were the primary cause of pine mortality in subsequent years. One effect of soil salinization was the long-term displacement of ammonium ions by sodium in the soil complex. Table 20 contains approaches for assessing the effects of the Hurricane Andrew storm surge on national park system lands.

Storm-generated Herbaceous Detritus

Qualitative aerial observations made as part of the resource damage assessment identified obvious accumulations of detritus, particularly of saw grass, on the windward side of tree islands and in other locations in Everglades. These observations did not provide a reliable quantitative estimate of the detritus, particularly in comparison to detritus that was present

Table 20. Approaches for assessing effects of the Hurricane Andrew storm surge on upland forests.

1. Assess which islands, portions of islands, or coastal shorelines were inundated by Hurricane Andrew.
2. Assess erosional and depositional effects of the storm surge on redistribution of soils on inundated sites.
3. Compare conductivity of soils in inundated and noninundated sites.
4. Establish wells to sample salinity and nutrient (N and P) concentrations of ground water in inundated and noninundated sites.
5. If significant salinization of the soil or ground water is observed, its effects on the physiological status and post-hurricane survival of resident plant species will be examined. Moisture status of plants will be estimated using bimonthly measurements of pre-dawn moisture stress and carbon isotope ratios of newly matured leaves. The source of water used by the plants will also be assessed, based on hydrogen and oxygen isotope composition of stem water.

before the storm. A systematic aerial survey using GPS and GIS technology should be conducted to establish the distribution and surface area of the detritus accumulations. Ground surveys should establish a surface area-mass relationship so that detritus quantities could be estimated. Ground surveys at less impacted sites should determine the background levels of detritus before the storm. This information is necessary to assess the potential impacts of storm-generated detritus on wetland food webs. This task should be initiated immediately, before significant decomposition and redistribution of the detritus has occurred. Long-term follow-up studies should also be conducted.

Role of Herbaceous Detritus on Wetland Food Webs

Detritus (dead organic material and its associated microflora) is an essential component of wetland food webs. Storm-generated detritus in Everglades may be significant relative to the amount of pre-storm detritus available to the food web. Freshly fallen plant material may have measurable effects on water quality in the wet prairie and slough habitats. Numerous studies of aquatic decomposition dynamics of herbaceous plant litter have demonstrated notable leaching (up to 50% of initial litter mass) of soluble inorganic and organic materials in the first 24 to 48 hours of inundation. If this type of leaching occurred following storm-related litter inputs, poststorm water quality sampling (4 and 24 days following the hurricane) may have missed the leaching. Further, any nutrients leached from the litter are assumed to have been rapidly recycled and assimilated by bacteria, periphyton, and other microbial communities. Possible effects of this leaching are unlikely to be observed in ecosystem structure or function due to insufficient prestorm data. Potential longer-term effects should be assessed by conducting in situ experiments that decomposition dynamics and the effect of inorganic nutrients. Storm-generated detritus should be studied with respect to metabolic activities, such as respiration, primary production, nutrient retention, and microbial enzyme activity, and their response to phosphorus inputs. These experiments should be conducted as soon as possible before complete decomposition and redistribution of the detritus has occurred.

Marsh Fishes and Plants

A more extensive survey of fish and macroinvertebrate communities associated with periphyton mats and their linkage to fish populations should be conducted to delineate the possible effects of Hurricane Andrew on the freshwater ecosystem. This survey should be coupled with records of periphyton and plant abundance and characterization of bottom sediments. This effort should be completed as soon as possible (preferably within 1 month) to evaluate the poststorm environment. Data collection should include sites from the Tamiami Trail to the mangrove areas fringing Florida Bay. Little information on the transition of communities between freshwater and saltwater areas is available. These transition areas are critical as nursery grounds for fishes, however, and their geographic distribution is directly tied to freshwater distribution in Everglades National Park. The cursory survey on the Lostmans sites 1 and 2 suggested that fishes in these areas were unaffected by the storm, but no prestorm data are available for comparison. Wracks of periphyton and grass stems were observed in the upper reaches of the Lostmans River drainage.

The poststorm survey should be repeated monthly during the upcoming year to monitor the dynamics of periphyton abundance and consumer communities. Stomach contents of selected species should be examined to analyze the trophic dynamics of these communities. This examination should include areas where periphyton loss is proposed and areas where it is not, based on results from the poststorm sampling effort. A unique opportunity exists to examine the role of periphyton in nutrient cycling by providing information on the system when it is absent. All data should be collected in a format that will contribute to a formal food-web analysis of major aquatic habitats in the southern Everglades.

Because current park staff will not be able to complete this task, the cost estimate in Table 21 is based on hiring one technician and three graduate students to assist in field monitoring efforts and includes the monthly sampling of 20 sites and laboratory work accompanying that effort, including gut content analysis. Helicopter time and airboat fuel and upkeep have been considered, as well as extra laboratory equipment for sorting macroinvertebrates and quantifying gut contents (e.g., dissecting microscopes, balances, etc).

Mercury Accumulation in Everglades Fishes

The sites and species of fishes analyzed in the 1989-90 survey should be resampled to characterize mercury concentrations. Resampling would permit an assessment of the hypothesis that the perturbation of bottom sediments may have released mercury into the water column. The original fish survey of mercury in fish tissues (Loftus 1991) should be repeated as soon after the storm as possible and again approximately 2 months later. Mercury is expected to accumulate and reside in fatty tissues until those tissues are metabolized. In fish, the mercury could accumulate for long periods of time. Thus, we do not currently have a precise projection of the time course for accumulation of mercury in Everglades fishes and propose that monitoring should be done over time.

Mercury in Everglades Marsh Food Web

Additional analysis of mercury distribution at several levels in the food web should include invertebrates, such as crayfish, prawns, and fishes feeding lower

Table 21. Recommended equipment and analyses, cost estimates, and potential suppliers for determining urban debris disposal impacts.

Equipment and Analysis Type	Cost Estimates	Potential Suppliers
1. Wet Deposition Samplers (3 each at 2 locations, Research Center & Headquarters) 1 sampler regular NADP analysis + pesticides, 1 sampler metals (no mercury - Hg), 1 sampler Hg only.	1@$3K/site 2@$5K/site Total: $26K	AeroChem Metrics; Modifications by Illinois State Water Survey (Possibly)
2. Wet Deposition Analyses		
- Routine NADP, nutrients, & organics	$21K ea. site	Illinois State Water Survey; USGS (Pesticides)
- Metals (w/o Hg)	$12K ea. site	Illinois State Water Survey or Contract Lab
- Hg	$5K ea. site Total: $76K	Illinois State Water Survey or Contract Lab
3. Supplementary organics analyses at existing surface water monitoring network	Total: $20K	
4. Particulate Sampling, IMPROVE 4-module system (1 each at 2 locations as for wet deposition)	$12K each Total: $24K	Univ. of California at Davis, Crocker Nuclear Lab
5. Particulate Analysis (Elements, carbon, ion, PM-10 & SO_2) Pesticides Analysis of PM-10 filter (if possible)	$33K each site $10K each site Total: $86K	U. of CA at Davis (elements); Research Triangle Institute (SO_2); Global Geochemical Corporation (ions); Desert Research Institute (Carbon)
6. Meteorological Monitoring at Research Center and Headquarters	Total: $13K	(Weathermeasure/Qualimetrics or equivalent)
7. Monitoring Shelter to Move Gaseous Monitoring Equipment from Research Center	Total: $10K	Misc. suppliers. (EKTO shelter or equivalent)
8. Camera system and housing for visibility monitoring	Total: $6K	Air Resource Specialists, Inc.
9. Engineering Support (40%) & Administration	Total: $105K	
GRAND TOTAL:	$366K	

on the food web than those surveyed before. The fishes surveyed in 1989-90 were top-level aquatic predators. Additional analysis should be considered for wading bird tissue.

Marsh Primary Production Protocol

Immediate hurricane effects on the primary production dynamics and community structure of the herbaceous and periphyton communities were not apparent, except for some redistribution of periphyton community structure and an apparent release of dead-standing herbaceous biomass (i.e., wracklines). Plots should be established (perhaps coupled with the fish and macroinvertebate sampling) to evaluate (1) annual primary production and decomposition dynamics of saw grass and other dominant herbaceous communities, (2) annual primary production and turnover of the periphyton community, and (3) species composition changes in these communities. To enhance the role of this data set in supporting tropic dynamics studies, determining the protein content and C:N:P ratios would be valuable. This study should be implemented immediately with long-term monitoring being pursued by the Everglades threshold study.

Mangrove Litter

Severely damaged mangrove and upland sites should be monitored for decay and release of soil and organics. Accumulations of mangrove litter could provide a major long-term increase in the input of organics and nutrients to the coastal waters.

Subtidal Storm Sediments

The distribution of the subtidal storm layer (including deltas) should be sampled throughout the reef tract, Biscayne Bay (including north of the park boundary because the deep central area near Rickenbacker Causeway is a likely repository for a major sediment layer), and the west coast bays, nearshore and offshore (to 10 km [6.2 mi]).

Satellite imagery and aerial photography should be used to follow prevailing and winter storm dispersal of unconsolidated sediments deposited in the coastal region. These parameters should be monitored monthly on transects from the turbidity-nutrient sources to the likely affected reef areas.

Sea Grass Beds

More detailed mapping of the changes to sea grass beds (erosion and smothering) and areas of reef smothering, sand blasting, breakage and overturning with respect to observed current flow patterns should be done to fully understand the changes that may have occurred during the storm. Mapping should be done using pre- and post-storm aerial photography complemented by the diving observations.

Marine Hard-bottom Communities and Lobster Fishery Recruitment

Hard-bottom communities serve a variety of functions in the South Florida marine ecosystem; approximately one-half of the sea floor in Biscayne Bay was lush hard-bottom habitat before Hurricane Andrew. Many of these communities, particularly those in the central basin, were obliterated by the storm. Sponges, soft corals, hard corals, and macroalgae are prominent features of these hard-bottom communities. They serve as nursery areas for many fishes and invertebrates, including spiny lobster. Planktonic postlarval lobsters settle into the macroalgae and spend the first 2 years of their lives seeking shelter and food in these hard-bottom communities.

One month before and immediately after Hurricane Andrew, hard-bottom communities in the Biscayne and Florida bays were quantitatively assessed by a research team from Old Dominion and Florida State universities and the Florida Department of Natural Resources. The impact of the storm on future lobster fishery potential and population recovery can now be determined.

Sportfish Catch Rates

The long-term monitoring of sportfish catches from Everglades and Biscayne national parks should be reestablished as soon as possible. A detailed statistical analysis of reported catches should verify overall changes in sportfish catch rates following the storm event.

Heavy Metal Distribution in Hardwood Hammocks

Prestorm data on heavy metal concentrations in a variety of hardwood hammocks are available from research by Deborah Shaw-Warner, University of California, Davis. These data evaluated storm effects and documented potential pollution from urban debris disposal. Lichens, algae, and tree snails probably act as conduits carrying heavy metals into the food web with unknown implications for higher level consumers.

Mangrove and Schinus Litter Dynamics

A tremendous pulse of mangrove litter has been produced. Secondarily, *Schinus* may replace the traditional forest canopy in some ares. The dynamics of mangrove litter decomposition, under the conditions which prevail in forests where varying degrees of canopy loss have occurred, should be studied immediately. This study should include a parallel effort to compare and contrast the process and fate of *Schinus* litter with the South Florida traditional mangrove forest species.

Marine Water Quality from Biscayne Bay Canals.

A short-term study should evaluate water quantity discharges and water quality conditions in Black Creek, Goulds canal, Mowry canal, and Princeton canal for a 1-month period before and a 3-month period following the storm in order to compare pre- and post-storm conditions.

Manatee Warning Signs for Boaters

Damaged or missing signs should be replaced before the winter season to warn boaters of manatees. The placement of signs should be coordinated with the park natural resource management specialist. The signs are acquired at no cost to the park from the Save the Manatee Club, and the resource management program currently has 25 signs on hand.

Plant Population Status

Selected Rare Plants

Rare plant surveys during the coming year are crucial in evaluating the effects of Hurricane Andrew on individual species (Table 17). Attention should be given to all species that the assessment team has singled out, with special attention to those for which good baseline data exist and those most likely to have been affected negatively or positively by the hurricane. The primary approach to conducting this assessment should be on-the-ground visits to known sites where these species occurred before the hurricane.

Melaleuca

Surveying for posthurricane *Melaleuca* dispersal in Everglades and Big Cypress should be done. This work should be conducted in the second year following the hurricane, when seedlings are detectable (0.3-0.9 m (1-3 feet) tall) but not yet seeding. Fire has been used as a management tool to kill *Melaleuca* seedlings while they are still small and is particularly effective in areas lacking seed trees. If trees with seeds exist in the area burned, however, seeds will be dropped after the fire, resulting in probable perpetuation of seedlings at the site.

Nonnative Plants

The nonnative plant situation at Biscayne should be thoroughly evaluated strategically after 3-6 months of recovery from Hurricane Andrew. Particular consideration should be given to early control of *Schinus*, *Colubrina*, *Casuarina*, and *Scaevola*, if the species are sufficiently localized to allow effective control.

The general nonnative plant situation at Everglades should be thoroughly evaluated after 3-6 months of recovery from Hurricane Andrew; particular consideration should be given to early control of *Casuarina* and other species that appear to be responding to hurricane dispersal and habitat modification.

Mangrove Forests

Quantitative plots with which to reconstruct the prehurricane forest and with which to monitor recovery of the forest from Hurricane Andrew should be established in both the west coast mangrove forest and the mangrove forest of Florida Bay. Historical plots should be located and revisited and included in the Hurricane Andrew plots.

Wildlife and Fish Population Status

Wading Bird Surveys

The initial poststorm wading bird systematic reconnaissance flights (SRF) survey suggests that the hurricane caused no immediate changes in wading bird populations in Everglades. Given the potential damage to rookery sites and potential changes in poststorm trophic dynamics in the ecosystem, however, intensive follow-up surveys of wading birds should evaluate delayed responses in foraging and population levels. In cooperation with other agencies (South Florida Water Management District, Florida Game and Fresh Water Fish Commission), survey grids should be expanded to Collier (Big Cypress) and Hendry counties and the survey schedule enhanced (October, November, June, July, September). Given that significant delayed responses are found following 1-year poststorm, the expanded and intensified survey should be continued.

Eagle and Osprey Breeding Surveys

Bald eagles have been surveyed in selected areas in Everglades, Big Cypress, and Biscayne on an annual basis since 1950; however, surveys have been sporadic throughout much of the storm-impacted area (i.e., Ten Thousand Islands). The condition of nests should be surveyed within several weeks of the storm. More importantly, beginning at the 1992 nesting season (October) and continuing through the 1994 nesting season, surveys should evaluate the poststorm breeding success of bald eagles. Similarly, osprey nests and poststorm breeding success should be evaluated for a 2-year period. Comparative prestorm data are available (i.e., 1980s). Finally, the status of rookeries should be evaluated and monitored.

Alligator Hatching Survival

The 1992 alligator nesting success will be low because of the high-water conditions and the hurricane event. Survival rates of the hatchlings should be followed for at least 1 year. The survey should be conducted at selected nest sites that were surveyed poststorm.

White-tailed Deer

The eye of the hurricane passed over the southern end of the Stairsteps unit of Big Cypress and the upper Shark River Slough area of Everglades where the NPS 3-year study of the population ecology of white-tailed deer was completed in March 1992. Monitoring the deer that still had functioning radio-transmitters showed that none of the 32 deer died as a direct result of the storm. The hurricane had a severe impact on the tree islands that constitute an essential part of the deer habitat in this area, and indirect mortality due to the increased stresses caused by a reduction in food resources, a lack of cover, and high-water levels may occur. Reestablishing the sampling methodology of the original study through the fawning period should determine the posthurricane survival of the deer; the impacts of habitat alteration on spatial distribution, habitat use, and movements of deer; and the possible impacts of the storm on the fecundity and productivity of the population.

Little evidence exists that white-tailed deer populations in Everglades and Big Cypress were impacted by the hurricane event except some deer migrated from their feeding areas. The longer term response of the deer population to the hurricane should be evaluated, especially when considering the potential changes to the upland habitat structure and food supply.

Red-cockaded Woodpeckers and Habitat

Three of eight woodpecker colonies in the Lostmans Pines area of Big Cypress, representing the southernmost location for these species, were active before Hurricane Andrew. Whereas old-growth cavity trees were severely damaged by the storm (90% killed), this subpopulation has possibly been lost. The area should be surveyed for the presence and number of remaining birds and the amount of remaining suitable habitat to decide if management actions are needed. In addition, long-term vegetation plots should be established to document the rate of recovery of suitable red-cockaded woodpecker habitat.

Cape Sable Seaside Sparrow

The path of maximum damage was in the northern part of the Cape Sable seaside sparrow's small range in Everglades and Big Cypress. The helicopter survey in spring 1992 should be repeated in 1993 to see whether the birds suffered any mortality.

Swallow-tailed Kites

Hurricane Andrew will likely have considerable effects on future reproduction of swallow-tailed kites in Everglades, particularly on nesting substrate, foraging habitat, and the availability of nesting material. A 3-year field study should be initiated early in 1993 to assess these effects. The study should measure breeding success and productivity, species composition and biomass of diet, range sizes, and foraging habitat selection. Data from Everglades should be compared with the results from previous years and with data collected concurrently in Big Cypress north of U.S. 41 where the hurricane effects were less severe. The availability of nest material on initiation and outcome of nesting attempts should be tested experimentally by provisioning selected areas in Everglades with moss and lichens.

Besides documenting the immediate response of swallow-tailed kites, the study should measure the impact on the broad array of small vertebrates (e.g., frogs, snakes, anoles, nestling birds) and insects on which nesting kites rely. In addition, the study should capitalize on a rare and extreme natural event to elucidate the extent to which the diversity and structure of available vegetation limit the reproductive potential of the reduced population of this highly vulnerable species, which has been recommended for listing as endangered at both state and federal levels.

Pineland Breeding Birds

The loss of pinelands from the South Florida landscape and the extirpation of several endemic bird species (i.e., those that breed only in active pine forest in this portion of their range) from the remaining habitat on national park system lands is cause for great concern. Even before Hurricane Andrew, the most striking changes in protected areas were evident in Long Pine Key, in Everglades where red-cockaded woodpeckers, southeastern American kestrels, eastern bluebirds, hairy woodpeckers, and brown-headed nuthatches no longer occur. Kestrels and hairy woodpeckers are rare or absent in Big Cypress; the other species probably have declined since the early part of the century and are assumed to be at risk. Although the causes of these recent declines and extirpations are not known, the most likely underlying factors are logging, altered fire regimes, and isolation from the fragmentation and elimination of vast areas of adjacent pine forests. Hurricane Andrew, which left one-third of the pines at Lone Pine Key broken or uprooted and severely damaged the associated hardwood hammocks, undoubtedly will have marked effects on the pineland avifauna of Everglades.

In light of the growing threats to the ecological integrity of the Florida remaining uplands, the impact of Hurricane Andrew, the recent extirpations and tenuous status of the extant avifauna on these national parks, and the increasingly important role of these lands as habitat islands in South Florida, a 3-year study should assess the current status of the pineland avifaunas of Big Cypress and Everglades, with particular emphasis on the effects of Hurricane Andrew; form a baseline for future monitoring; determine the ecological correlations of nesting success and density for the species of greatest concern (focal species); identify the principal causes of recent changes; and provide management recommendations aimed at restoration and long-term protection.

In addition to forming the basis for long-term monitoring, the study should produce management recommendations, such as burn schedules and habitat manipulations (e.g., snags, cavities, subcanopy vegetation), for protecting the present assemblage of pineland birds in Big Cypress and Everglades. The prospects for long-term viability, given the increasing isolation of these populations in the South Florida landscape, should also be assessed. Finally, the project should evaluate the advisability, feasibility, and methods of translocations and reintroductions to bolster or restore populations of pineland endemics on national park system lands.

Tree Snails

Some mortality of tree snails were noted in the first few weeks after the storm, and their habitat was severely damaged. Indirect mortality may occur due to reduced preferred food sources (e.g., on bark of *Lysiloma*), altered microclimate, and the likelihood of devastating fires. An immediate assessment on rare color forms would formulate management recommendations such as prescribed fire or translocations. Long-term monitoring of selected tree islands should evaluate the snails response to altered conditions.

Schaus' Swallowtail

Surveys of torchwood and wild lime, the primary foods of the Schaus' swallowtail larvae, should be conducted in fall-winter 1992 on Elliott, Old Rhodes, and Totten keys and in north Key Largo to assess their mortality and recovery status. Intensive hunts for flying swallowtails should be conducted next April through July in all of these areas. Particular care should ensure that no mosquito control activities affect the swallowtails in 1993.

Biscayne Sponge Monitoring Plots

The loss of sponges at Pelican Bank and at Billys Point suggests that the overall populations may have been impacted substantially. Relocating all of the previously established monitoring plots in Biscayne Bay and conducting a detailed inventory of the recorded and tagged sponges is extremely important. An analysis of the data from these sites should include losses by size class and species composition.

Coral Reef Fishes

All of the information currently available on the change in fish populations has been qualitative and anecdotal. Although these initial observations reveal that many fish survived and populations may not have been extensively altered, exact impacts can only be determined through more quantitative surveys where comparable data from before the storm are available.

Quantitative surveys of reef fish conducted by Dr. James Bohnsack of the National Marine Fisheries Service in Biscayne National Park should be repeated as soon as possible to quantify changes in the reef fish community.

Sea Turtle Nesting

Monitoring sea turtle nesting activity and success during the coming year should document changes in nesting activity and selectivity of nesting sites that may be associated with the geomorphological changes noted on the nesting beaches of Biscayne and Everglades.

Manatee Rescue and Survey

Everglades should continue to participate in establishing statewide marine mammal rescue and carcass salvage programs. Field personnel should be alerted to the possibility of live marine mammals (manatees and dolphins) having been "trapped" upstream or inland of shoals, oyster bars, significant waterway debris (log jams, etc.), and control structures on canals. They should also be alerted for the possibility of dead marine mammals appearing in these same areas, or elsewhere. Sightings should be reported to the natural resource management specialist for verification and coordination with district personnel and appropriate state authorities.

The study of manatee distribution and relative abundance in Everglades National Park is scheduled to end in February 1993. Monthly aerial surveys should continue for a minimum of 1 year, through February 1994.

Status of Crocodile Population

The current distribution, habitat relations, and abundance and nesting success of crocodiles in Everglades should be determined through the 1993 nesting season. Beyond assessing the immediate effects of the storm, the distribution and habitat data should separate the effects of future management actions (allowing recreational access to the sanctuary or manipulating water deliveries) from storm effects on crocodiles.

Mangrove Faunal Dynamics

Faunal dynamics in the west coast mangroves forest are poorly documented. A 2-year project to survey this community relative to mangrove forest damage and recovery in terms of habitat relationships, community structure, and trophic structure should be done to evaluate estuarine function. Different river drainages exhibiting different damage levels exist as an initial experimental design.

Environmental Monitoring Networks

Everglades Hydrologic Monitoring Network

The destruction of most of the hydrologic monitoring network in Everglades, even those that were along the periphery of the storm, indicates the need for not only restoring the stations but also improving the reliability of the undamaged stations. Several of the stations have fallen in advanced states of disrepair and more than one has been closed for lack of proper support structures. A large part of the network is not collecting data at the present time, and this situation (already 4 weeks old) appears likely to continue for some time. Valuable data is being lost for short- and long-term assessments. For example, the loss of data from station P38 impacts the proper evaluation of the last of the alligator nests in Shark Slough. Flooding of nests, due to the redirecting of excess recent rainfall into Shark Slough instead of into the East Everglades, could have been discovered earlier and remedied if strong stations and real-time (telemetry) access to stages in the wetlands were available. If a large rainfall had been associated with Hurricane Andrew, the lack of an adequate hydrologic network would have severely hampered the short- and long-term evaluation of the ecology.

To provide the hydrologic data for evaluating future storms and for providing the data for current water management strategies, the Everglades hydrologic network should be improved, expanded, and made capable of withstanding major storm events. The network should have a certain amount of redundancy, which currently does not exist in most areas, to provide the hydrology staff with accurate and sufficient data at all times. The importance of an adequate hydrologic network should not be underestimated. Assessing all ecological functions in the Everglades is contingent on the availability of proper hydrologic data.

The expense of improving and telemetering the network will eventually be offset by the saving in human resources and helicopter costs. The accuracy and adequacy of the data will be improved by providing the monitoring group with the real-time information of when a station is not functioning properly.

A core of stations should be upgraded to include sturdy construction, more reliable instrumentation, and telemetry in each major basin of Everglades, Big Cypress, and the marine environment. Upgrading all of the hydrologic monitoring network is apparently not necessary. An appropriate selection of stations would include the following:

• Eastern Panhandle	5 core stations
• Shark River Slough	10 core stations
• Taylor Slough	5 core stations
• Big Cypress NP	5 core stations
• Marine Environment	10 core stations

Selecting station locations and installing instruments should be done after carefully consulting with all hydrologic and ecological staffs. Further, the telemetry and data management network would be more effective if designed consistently with the South Florida Water Management District and the U.S. Geological Survey. Back-up telemetry and instrumentation should be stored and readied to immediately replace malfunctioning stations. For this short-term effort, two full-time technicians are recommended.

Historical Water Quality Data

Water quality data typically assess background conditions and determine any potential changes resulting from natural or human-related activity. Parameters include physical measurements such as temperature, dissolved oxygen, and pH and chemical measurements such as biological nutrients. Water quality data are inherently variable, however, and monitoring programs are usually designed around funding and logistical constraints rather than around constraints imposed by this large variability. Given these considerations, a systematic analysis of the historical water quality database for Everglades should be conducted to design future monitoring programs. This approach would ensure that data are collected to include any potential changes in water quality resulting from disturbance events such as Hurricane Andrew to quantify the data in a reliable fashion. The analysis of the historical database should also consider spatial patterns in water quality so that recommendations concerning the possibility of additional stations in Everglades could be made. Water quality monitoring should be pursued at Big Cypress National Preserve and included in a systemwide program.

Freshwater and Marine System Networks

Water quality in Everglades is affected both by the inflowing and outflowing water quality patterns. Measurements of inflowing water quality are included in the SFWMD water quality monitoring program, and regular downloading of this data to the Everglades water quality databases should facilitate future analyses. The sampling schedule of this program should also be coordinated with the Everglades program and the recommended Big Cypress program. Had such a coordinated effort already been in place before Hurricane Andrew, the potential impacts would have been much easier to assess in a timely fashion. A contractual water quality sampling program is currently underway in Florida Bay and in the west coast estuaries (Dr. R. Jones, Florida International University). Analysis of this database should be coordinated with the analysis of the Everglades database to determine future sampling station locations and sampling schedules.

To fully understand the extent of water quality impacts, the current monitoring network should be extended seaward along the west coast of Everglades. Currently little data collection is taking place in this area, and adding the west coast to the marine water quality network would be beneficial.

Marine Water Quality Data and Monitoring

During the brief initial assessment period, only a small portion of the overall data concerning storm event conditions and poststorm changes in water quality were analyzed. Data analysis should continue, and a comprehensive report of observations and environmental changes should be targeted.

During the next year, monitoring efforts should be increased for all aspects of water quality conducted by the park staffs and local cooperators. The potential for wide-ranging ecosystem impacts from degraded water quality associated with upland storm impacts cannot be overemphasized. The magnitude of the vegetation blowdown represents many years (perhaps normal decades) production of all forms of carbon, nitrogen, and phosphorus. These nutrients will be released into the adjacent marine system for many years.

Marine Turbidity and Chlorophyll

Water quality studies, particularly involving turbidity and chlorophyll, should be done in coordination with the permanent plots and productivity studies. The rapidly decreasing light levels in the fall of the year will exacerbate the present sediment loads, and undoubtedly plankton blooms. The potential for increased sea grass dieoff is high and might spread to new areas.

Urban Debris Disposal Sites

The National Park Service should encourage the Army Corps of Engineers and Dade County to design and construct temporary, fixed incinerator facilities that have known efficiencies for air pollutant emissions control and that limit groundwater contamination potential. When air-curtain destructors are used, Dade County and the Army Corps of Engineers should require that incineration pits be constructed in accordance with proper design parameters, including an impervious base layer, sheer wall construction, and the proper sizing, placement, and operation of the air-curtain destructors. Dade County should require (as part of the permitting process) air pollutant emission characterization (i.e., source monitoring) and appropriate background and downgradient monitoring for potential groundwater contaminant indicators, including volatile organic compounds, total petroleum hydrocarbons, and base acid neutral compounds. The Corps of Engineers and Dade County should use methods to contain and stabilize temporary ash storage piles, and strictly enforce against open burning of hazardous and toxic substances and other prohibited materials.

NPS staff should coordinate and implement these actions. Technical expertise should also support mid- to high-level NPS officials in working with external agencies in implementing the recommended management actions. NPS staff should solicit contract services and administer monitoring activities. In addition to the engineering support services for field monitoring, staff should provide oversight and support monitoring activities, including data collection and reduction, quality assurance-quality control, and preparation of reports.

Disturbed Archeological Resources

Before constructing disposal facilities, an archeological survey should be conducted for possible subsurface cultural resources that could be impacted by facility construction.

Artificial Reef Debris

A 75-foot-long vessel that had been sunk as an artificial reef just outside the Biscayne National Park boundary was broken up and moved onto the coral reef in the park during Hurricane Andrew. A survey of the natural reef at this location indicated little damage to the rock substrate, and ecological impacts at this point may be minimal. This wreck should be removed as soon as possible, however, to prevent the artificial surface and habitat from being colonized by marine organisms. Dade County and their artificial reef program should pay for this removal.

Cape Sable Marshes

Canals constructed to drain coastal marshes on Cape Sable before Everglades was established caused saltwater intrusion and altered the marshes. Several attempts have been made to close these canals at the shoreline. Tidal surges and storm waves from hurricanes routinely damage the barriers and reconnect the canals with the Gulf of Mexico, however, threatening the integrity of the coastal marshes. A long-term solution to this problem is needed to reduce repairs and damage costs to natural resources. Options, such as filling in significant lengths of the canals from the shoreline, should be evaluated and executed.

Cleanup Activities

Approaches to protect unique and valuable biological resources from cleanup activities should be evaluated. Important vegetation in Everglades and Biscayne should be protected from boardwalk and trail rehabilitation in hammocks, pinelands, and coastal vegetation. In some cases, large examples of some species or individuals of rare species may now interfere with safe use of trails. Removal of or damage to these plants should be minimized, even if it requires rerouting trails to protect these resources.

From an interpretive standpoint, the sense that vegetation of South Florida has been repeatedly hit by hurricanes should be retained in interpretive programs. Accomplishing this objective would require a person familiar with South Florida plant communities to assess the value of plant resources that may currently be impeding use of boardwalks or trails, before cleanup along these trails.

Storm-altered Management Practices

Fire Management Practices

Although analysis using current fuel models indicates no need for changing fire management prescriptions, the increased amounts of large fuels and more open canopies would suggest that the application of past fire management practices should proceed with caution. Hammock soil moisture should continue to be used as an index of whether or not burning is safe, but more postburn field verification of predicted objectives should be undertaken. The presence of new environmental conditions in the field may even allow the attainment of certain objectives that otherwise might not be possible. Biscayne National Park, in particular, should attend to fire hazards sooner than is normally warranted due to the greatly increased fire potential that will exist there for several years following Hurricane Andrew.

Additional park staff time should be given to evaluating the effects of future prescribed burns in the light of changed environmental conditions as a result of Hurricane Andrew. These evaluations should particularly focus on assessing the benefits or impacts to important plant and animal populations.

The most striking impact of Hurricane Andrew on the South Florida parks was damage to trees. In the unique rockland pine forests of Everglades, more than 40% of the trees with diameters greater than (25 cm) were snapped or uprooted. The fire management staff has determined that, on average, additional fuel to the understory should result in only modest increases in rate of spread and flame lengths. The nature of the added fuel, however, will result in patches of markedly higher fuel loadings (trees crowns with needles and small branches) where higher fire temperatures and longer fire residence times may kill the normally resilient understory vegetation.

Marked individuals of selected species (including endemic taxa and common species) and quadrants should be established under fallen tree crowns and in randomly selected locations away from tree crowns. After prescribed burns (or wildfires), mortality, recovery, and colonization can be compared.

Manatee Protection Plan

Before Hurricane Andrew, a manatee protection plan was being prepared for Everglades National Park. This plan should be finished and include posthurricane distribution analysis. Posthurricane facility reconstruction, rehabilitation, or relocation, repair of navigational aids, and other hurricane-related research and resource management actions should be reviewed for their potential impact on manatees.

Access to Florida Bay

Planning for any changes in recreational access to the "crocodile sanctuary" in northeastern Florida Bay should be postponed until the status and distribution of the crocodile population is determined.

Urban Debris Disposal Impacts

The emissions from debris burning should be characterized. Modeling should be conducted to predict potential air quality and visibility impacts on park resources from debris-burning operations. Modeling results would also be useful in selecting appropriate remote monitoring locations. Ambient air quality, atmospheric deposition, visibility, and meteorological monitoring should assess air pollution impacts at specific locations in Everglades. At least two sites should be established to determine the spatial extent of impacts: one site should be established in the area of park headquarters and another at the research center. Table 21 contains the recommended equipment and analyses for determining urban debris disposal impacts.

Long-term Recommendations

Two long-term projects should be taken to protect park resources relative to extreme natural events. Together, these actions will provide a basis for understanding resource dynamics and the relative effects of human activities in South Florida on resources and those of natural extreme events like hurricanes. The projects are as follows:

1. establish ecological monitoring programs
2. conduct long-term research on major resource issues

Ecological Monitoring

Ecosystems and the resources that comprise them are naturally dynamic features. Resource managers must acknowledge the dynamic nature and ask: How healthy are ecosystems? Without management intervention, are the systems capable of fending off altered water supplies, human extraction of "renewable" resources, accelerated invasions of nonnative species, physical impacts of intrusions, and air pollution? These issues threaten ecosystem integrity in natural areas worldwide. How do we determine when to intervene in natural resource issues, how far to carry remedial actions, and how to evaluate efforts to restore impaired resources?

Ecosystems are changing in ways never before seen. Lack of historical and contemporary data makes it difficult to clearly define the nature and extent of these changes (Orians 1986). Unless we begin to gather empirical data on the health of natural area ecosystems now, the changes may become irreversible and fatal. Alternately, out of fear of the unknown, we may unnecessarily impose constraints on human endeavors. Politically, this kind of uncertainty tends to restrict action for fear of overreacting or changing systems perceived as naturally static (Wurman 1990). Doubts about ecosystem dynamics range from concerns for global climate change to worrying about human disturbance of wildlife. Limited information on South Florida ecosystem dynamics impedes assessing storm impacts and evaluating anthropogenic stresses.

A natural resource ecological monitoring program should reduce uncertainty and address questions about system dynamics. What to monitor, and an appropriate level of accuracy, should be established, but the basic reasons for monitoring are to (1) determine present and future ecosystem health, (2) establish empirical limits of natural variation, (3) diagnose abnormal conditions to identify issues in time to develop effective mitigation, and (4) identify potential agents of change.

Designing a long-term monitoring program begins with a conceptual model of the ecosystem (Fig. 24). This model should consist of an exhaustive list of mutually exclusive system components and a description of their relationships. From components such as birds, vascular plants, and water, representative elements (e.g., species and watersheds) should be selected and tested for sensitivity to change. The adequacy of existing resource inventories should become apparent at this stage. Certainly not all identifiable elements of the ecosystem should be monitored, but the list of components should include categories for all biotic and abiotic resources and the processes by which they interact.

Measures of population dynamics offer a good solution to monitoring the biological elements of natural area ecosystems. Parameters of populations such as abundance, distribution, age structure, reproductive effort, and growth rate are relatively easy to measure. Many of these populations are sensitive to subtle, chronic stress, and permit projection of future conditions. This approach is also sensitive to a variety of environmental conditions because organisms integrate the effects of influences like predation, competition, and pollution. Even though population monitoring is not the quickest or surest way to determine causality, monitoring population

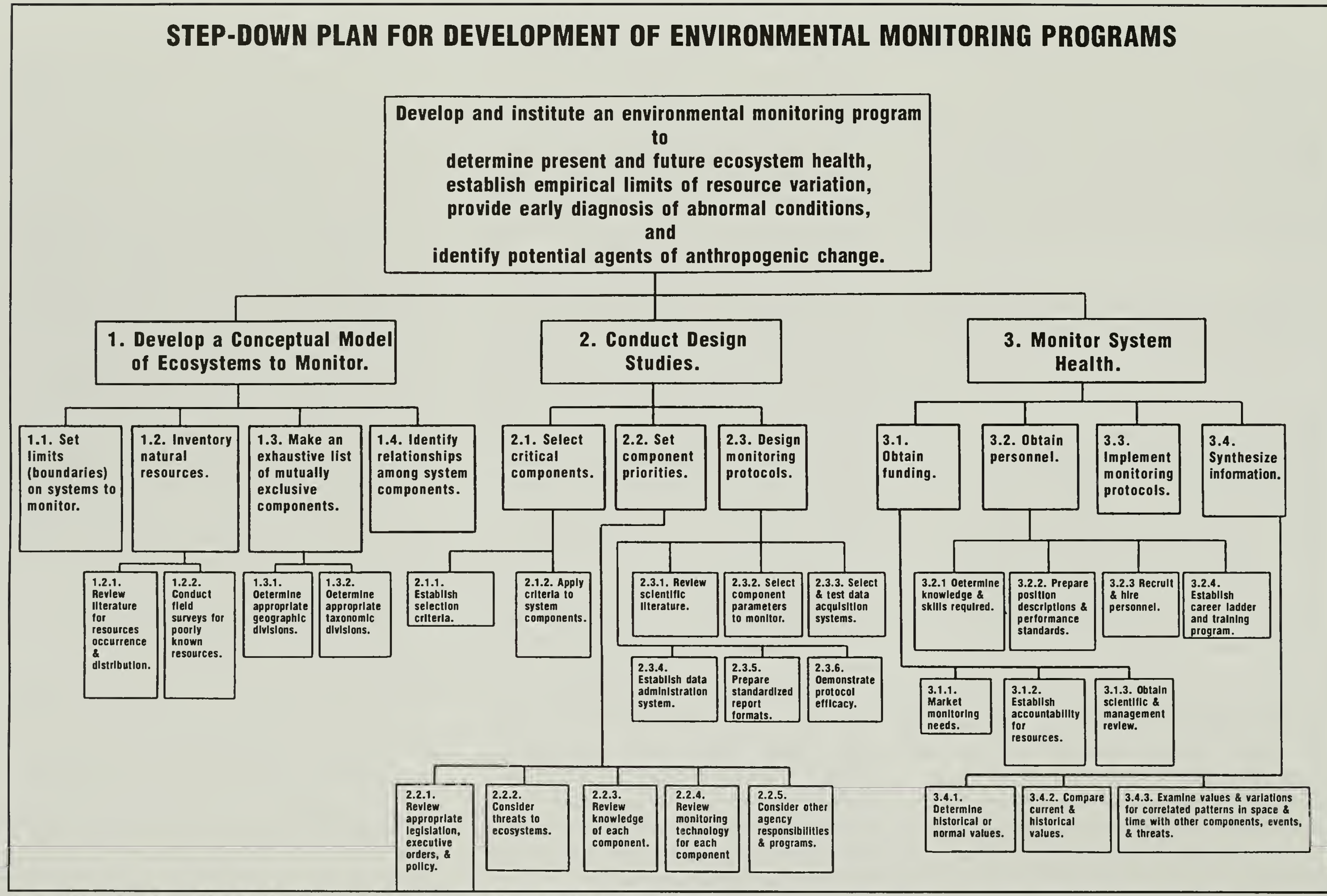

Figure 24. *Step-down plan for development of environmental monitoring program.*

dynamics provides an unparalleled indication of future conditions. Parameters such as age structure and reproduction permit projections of future conditions, providing early warnings of pending problems. Reduced growth and reproductive rates often reflect subtle, chronic stresses. Synthesis into system-level applications and interpretation of population parameters is relatively direct. Many management controls also operate at the population level, so application to management issues is direct and measurable.

Biodiversity is an important attribute of ecosystems and functions at many levels: genetic, individual, population, community, and even ecosystem. Nevertheless, the repeated inventories to measure and monitor biodiversity are expensive and difficult to conduct. Highly skilled surveyors are required to find and identify the elements of diversity. Alone, repeated inventories do not meet the goals of diagnostic monitoring. Down to the species level, diversity is not sensitive to environmental stresses and records only the past. Changes in diversity and other broad community measures are also hard to assess, ambiguous to interpret, difficult to apply to management issues, and may not be sensitive to significant environmental changes, such as habitat fragmentation (Robinson et al. 1992).

Conceptual models of park ecosystems should be developed, design studies should be initiated for selecting and testing the monitoring protocols, and a program that institutionalizes the monitoring protocols should be established. The following project descriptions define ecosystem components that should be monitored and the kinds of research needed to begin this process. The projects identified in Table 22 are only half of the monitoring work that is recommended. A more comprehensive, integrated program for all three parks would cost about $2.1 million a year.

Marsh Fishes and Macroinvertebrates

A monitoring program based on the results of the 1-year survey and previous data should be developed. This program should promote study of the trophic dynamics of this system. In particular, studies of the feeding habits of prominent species should be undertaken to better elucidate the food web of this ecosystem. This storm underscores the need to develop baseline data on the freshwater ecosystem. One problem confronting us at this time is the annual variation observed in the existing data. More stations are required to better characterize patterns of variation in the fish and macroinvertebrate communities. An expanded monitoring network would track trends in nonnative fish survival, demography, and distribution. Better spatial coverage would assess future perturbations like

Table 22. Long-term monitoring projects for Big Cypress National Preserve, Biscayne National Park, and Everglades National Park, Florida.

Monitoring Projects	Cost Estimates
1. Monitor marsh fishes and macroinvertebrates	$175K
2. Monitor mercury in aquatic community	$ 50K
3. Increase water quality in Ten Thousands Islands	$120K
4. Increase Biscayne water quality monitoring	$150K
5. Monitor Biscayne Bay sediments	$ 20K
6. Monitor sea grass bed water quality	$150K
7. Monitor sea grass bed population dynamics	$125K
8. Monitor hardbottom community population dynamics	$ 80K
9. Monitor mangrove forest dynamics	$150K
10. Monitor coral reef fish population dynamics	$ 60K
11. Monitor sea turtle nesting	$ 46K

this storm by providing long-term records in areas with and without effects. The paucity of long-term records hinders scientists from interpreting the poststorm fish and macroinvertebrate communities.

Mercury in Everglades Aquatic Community

Because mercury contamination is a long-term problem, a long-term monitoring program should include monitoring organisms at several levels in the food web, identified by studies proposed for the first year of this effort. The Hurricane Andrew storm event permits an excellent starting point for this monitoring effort.

West Coast Water Quality Monitoring

The existing water quality monitoring network should be increased in Ten Thousands Islands and be maintained on a routine monitoring basis indefinitely in both parks.

Biscayne Bay Water Quality Monitoring

The existing DERM long-term monitoring program, which is supplemented by Biscayne, provides an adequate water quality monitoring database. Toxicological studies should be completed and acceptable water quality standards met

Biscayne Bay Sediments

The fine flocculent sediments that have accumulated on the seafloor over much of the western portion of Biscayne Bay should be monitored. The sediments are currently soft, unconsolidated, and likely to be resuspended in the water column during any moderate-to-heavy wind conditions, which may lead to increased occurrence and duration of high turbidity in the bay and repeated exposure of benthic organisms to heavy fine sediment loads. Mortality of organisms exposed to such sediment stress may increase over time.

Sea Grass Bed Water Quality

This storm demonstrated the resistance of sea grass beds to erosion. The real concern is not for the direct destruction but for the poststorm loss resulting from prolonged increased turbidity and associated reduced light penetration and reduced oxygen levels. A 2-year monitoring of turbidity (including type of organics, dissolved and particulate organics, mineral concentrations, plankton concentrations), light penetration profiles and bottom oxygen levels should be done in conjunction with monitoring about 15 sea grass beds sites in Biscayne Bay, 10 on the outer shelf, and 10 on the west coast. At the sea grass sites, the sea grass productivity, community structure, and survivability should be monitored, as well as changes in the nature of the substrate surface (if sea grass dies, waves and currents will more easily attack the substrate increasing the turbidity problem). Turbidity should be monthly through two winter storms events; bottom observations should be bimonthly.

Sea Grass Bed Population Dynamics

Because of the sea grass dieoff, several projects (Everglades; University of Virginia; Florida Department of Natural Resources) have been monitoring the sea grasses for several years. These projects include measuring abundance, productivity, and turnover rate of the plants, epiphyte loading on the leaves, and other pertinent measurements. This work should continue indefinitely and is the primary link with the prehurricane conditions.

Hard-bottom Community Population Dynamics

The established sponge, soft coral, and lobster plots should continue to be monitored for future recruitment, survival, and recovery from the losses incurred during Hurricane Andrew.

Mangrove Forest Dynamics

Permanent plots should be established in Biscayne and Everglades national parks to measure growth and recovery of the mangrove forests. A stratified random sampling design should be employed in setting up this permanent plot network. The strata considered for the design should include forest type (e.g., riverine, hammock, dwarf), degree of damage (i.e., the plots should not all go into heavily damaged sites), soil type, etc. Replicate plots (a minimum of three) should be established in each stand to ensure a modicum of statistical veracity for the measurements obtained. Individual trees in each plot should be permanently tagged so that a time series of measurements relating to tree growth, survival, etc., can be collected. Seedlings and saplings in the permanent plots should be measured on a monthly basis for at least 3 years to determine patterns of growth and survival. Measurements of soil chemical parameters should be undertaken at a subset of the permanent plots. Parameters of interest include nutrients (N and P), salinity, pH, and especially to assess the effect of these on the establishment and growth of mangrove seedlings as they recruit into the forest.

Logistic support of west coast field research is essential. The difficulty of working in these habitats is the primary reason that they are so poorly studied. A houseboat and three 5.2-m (17-foot) open fishing boats are essential for adequate support of intensive research in the mangrove forest of Everglades National Park. Initial purchase of this equipment would cost $120,000, and annual operating costs $10,000.

Coral Reef Fish Population Dynamics

Long-term monitoring of reef fish populations at Biscayne National Park should be continued to detect delayed changes associated with future nutrient loading and deteriorated water quality.

Sea Turtle Reproductive Activity

A long-term monitoring program of annual sea turtle nesting success in both Biscayne and Everglades national parks should be maintained. At a minimum, selected nesting beaches should be monitored annually from 15 May to 15 August, to the USFWS and FDNR standards prescribed for index nesting beaches. Due to the variability in nesting activity from year to year, this monitoring effort must be base-funded and long-term (10+ years) before any trends can be observed. In addition, aerial surveys should be funded to determine the distribution of nesting effort and use of the outlying beaches.

Long-term Research Program

Long-term, experimental research is required to determine the potential of Hurricane Andrew altering energy and nutrient flows in the Everglades ecosystem. The possibility of nutrient release from storm-related detritus should be monitored, as well as potential effects of changes in landscape heterogeneity on large animals. Because the Everglades landscape is a mosaic of terrains or drainage basins that traverses several physiographic subregions in South Florida, a variety of approaches should be used to address these questions. Past research and restoration efforts have focused on individual species or habitats, usually within limited spatial or temporal scales. A lack of an integrated understanding of the system response to natural or anthropogenic perturbations, such as Hurricane Andrew, severely restricts ongoing restoration and management possibilities. Several critical hypotheses concerning the ecosystem productivity and resilience must be resolved to produce a scientific basis for restoration and management. Table 23 presents long-term research projects that vary in duration from 3 to more than 15 years.

Table 23. Sample of long-term research projects that vary in duration from 3 to more than 15 years.

Projects	Duration	Cost Estimates
1. Hurricane effects on Everglades food web and material transfer	5 years	$1.4M/year
2. Hurricane effects on fragmented habitats and small, isolated populations	Unknown	$210K
3. Hurricane effects on forest dynamics		
• Canopy replacement dynamics	Annually for 3 years after completion of initial baseline studies; then every 2 years during the next 6 years, and finally every 5 years for the next 15 years.	$44K/year during first year
• Woody debris dynamics	Annually for 3 years after completion of initial baseline studies; then every 2 years during the next 6 years; and then every 5 years during the next 15 years.	$53K during first year; then $38K/year
• Herbaceous subcanopy dynamics	Annually for 3 years after completion of initial baseline studies; then every 2 years during the next 6 years; and then every 5 years during the next 15 years.	$90K during first year; then $59K/year
• Forest recruitment dynamics	Annually for 3 years after completion of initial baseline studies; then every 2 years during the next 6 years; and then every 5 years during the next 15 years.	$50K during first year; then $39K/year
• Rare and endangered plant populations	Annually for 3 years after completion of initial baseline studies.	$30K during first year
4. Hurricane effects on marsh primary production		$60K
5. Model storm effects on marine nutrient budgets		$100K
6. Map and describe west coast sea grass beds		$80K
7. Commercial sponge survey		$60K
8 Hurricane effects on mangrove forests		$50K
9. Hurricane effects on manatees		$150K

Hurricane Andrew Effects on Everglades Food Web

A trophic-network flow analysis should be conducted to quantify networks of material and energy flows among the variable trophic elements of the ecosystem. Because the flow networks may be expressed in units of carbon, nitrogen, or phosphorus, cycling of those elements should also be described on an ecosystem-level and quantified to assess water quality issues and impacts. The effects of Hurricane Andrew on the Everglades provide a special opportunity to study recovery of the system. Monitoring changes following the hurricane should give information on the altered flows of energy and nutrients and rates of their recovery to former levels. In addition, the effects of a sudden potential release of nutrients due to the impact of dead biomass should be monitored, as well as the effects of changes in landscape heterogeneity on large animals. The research will provide a framework in which ecological research will be identified and completed, contributing to predictive and diagnostic models useful to park management.

The following hypotheses should be addressed: (1) primary production is dominated by algal rather than macrophyte communities; production is directly related to hydroperiod, (2) the detrital pathway supplies more carbon to higher trophic levels than the grazing pathway, (3) marsh food webs in which most carbon moves via the detrital *vs.* the grazing pathway support higher standing stocks of fishes and invertebrates, (4) the production of higher consumer populations ultimately depends on secondary consumer production, but their stability also depends strongly on landscape spatial extent and heterogeneity, (5) higher trophic-level consumers will be affected more than the lower trophic levels by changes in landscape spatial extent and heterogeneity, (6) the home range and foraging patterns of large animals will change following a major hurricane due to structural changes (destruction of many trees, etc.) in the habitat; this loss of structural heterogeneity may cause a decrease in animal diversity, and (7) the release of nutrients from dead biomass following a major hurricane will produce a major increase in algal primary productivity and secondary production (fish, other aquatic organisms).

The research should involve a multidisciplinary, multiyear approach between NPS and other scientists through cooperative and interagency agreements, NPS-funded contracts, and outside funding sources (primarily the Corps of Engineers). Empirical field research and modeling domains should include the suite of freshwater wetland types, and major habitats in the downstream estuaries. Process-oriented models should follow a state-variable approach (Swartzman and Kaluzny 1987) using Stella software. Spatially explicit, structured-population and individual-oriented models should follow the principles and mathematical techniques described in Huston et al. (1988) and DeAngelis and Gross (1992). Network analysis methodology and software developed by Ulanowicz (1986) and Key et al. (1989) should be used to produce and analyze the trophic flow network models.

South Florida Forested Ecosystems

Mortality of canopy trees is a major cause of variability in forest community structure. Mortality can be an isolated phenomenon affecting only single individuals, which creates small gaps in the canopy. At the opposite extreme, severe perturbation affecting numerous individuals may occur. These extremes produce different responses in the understory, shrub, subcanopy, and canopy populations.

Death of a single large forest tree can result in recruitment of one or a few saplings or subcanopy individuals into the canopy; or the canopy of existing trees can merely expand to the fill the gap. The primary effect of this is a slight modification of the age structure and species composition of the canopy. Given the time periods over which forests exist, however, this mechanism would produce stands with uneven-age structures. Its species dominance would gradually shift over time depending on how environmental conditions have influenced the recruitment and survival of canopy species before occurrence of the forest canopy gap.

When larger gaps occur as a result of severe perturbations, many of the subcanopy individuals are lost as well. This major loss of trees, and the resulting sunnier and drier site microclimate produces a different community. Recovery of the forest is more a result of seed germination and seedling survival. Those species that dominate in later successional forests, however, are frequently at a competitive disadvantage to earlier successional species in an open, sunny environment. Also, herbaceous vegetation, shrubs, and vines are more prominent components in these more open situations. As a result, a different community will likely dominate these sites for many decades before a mature forest can again become established. Over the long run, these small-to-large modifications in forests ultimately lead to the high diversity of these ecosystems.

Canopy Reestablishment in Major Forest Community Types

The forest canopy effectively determines environmental conditions for most plants and animals existing on a forested site. Thus, recovery of the forest canopy is probably the most critical factor in reestablishing the level of ecosystem organization that existed before the storm. Recovery will be more rapid where the source of the posthurricane canopy is primarily from the expansion of surviving canopy individuals than where its origin is in the former subcanopy. Different community types will also likely differ in their rates of recovery.

The plots established for documenting past and current status of tagged canopy trees in all major forested community types should be used to follow canopy recovery dynamics. These studies should document delayed mortality, changes in damage class and degree, leaf resprouting and growth of surviving trees, and redevelopment of the forest canopy. At prescribed intervals, each tagged tree should be examined, and new trees exceeding the minimum size range should be documented and tagged. Canopy cover should be measured, and the trees contributing to it identified, and if outside the plot, documented and tagged.

Woody Debris Dynamics

An obvious major alteration of South Florida forests following the hurricane was the greatly increased amount of deadwood present in the form of standing snags or fallen logs. These materials have been shown to play a critical role in maintaining the diversity and continuity of Pacific Northwest forests. The interactions of small mammals, invertebrates, fungi, and other organisms are involved in nutrient cycling, wood decomposition, and seedbed microhabitat processes important to the survival of these communities. The role of coarse woody debris in southeastern U.S. forests is essentially unknown, and Hurricane Andrew's passage through South Florida presents a rare opportunity to document the influence of a major infusion of this material. This is especially critical given the relative paucity of ants and termites in most park habitats, especially mangroves.

The plots established for documenting past and current status of tagged canopy trees in all major forested community types should be used to follow the long-term accumulation and loss of coarse woody debris. The information generated on these sites during the initial and long-term studies of the forest canopy will greatly facilitate interpretation of data on changes in the amounts and characteristics of coarse woody debris. The work should primarily involve tagging and quantitatively documenting the condition and location of a representative subset of large boles and branches from trees killed during the hurricane, and repeating these observations during subsequent visits.

Herbaceous Subcanopy Dynamics

Forest canopy characteristics determine amounts of light reaching the forest interior as well as its microclimate, both of which strongly influence composition of the subcanopy, shrub, and understory components of these plant communities. The resulting plant community structure and composition in turn influence animal populations that use this environment. When the forest canopy is disrupted, the other components of the plant and animal community are likewise altered. If the disruption is sufficiently severe, herbaceous components can dominate the plant community for some time by suppressing development of canopy species.

Analyses of components below the canopy should quantify their composition and structure in the canopy plots and how they change over time. A variety of vegetation sampling techniques should adequately evaluate this diverse assemblage of plants.

Forest Recruitment Dynamics

The composition and structure of forested communities is significantly influenced by the recruitment of young individuals into the forest canopy. This recruitment requires the availability of seeds, their successful germination, and their long-term survival. In mature forests, overall canopy composition and structure remain relatively stable for long periods of time, although at any particular location, it may vary considerably.

When a major disturbance dramatically alters composition and structure of a forest, the population of new seedlings present in the forest may also change dramatically due to alterations in a variety of factors, including seed dispersal patterns, ability to germinate and survive under new microclimatic and light conditions, and ability to survive in the face of changing competition from other plants and herbivory by animals that might not have been present before. These changes in the seedling environment can delay recovery of the original mature forest, and may result in the development of a completely different type of forest, particularly if nonnative species are able to invade the site.

Documenting these effects should require establishing seed germination subplots in the forest canopy plots, and periodically assessing seedling survival on sites with several levels of disturbance in each major forest community type. Environmental conditions likely to affect seedling germination and survival should be monitored, since year-to-year variation in water levels, light, temperature could all influence these processes. This work should complement other studies looking at posthurricane development of canopy, subcanopy, shrub, and herbaceous components in describing the rates and mechanisms by which forest communities recover from the impacts of Hurricane Andrew.

Rare and Endangered Plants

Hurricanes may be catastrophic for local populations, which may be all that remains of formerly more widespread taxa. Alternatively, hurricanes may enable small populations to expand to suitable habitat nearby. Assessing the status of federally endangered, threatened, and C1 (category one candidate for listing) plant populations in the storm zone of influence on national park system lands should be done.

This effort would require monitoring growth, flowering, fruiting, and establishing individuals at selected sites identified in the initial reconnaissance of the effects of the hurricane on these species. Frequency of monitoring should be adjusted for each species in order to suit what is known of its phenology.

Archeology

Of all NPS-administered lands nationwide, less than 10% has been adequately examined to identify and evaluate archeological resources; this number is considerably lower for submerged lands. Although archeological surveys have been done in all three parks, the surveys fall within the NPS national statistics. Incomplete baseline information on cultural resources presents serious management problems in situations such as Hurricane Andrew where only known sites can be evaluated. Evaluating current and previous site damage also presents problems. Based on the amount of land remaining to be surveyed in these parks, hundreds of sites remain to be located and evaluated.

Multiyear archeological surveys should be developed and implemented, locating and evaluating the majority of significant cultural resources in Big Cypress, Biscayne (terrestrial and submerged), and Everglades, and the data from the survey should be intergraded into GIS. Table 24 contains the costs over three years exclusive of logistic support such as helicopters, boats.

Monitoring natural and man-made damage to cultural resources affords both short- and long-term protection to these resources, provides baseline data on the progression of destructive events on sites, and provides a basis for developing site protection methods. In cases like Hurricane Andrew, baseline data against which to evaluate and predict site damage to a range of cultural resources would be necessary.

Currently, Big Cypress and Everglades have monitoring programs to evaluate natural and man-made impacts on cultural sites. Biscayne does not currently have such a program.

At Big Cypress and Everglades, current site monitoring programs should be evaluated with respect to the sites that were visited, timing of the visits, data that were collected, and methods that were used to report damage. A monitoring program should be developed and implemented at Biscayne. Associated costs and personnel are in Table 25.

Table 24. Long-term archeological research projects.

Parks	Year 1	Year 2	Year 3	Total
Big Cypress National Preserve	$100,000	$100,000	$50,000	$250,000
Biscayne National Park	$150,000	$150,000	$50,000	$350,000
Everglades National Park	$100,000	$100,000	$50,000	$250,000

Table 25. Long-term cultural site monitoring programs.

Parks	Personnel	Costs	Equipment
Big Cypress National Preserve	1 FTE GS-7	$21,000	GPS Unit $4,000
Biscayne National Park	1 FTE GS-7	$21,000	GPS Unit $4,000
Everglades National Park	1 FTE GS-7	$21,000	GPS Unit $4,000

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Appendixes

Appendix A. Descriptions of Dade County Department of Environmental Resources Management Long-term Monitoring Stations

Station 920918-01
Appx 4m depth; 25 30 33.0 80 08 58.2
100-200 m NW of marker R "8" in Hawk Channel

Thalassia meadow with blowouts. *Halimeda, Pelagiobryssus* are abundant. Blowouts show some scour to at least 30 cm (11.8 inches). Blowouts appear unique from air as they are white with black patches in the centers. The black is dead *Thalassia* leaves. Numerous *Lytechinus* tests are also present, rolling around and unbroken. While some storm erosional effects are evident, they are just an enlargement of existing structures.

Station 920918-02
Appx 4m depth; 25 30 36.6 80 09 0 7.1
100-200 m nw of station -01, further inshore

Sparse to moderate *Thalassia* meadow. *Syringodium, Halimeda, Avrianvillea, and Pelagiobryssus* are present. Similar to previous station, but higher velocity jets of erosion are indicated in the blowouts with deposition of 2-3 cm (0.78-1.2 inches) of sediments on the downstream (westerly) beds. These depositional areas are only several square meters in size. Other depositional areas were definitely vegetated topographical lows that are now filled in with several centimeters of sediment and are even in height with the surrounding bed. All of the sea grass, including that with several additional centimeters of sediment, appears healthy.

Station 920918-03
Shoreline 25 29 05.1 80 10 37.2
Shoreline cove on Elliott Key, just S of Sands Cut

Dense *Thalassia* beds are present when approaching the key from seaward. Hard-bottom communities are prevalent and seem normal. The last 30 m (98.4 feet) to shore is a deeper sediment wedge with patchy *Thalassia*. In this area, fire coral is broken into a few pieces, but delicate algae are fixed and intact. By comparison the forest a few meters landward is flattened. It is difficult to comprehend the difference in destruction versus normalcy just a few meters either side of the high waterline.

Of high interest here is the wrack line. The outermost edge, some 3-5 m (9.8-16.4 feet) in lateral depth at this time is green and floating. This edge represents recently defoliated trees and is not storm-related. The early fall is the time of maximum defoliation of south Florida sea grasses, and this seems normal, with a mixture of *Thalassia* and *Syringodium*. The *Syringodium* leaf wrack typically has one end cut on a diagonal, indicating that it has been bitten off by a parrotfish; a normal occurrence. Shoreward of this zone is a zone, several meters wide, of dense *Thalassia* and *Syringodium* litter and *Thalassia* short shoots. Further shoreward is a zone beginning just below the surface and extending about 3-5 m (9.8-19.6 feet) deep that is rich in *Syringodium* runners and short shoots with leaves. In essence, entire plants are up to 1 m (3.3 feet) long from erosion of the back-reef or midchannel *Syringodium* beds at the peak of the storm. Inshore of this is a layer of *Thalassia* litter and *Rhizophora* propagules that is back in among the mangrove roots, and both *Rhizophora* and *Avicennia* propagules are actively sprouting

Station 90918-04
1-1.5m; 25 31 5.4 80 10 39.3
West end of Lewis Cut

Several sea grass blowouts are on the northern side of the cut, extending from the middle of the cut westward into Biscayne Bay. These show from 1-4 m (3.2-13.1) erosion on the western edge into dense *Thalassia* beds. Some of this material is deposited in patches in the adjacent beds but most has been removed. *Thalassia* roots are in the bedrock, indicating the former extension of the bed. The most unusual feature here was that the sediments seemed to have been shaken and loosened. The surface 1-3 cm (0.39-1.18 inches) of fine sediment was gone, which was not surprising, but the next 30-40 cm (11.8-15.7 inches) of sediment were loose and unconsolidated. In fact, the short shoots were actually leaning westward, similar to the trees on land. Normally sediment in this area would be hard packed, but here you could ram your fist in to the elbow. Although the sea grass appears healthy now, this area definitely should be monitored for long-term damage. This removal of the litter and surficial sediments, and the shaking loose of the deeper sediments, must have released huge amounts of nutrients into the water column.

Just a few meters from the edge of the blowouts, on hard ground, large gorgonians were still intact and are apparently healthy. Some sparse *Syringodium* is present.

Station 920918-05
~1m; 25 30 07.6 80 13 13.3
S side of Featherbed Bank, just E of BW "S"marker

Dense, typical banktop *Thalassia*. Banktop blowouts show some erosion on edges and in the bottom. Some root and work tube are exposure. Some jet scouring, similar to station -04, and some deposition are evident the in adjacent beds. Boat cuts have slight erosion, but calcareous algae is still firmly attached to bottom of cuts. Huge fish schools are present: mangrove snappers, small barracuda, and porgys. Loggerhead sponges are still pumping. Fresh parrotfish bites were seen on the leaves.

Station 920918-06
~1.5m; 25 32 42.6 80 17 59.7
200-300 m off Black Point

Dense *Thalassia* appears all right at this time. Mixture of hard-bottom, *Thalassia*, and *Halodule* patches was seen. Grass is green with numerous hydroid epiphytes. There are some areas where *Thalassia* was formerly extending runners into areas with sparse sediments, and the sediments and short shoots have been eroded leaving only the roots and anchored short shoots. About 100 m (328 feet) shoreward, a white floc was settling over everything, much like marine snow. Dense *Thalassia* litter was present.

Station 920918-07
Shoreline 25 33 48.0 80 18 24.6
Just S of Black Point

Mucky shoreline sediment with *Halodule* was present. Occasional patches of bare bedrock, which may be recent scour from storm. Sediment wedge on shoreline with dense *Halodule* and some *Thalassia*. The wrack line onshore is similar in structure to the one off Elliott Key. Especially noticeable is the presence of fresh, floating material on the seaward edge, and a deeper zone containing sea grass rhizomes 30-60 cm (11.8-23.6 inches) long.

The water here and at the previous station is a dark tea color, and the combination of light attenuation and increased BOD may severely stress some organisms. The *Thalassia* at this station is dying rapidly in a manner similar to sea grass die-off in Florida Bay. The leaves are greenish, and seemingly attached, but if you sweep through them with your hand, they all come out at the base. This needs close study.

Everglades National Park, Florida Bay. Florida Bay has been undergoing dramatic changes in its sea grass beds since 1987, due to the sea grass die-off. This die-off has left much of the bay vulnerable to disturbance due to the decay of the stabilizing rhizome mat. In the past 6-9 months, the die-off has spread rapidly into the western bay, especially in the area around Sandy Key basin. Sediments have been disturbed and suspended, and an area of milky green or brown water has persisted in an area greater than 100 square nautical miles for some time.

Following Hurricane Andrew, the area appears unchanged. University of Virginia graduate students and Everglades technicians resurveyed stations that we have monitored for several years and found them unchanged. From the air and in the water, Florida Bay does not appear to have been directly affected in the short-term.

Longer-term damage may be more extensive. The bay is suffering continued expansion of the sea grass die-off, especially in the west. The turbulence from the storm continued to keep sediment in suspension, and nutrient levels in the water column are increased, due to re-suspension and washout. These nutrient levels will contribute to phytoplankton blooms, with a resultant shading of the sea grasses. This increased shading comes at a time when light levels are declining naturally and may exacerbate the die-off.

Quantitative stations that were sampled are as follows:

1. Duck Key
2. Rabbit Key Basin
3. Johnson Key Basin
4. Sprigger Bank
5. Rankin Lake (not sampled, too turbid)
6. Sunset Cove
7. Tavernier Creek
8. Conch Reef

Western Florida Bay and West Coast. On the west coast, the sea grass beds show only minor modification or damage. The *Halodule* on the shallow muddy sand bottom just adjacent to Highland Beach was generally unaffected. The *Thalassia* beds, seaward of the Broad River to the Lostmans River area, were unaffected except for local sites where north to south current scour cut lineations. In many areas the old blades were still intact, but in some areas the blades had largely been snapped off by the storm, and the observed growth on 20 September was mostly new blade growth.

The following specific observations were made:

Station 920920-01
1-3m; 25 12 32.3 81 09 24.8
200 m S of NW Cape

Sandy beach with steep slope. Shoreline eroded. Wrack line consists mainly of beachgrass with little sea grass. Band of *Halodule* along shoreline looks healthy. Normal epiphytes present. Not obvious scouring or burial.

Station 920920-02
1-3m; 25 13 46.7 81 10 20.7
N of NW Cape; about 300 m from S end of sand beach

Halodule growing in bands and patches. Small *Avrainvillea* and *Udotea* growing in patches. Mullet are everywhere feeding in the offshore *Halodule*. Manatees present also.

Station 920920-03
1-3m; 25 14 45.6 81 10 20.3
In erosional mangrove coast

Heavily eroding mangrove coastline. Steep scarp dropping to hard mud, obviously from mangrove shoreline. Appears to be eroded about 5 m (16.4 feet). Sand thrown back into mangroves but no beach present, no *Halodule*. Water *much* browner and muddier north of Little Sable Creek.

Station 920920-04
~1m; 25 30 24.1 81 12 54.6
Off Highland Point, just S of Lostmans River

Dense lush *Thalassia*. Monospecific with low energy epiphytes, including scuzzy algae and *Spirorbis*. Sediments are dense. Some holes 0.5 - 1 m^2 (5.3 - 10.8 $feet^2$) in size. These could well be manatee grazing scars. No sign of damage in sea grass beds. By contrast, land is devastated. This is a huge bed on a flat lobe of sediment. Its lower end is undoubtedly determined by the relatively high turbidity of the water.

Station 920920-05
1-2m; 25 25 23.0 81 12 01.0
Off Highland Beach, just S of -04

Sea grass primarily *Thalassia*, but with *Halodule* and *Syringodium* present. Epiphytes are calcareous, although some fleshy are present. Water is tea-turbid. This and station -04 are reminiscent of Texas sea grass beds. Seemingly untouched by storm damage.

Appendix B. Locations Where Dade County Department of Environmental Resources Management Monitors Water Quality at Monthly Intervals

Lower Canal (upland sites)

BL03	Black Creek (C-1)	SW 97 AVE & SW 236 ST
GL03	Goulds Canal	SW 94 AVE & SW 248 ST
PR03	Princeton Canal (C-102)	SW 97 AVE & SW 268 ST
MW04	Mowry Canal (C-103)	SW 117 AV & SW 320 ST

Canal/Bayside Sites

BL01	Black Creek (C-1)	Mouth of Black Creek
BL02	Black Creek (C-1) Upper Boat Basin	253216N 0801954W
GL02	Goulds Canal at Drainage Culvert	253206N 0801957W
PR01	Princeton Canal (C-102)	Bayside of Control Structure
MI01	Mowry Canal (C-103)	Bayside of Control Structure

Constituents routinely analyzed in the DERM monitoring program include the following:

(Surface / 1 m / Bottom Profile)—

water temperature	salinity	pH
dissolved oxygen	conductivity	redox

(Surface only)—

total coliform bacteria	color	turbidity
fecal coliform bacteria	chlorophyll a	ammonia-N
total phosphorus	NO_2+NO_3	cadmium
copper	mercury	lead
zinc		

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As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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