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Hurricane Hugo:

South Carolina Forest Land Research and Management Related to the Storm

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HURRICANE HUGO:
SOUTH CAROLINA FOREST LAND RESEARCH AND MANAGEMENT RELATED TO THE STORM

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FOREWORD

Hurricane Hugo was probably one of the most destructive hurricanes to assault the forests of the Eastern United States in recorded history. Four and one-half million acres were damaged in North Carolina and South Carolina, an estimated 21.4 billion board feet of timber were destroyed or damaged, and several federally listed endangered species (red-cockaded woodpecker, bald eagle, and red wolf) were impacted. This toll does not include property damage or human suffering in the United States or the destruction in Puerto Rico. Hurricane Hugo is probably the most studied and best documented hurricane ever to have reached landfall in the mainland. In addition to the reports in this compilation, more reports can be expected as on-going and new studies of forest damage, restoration, and rehabilitation are completed.

We made no attempt to synthesize or summarize the papers in this publication because the topics covered are too diverse. However, we offer the following thoughts about how to lessen impacts of hurricanes on forests.

Hurricanes are a natural, integral part of ecosystem processes in Eastern forests. Hurricanes occur infrequently and unpredictably; therefore, the significance of their impact on the forest tends to be quickly forgotten as the visible evidence of their effects fade from the landscape. The net result is that the next hurricane can be as destructive as the last hurricane. The land manager must remain aware of the risk of windstorms and use known silvicultural techniques to develop a wind-resistant forest. Although nothing can be done to protect forests against maximum catastrophic winds of Category 4 or 5 hurricanes, much of the damage from hurricanes comes from lesser winds, and forests can be managed to be more resistant to such winds.

For example, several of the reports in this compilation, as well as reports published from studies of other hurricanes and windstorms, show that damage within stands from hurricane-force winds occurs predictably. The extent of damage is, for the most part, explained by age, size, and canopy position. Large crown-overstory trees suffer greater damage than trees in the lower canopy; and trees in young, dense stands generally suffer the least damage. These observations suggest that silvicultural intervention could produce stands of trees that are more wind resistant.

Research has shown that trees grown in stands maintained in sufficiently open conditions so that healthy crowns and root systems develop are stronger and more windfirm. This means control of spacing by planting, weeding, or thinning enhances growth of desirable trees. Where forests are managed on short rotations of 30 years or less, there is probably little incentive to invest the necessary dollars to develop windfirm stands, but on public forest and parklands where large trees and old-growth stands are desired, more thought needs to be given to producing wind-resistant forests.

INTRODUCTION

During the months after Hurricane Hugo's landfall in South Carolina on September 22, 1989, hundreds of people became involved in salvage, recovery, and restoration of our forests. We turned to the lessons learned from previous hurricanes for guidance in our efforts. Unfortunately, published information on salvage, recovery, and restoration was limited, scattered, or difficult to obtain. We attempted to fill that information void by documenting our work in the aftermath of Hurricane Hugo in one book. We hope this publication will help those faced with similar challenges presented by future hurricanes. Much of the work reported here was done with special funding provided by the United States Congress.

This compilation includes 69 published and previously unpublished articles relating to the effects of Hurricane Hugo, a Category 4 storm, on forests primarily in South Carolina. The articles record the response of the forests to the storm and the activities of those who cared for these forests. Broad topics include historical background, damage assessment, forest restoration, and evaluation of recovery programs.

Seven years have passed since the storm. Some papers report findings from field work done immediately after the storm; others are based on later activities and effects. This book contains 1-page abstracts, comprehensive final reports, papers presented at professional meetings, journal articles, interim reports of work in progress, and other types of articles. Readers will find indepth reports of scientific studies, discussions of management strategies, and suggestions for better problem resolution in similar catastrophes. The papers are organized according to dominant subject matter. Valuable suggestions for improving response activities often appear as a small part of many of the articles.

The editors have attempted to capture all currently available information on forest research and management related to Hurricane Hugo in South Carolina. However, some articles were impractical to include, many of them have been referenced by authors or have been listed in the "Additional Reports" section. In spite of our best efforts, we have probably excluded valuable information that we were unaware of at the time of printing.

The editors did not verify the data presented in each article. No attempt was made to condense articles or remove repetition between articles. We have standardized the format for ease of reading and made minor editorial corrections in the text. Papers were not proofread by each author after final word processing. Therefore, the editors are responsible for such errors.

HISTORICAL BACKGROUND

HISTORY OF DAMAGING STORMS AFFECTING SOUTH CAROLINA FORESTS INCLUDING A REVIEW OF HURRICANE HUGO'S IMPACT ON SOUTH CAROLINA FORESTS[1]

John C. Purvis[2]

INTRODUCTION

South Carolina forests are vulnerable to several types of storm damage ranging from thunderstorms, tornadoes, winter ice storms, and hurricanes. While some damage occurs each year, occasionally a major event such as the 1967 ice storm, the 1984 tornadoes, or a major hurricane such as Hugo causes major damage to South Carolina forests. The purpose of this study is to look briefly at each of these weather hazards, using Hurricane Hugo as an example of the horrible impact damaging storms can exact on the forest industry of the state.

PART ONE: HISTORY OF DAMAGING STORMS AFFECTING SOUTH CAROLINA FORESTS

A. Thunderstorms are so frequent in South Carolina that their effect on the forest industry is usually accepted without undue concern. Damaging thunderstorms are more likely during the warmer part of the year, but they do occur throughout the year in every part of the state. Thunderstorm frequency varies from almost 60 days per year in southern South Carolina to a minimum of about 45 days per year in the extreme northwestern part of the state. Thunderstorm damage to forests usually ranges from a few trees killed by lightning to occasionally scattered areas of localized wind damage.

B. Freezing rain occurs almost every year in some part of the state. Fortunately, many occurrences are not severe enough to cause extensive damage to forests. There are times, however, when an intense winter storm, accompanied by strong winds and large ice accumulations, causes major damage to the forestry industry. The most severe damage in recent years was in February 1969 when an ice storm caused major damage to South Carolina forests from Sumter County northeast through Chesterfield County. Timber losses were tremendous and power and telephone service were seriously disrupted over a large area.

C. Tornadoes are a definite hazard to forests in southeastern U.S. including South Carolina. On a local scale, it is the most destructive of all atmospheric phenomena. According to the American Meteorological Society (1959), the tornado is "a violently rotating column of air, pendant from a cumulonimbus cloud, and nearly always observable as a funnel cloud or tuba". During the last 40 years, there has been on the average 10 tornadoes per year within the state (Purvis, 1990). While many tornadoes affect only a small area, a few tornadoes travel many miles and produce significant damage to forests. A severe tornado has the power to cut a 1/2- to 1-mile wide swath over a path of many miles. Trees are broken and twisted by the violent winds, greatly reducing their salvage value. Several years ago, a tornado moved across Lancaster, Chesterfield and Marlboro Counties. Near Jefferson, S. C., the tornado passed through an original stand of timber. The owner had many times been approached by loggers to sell the tract because of its value. But after the storm, the large original pines were so broken up that no one wanted them. Another example of a tornado causing major tree damage was on April 30, 1924. On that date, a violent tornado was first reported 11 miles

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[1] A paper presented at the 72nd Annual Meeting of the Appalachian Society of American Foresters held at Greenville, S.C., on January 20-22, 1993.

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northeast of Aiken. The storm moved rapidly northeastward to Darlington County causing major forest damage over a 105-mile path that was estimated at times to be more than 1/2-mile wide. The tornadoes of March 28, 1984 were also particularly devastating to South Carolina forests. There were eleven tornadoes on that date over an area that stretched from Anderson County to Horry County. Although there was damage along the entire route, forests in Kershaw and Chesterfield Counties were hit hard.

D. Hurricanes are an annual threat to South Carolina woodlands. There are on the average one or more hurricanes affecting southeast U.S. every three years. During any one year, there is an 18% chance of a hurricane penetrating the South Carolina coastline. There have been a few years such as 1959 when two or more hurricanes caused significant loss to South Carolina forests (Purvis and others, 1990).

Some hurricanes other than Hugo that have produced major damage to South Carolina forests in recent years were Hazel in 1954, Gracie in 1959, and David in 1979.

In order to appreciate the damage to forests that a hurricane can produce, it is important to understand the physical dimensions of this type of storm. A hurricane is a tropical cyclone that forms over the very warm waters of the world and moves with the prevailing winds within its immediate environment. The hurricane derives energy from the latent heat released by condensation of water vapor and, when fully developed in the Northern Hemisphere, consists of a giant counter-clockwise swirl of strong winds accompanied by clouds and heavy rains. The center of the hurricane, called the "eye", is a relatively calm area with little or no cloudiness and may vary in size from 5 to 10 miles in diameter to more than 30 miles. Immediately surrounding the eye are towering wall clouds, extremely heavy rains and high winds. Farther away from the center, the most intense rainfall and winds tend to be concentrated in giant spiral bands radiating in a counter-clockwise fashion from the wall clouds.

E. Wind Direction and Speed.--A hurricane is most fully developed while it is over the ocean but weakens as it moves over land. Forests directly in the path of the eye of a hurricane approaching the South Carolina coast from a southeast direction, would first experience increasing wind speeds, blowing from right to left. After the eye passes, the wind direction would reverse with the wind speed as high or higher than it was immediately ahead of the eye. The most extensive and widespread damage is usually on the right hand side of an advancing hurricane. Forests located to the right of the center would not experience a complete reversal in wind direction. The highest winds would be from the same general direction that the storm is moving. In other words, if the hurricane were headed in a northwesterly direction, the highest winds on the right hand side of the eye would likely be from an east to southeast direction.

Forests to the left of the center should receive their highest wind speeds from the general direction to which the storm is headed. For example, if the hurricane were headed in a northerly direction, the highest wind speeds would likely be from a northerly direction.

It should be emphasized, however, that outside the wall cloud area, the wind speeds are higher and cover a larger area to the right of the advancing hurricane eye than to the left. Also, as the storm moves inland and begins to weaken, the most intense activity is concentrated in spiral bands that rotate around the center in a counter-clockwise fashion. This will produce localized areas of heavier damage within a widespread area of lesser damage.

F. Hurricane Produced Storm Surge. --A hurricane moving over the ocean produces a higher water level that reaches a maximum to the right of the storm's center. This rapid rise in ocean level, or "storm surge", increases in height with the intensity of the hurricane. It is also important to note that the storm surge is added to the existing height of the ocean at the time of the arrival of the storm. Hence, if the hurricane were to arrive at the coast at time of high tide, the actual water level at the coast would be the height of the high tide plus the height of the storm surge. This sudden increase in the height of the ocean floods coastal areas that otherwise would never be flooded. Fortunately, a major hurricane does not penetrate the South Carolina coastline very often; but when it does, salt water penetration is a threat to forests in the immediate vicinity of the ocean.

PART TWO: HURRICANE HUGO AS AN EXAMPLE OF MAJOR DAMAGE TO SOUTH CAROLINA FORESTS BY HURRICANES

Hurricane Hugo made landfall on the South Carolina Coast late on September 21, 1989 causing major damage to South Carolina forests. Hugo began as a cluster of thunderstorms moving off the west coast of Africa on September 9. As this system became better organized and surface pressures began to fall on September 10, a tropical depression, centered 125 miles southeast of the Cape Verde Islands, formed. This tropical depression became a tropical storm, named Hugo, on September 11 and by late on September 13 had gained sufficient strength to be classified a hurricane. Hugo continued to move westward but gradually turned to a west-northwest course during the next several days. Hugo struck Guadeloupe on September 17 as a Category 4 hurricane passed across St. Croix of the Virgin Islands on September 18. The storm now moving on a northwesterly heading brushed Puerto Rico and continued to move in the general direction of the South Carolina Coast.

A hurricane watch was issued for the South Carolina coast at 7 a.m., September 21, 1989. The weather began to worsen along the central South Carolina coast during the late afternoon of September 21 as the forward speed of the storm increased to 25 mph. Just before landfall, a reconnaissance measurement of 27.58 inches and winds of 161 mph at an altitude of 12,000 feet were recorded --the basis of the estimate of the highest one-minute wind speed of 138 mph at landfall.

The eye of Hugo, measuring 20 miles in diameter, made landfall near Sullivan's Island, S.C. at midnight E.D.T. of September 21. The weather office in downtown Charleston measured a maximum sustained wind speed of 87 mph with a peak gust of 108 mph. The highest winds, category 4, associated with Hugo were located in the Bulls Bay area of northeastern Charleston County. There the winds in combination with the local high tide, caused a highest water level of 20.2 feet National Geodetic Vertical Datum, just south of McClellanville.

As Hugo moved inland over Lakes Moultrie and Marion, it began a gradual turn towards the north-northwest. The center of the storm passed between Shaw Air Force Base in Sumter County and Eastover in Richland County, causing 109 mph gusts at Shaw and a small tornado west of the base. The dissipating hurricane then moved northward over Camden with gusts estimated at over 100 mph. The disorganized eye of Hugo continued northwestward over Lancaster and York counties reaching central and western North Carolina by daylight of September 22, 1989.

Hugo weakened as it moved across South Carolina; however, winds near the center were still of hurricane force along its entire path across the Palmetto State. Damaging winds with localized areas of more severe damage extended out from the hurricane's path as far east as Horry, Marlboro, and Chesterfield Counties. Damaging winds west of the disorganized eye's path covered a much smaller area with only minor forest damage reported west of southern Charleston County, Lexington County, and York County.

The types of wind damage to forests varied, depending mostly on the location and direction of the forests from the path of the storm's center. Near the dissipating eye, and at times in spiral bands extending out from the eye, trees fell in various directions. However, generally on the eastern and western sides of the hurricanes path, the direction that the trees fell reflected the counterclockwise rotation of the wind around the center of the hurricane.

Aerial and ground surveys conducted by the South Carolina Forestry Commission (R. M. Sheffield and M. T. Thompson, June 1992) identified 23 counties with substantial forest damage. There were, however, additional counties with lesser damage. The damage to South Carolina forests from Hugo, according to a study prepared for the Governor's Office (The Fontaine Company, 1991), was $1,181,000 dollars. The report also stated that the estimated value of salvaged timber was only 150,000 dollars. There are approximately 6.5 million acres of timberland in the 23 counties inventoried by the Forestry Commission. Sheffield and Thompson state that two thirds, or 4.5 million acres, of the forests within these 23 counties sustained damage from Hugo. Also, about 37 percent of all timberland within the state suffered some storm damage.

Timberland damage was most widespread near the coast and on the northeast side of the hurricane's eye as it moved northwest from its entry along the central South Carolina coast. In six counties (Berkeley, Clarendon, Florence, Lee, Sumter, and Williamsburg), more than 90 percent of timberland was damaged. This severe damage was near and to the east of the path of Hugo's eye.

Lowland hardwood stands sustained the highest incidence of damage. Lowland hardwood stands often contain large, shallow-rooted trees with large crowns, factors associated with increased susceptibility to wind damage (Barry and others, 1982; Hook and others, 1991). Of the hardwood varieties considered, red oak fared the worst and red maple the best (Sheffield and Thompson, June 1992).

Declines in softwood inventory due to Hugo were recorded in all 23 counties inventoried, but declines were greatest in counties near the coast and along the path of the hurricane's eye. Of the softwood varieties considered, loblolly pines sustained the heaviest damage, while shortleaf pines suffered the least. The greatest losses were recorded in the larger diameter classes. Within the forest, wind speeds are much higher above the crown level than near the ground. The larger and taller trees are, therefore, subject to higher wind speeds than shorter ones nearby.

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IMPACT OF HURRICANES ON FORESTS OF THE ATLANTIC AND GULF COASTS

William H. Conner[1]

Abstract--Coastal forests have developed along the Atlantic and Gulf coasts with hurricanes as aperiodic natural events. Hurricanes are not unusual or rare, but they are very difficult to predict. As a result, it is almost impossible to plan hurricane-related research activities. For past hurricane events, available literature has focused on the short-term effects of these storms. Only now are scientists beginning to recognize the importance of natural catastrophes as critical to ecosystem dynamics. Hurricane Hugo made landfall in South Carolina on September 21-22, 1989. As a result of the damage suffered during this storm, an emphasis has been placed on long-term monitoring of the recovery of damaged ecosystems.

INTRODUCTION

Hurricanes are common, but unpredictable, occurrences on the Atlantic and Gulf coasts of the southeastern United States. There is evidence that indicates 160,000 to 320,000 hurricanes have occurred in the area of the Florida keys during the past two million years (Ball and others 1967). They occur about once every 20 years in south Florida (Lugo and others 1976) and are even more common on the Gulf coast (Conner and others 1989). South Carolina experienced 38 hurricanes between 1700 and 1983, or approximately one every seven years (Dukes 1984). Paths have been plotted for several time periods. Figure 1 shows hurricanes plotted for the years 1886-1963. As can be seen in the figure, the Gulf coast has been hit by more hurricanes than the Atlantic coast.

High winds are usually associated with hurricanes, but other forces include tidal storm surge and torrential rains. These latter forces are often more destructive than wind alone (Baker 1978). Hurricane winds cause defoliation, breakage, and windthrow in forests with the severity of damage related to storm intensity, forest structure, and soil conditions (Weaver 1989). The storm surge (also called storm tide, hurricane tide, or tidal wave) is a mound of water pushed ashore by the hurricane. In coastal locations, the combined flooding and pounding by waves can cause great damage (Baker 1978). Heavy rains associated with hurricanes can be both destructive and beneficial. Much damage has been caused in areas where large amounts of rain have caused flooding of tributaries and major streams. In contrast, crops in the southeastern United States have been saved from drought more than once by hurricane rains (Simpson and Riehl 1981). Tropical cyclone-related rainfall contributes about 15% to mean seasonal precipitation in the Gulf of Mexico region, and up to 30% or more in some areas (Cry 1967, Meeder 1987).

Despite the interest that hurricanes generate immediately following their destructive landfall, very little is actually known about their long-term impacts on forested ecosystems, mainly because of the difficulty in planning hurricane-related research (Lugo and others 1983). It is difficult to study an area in anticipation of a hurricane since it cannot be predicted where or when one will occur. After a hurricane occurs, it takes time to design a study and get money allocated for that study. It is often easier to study something else and hope that someone else will

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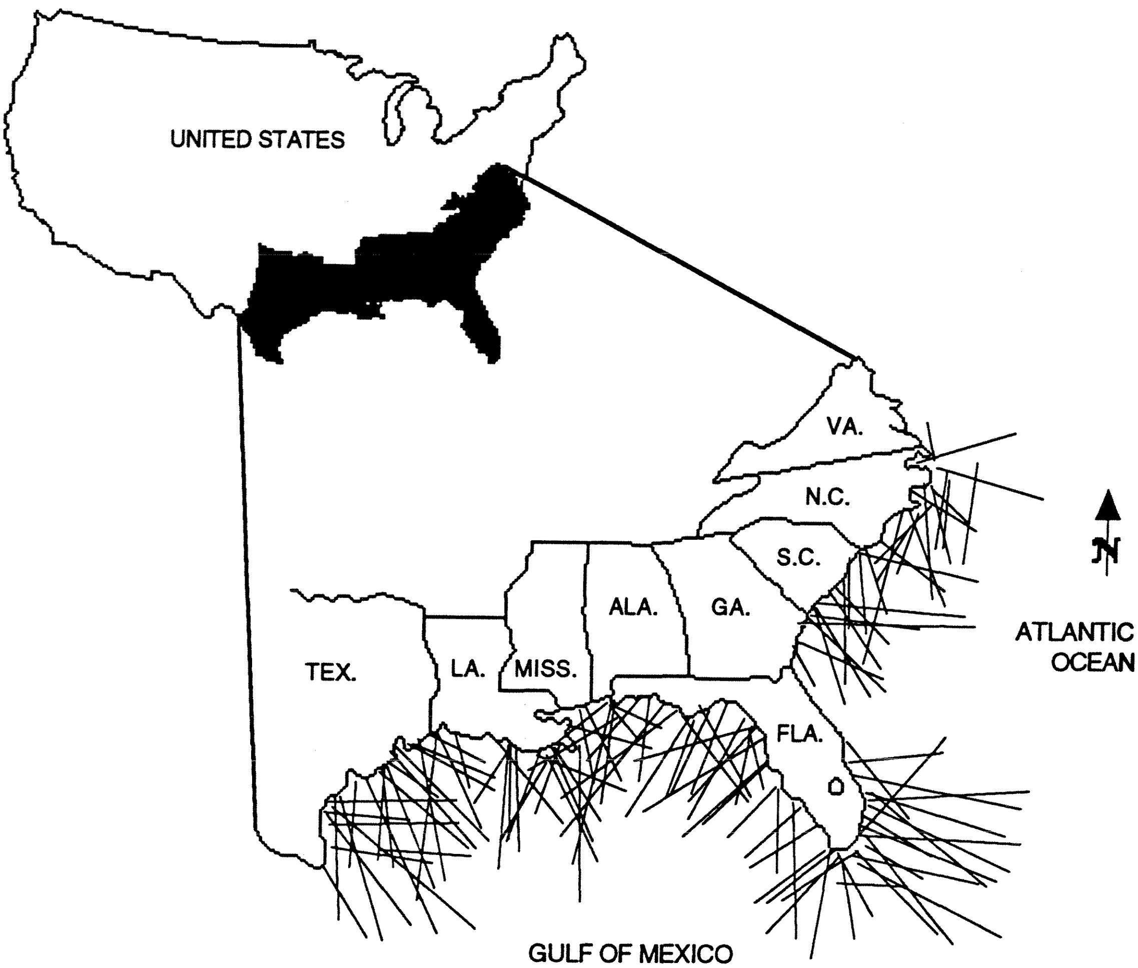

Figure 1--Hurricanes crossing the Atlantic and Gulf coasts, 1886-1963 (modified from Baker 1978).

follow up on the questions that have been raised. In this paper, I will attempt to synthesize what we know about the impacts of hurricanes on forests of the southeastern United States. Special emphasis will be placed on Hurricane Hugo as it may provide the best opportunity for long-term ecological research in the coming years.

IMPACT TO FORESTS

Mangrove Forests

Even though mangrove forests (see Table 1 for a listing of common and scientific names of tree species referred to in the text) represent a small portion of the total forested area of the southeastern United States, there is probably more information on impacts of hurricanes for this forest type than any other.

Table 1--Scientific and common name of tree species referred to in the text.

Scientific name	Common name
Avicennia germinans L.	Black mangrove
Laguncularia racemosa (L.) Gaertn. f.	White mangrove
Rhizophora mangle L.	Red mangrove
Taxodium distichum (L.) Rich.	Baldcypress
Taxodium distichum var. *nutans* (Ait.) Sweet	Pondcypress
Nyssa aquatica L.	Water tupelo
Nyssa sylvatica var. *biflora* (Walt.) Sarg.	Swamp blackgum
Pinus elliottii Engelm.	Slash pine

Various hurricanes have caused up to 90% mortality of mangroves in south Florida, and there seem to be differences in susceptibility between individual species of mangrove occupying the same general area (see Lugo and Snedaker 1974). Observations by Craighead and Gilbert (1962) suggest that hurricanes may, to some extent, control species composition within relatively large mangrove-dominated areas. Mangroves in the Gulf coastal area reach maturity in 20-25 years, coinciding with the mean frequency for major hurricanes in south Florida (Lugo and Snedaker 1974). Thus, hurricanes keep mangrove forests in a juvenile successional state, and net production over the long term is higher (Lugo and others 1976). Maximum biomass, on the other hand, is limited by hurricanes, as exemplified by mangrove areas of Florida, Puerto Rico, and Mexico where biomass may be only one-half of that reported for Panama (Lugo and Snedaker 1974, Flores-Verdugo and others 1987).

Another impact of hurricanes in the Everglades region of Florida is the construction of debris dams. High winds and waves literally roll up portions of mangrove swamps into long windrows of trees, grasses, aquatic plants and algae. These newly-formed ridges, with the added silt and peat, can impound large areas of freshwater dumped on the Everglades by the hurricanes, helping to prevent saltwater intrusion (Vogel 1980). At the same time, favorable conditions are created for mangrove reestablishment of newly exposed flats following hurricanes (Harlem 1979).

Freshwater Forested Wetlands

The ecological impacts of hurricanes on freshwater forested wetlands and upland coastal species are not well documented. The most often reported statistics include area affected, severity and type of damage, number of trees damaged, growing stock volume lost, and economic value of the timber lost. It has been shown repeatedly that coastal economies recover quickly following a major hurricane (Janiskee 1990), but little information exists on the recovery of forest ecosystems (Conner and others 1989).

Damage to forest types generally increases in the order pine > hardwood > swamp (Touliatos and Roth 1971). However, there are exceptions as in Hurricane Camille (1969) in Mississippi, where Hedlund (1969) reported that both pine and hardwood were equally vulnerable. During Hurricane Donna, slash pine was one of the most resistant species in Florida (Craighead and Gilbert 1962). A positive correlation between annual growth of slash pine on barrier islands along the Mississippi coast and hurricanes has even been reported (Stoneburner 1978). In addition, Stoneburner found that hurricane-induced washover deposits stimulated germination of pine seedlings by reducing the competitive shrub understory and exposing the mineral soil surface. Vogel (1980) hypothesized that hurricanes have replaced fire as a dominant perturbation that creates proper conditions for slash pine establishment.

In swamp forests (dominated by baldcypress, pondcypress, water tupelo, and swamp blackgum), hurricanes are capable of defoliating, topping, and overturning trees, but it is the defective and hollow trees that usually break, and windthrow of these wetland species is generally rare (Craighead and Gilbert 1962, Duever and others 1984, Hook and others 1991). Windthrow of bottomland species is more common and may be related to shallow rooting in moist, soft soil (Gunter and Eleuteris 1973, Hedlund 1969). In south Florida, new leaf growth was unusually rapid for several species of trees and many species flowered a second time immediately following Hurricane Donna (1960; Vogel 1980).

One aspect of hurricane-induced rains that has generally been overlooked is the role that hurricanes have in inducing high export of organic matter. Day and others (1977) reported that Hurricane Carmen (1974) caused litter fall to occur two months early in swamp forests of the Barataria Basin, Louisiana, and that a large pulse of carbon, nitrogen, and phosphorus was flushed from the area to the Barataria estuary following the storm. The material exported after the storm represented 20-30% of the total export for the year and the authors suggested that this input was important in stimulating the productivity of the Barataria estuary.

HURRICANE HUGO

Hurricane Hugo made landfall on the night of September 21-22, 1989, with the eye of the storm passing just north of Charleston, South Carolina.

Estimated maximum sustained winds were $54\ ms^{-1}$ at Charleston and destructive winds continued to do damage 325 km inland (Janiskee 1990). Although wind damage was widespread, a storm surge averaging approximately 3 m above sea level also caused major damage. Overall, Hugo was the costliest hurricane in history with nearly $7 billion in damage on the United States mainland alone (Case and Mayfield 1990).

The center of the hurricane followed a path as shown in Figure 2, causing damage to 1.8 million ha of forest (Hook and others 1991). This represents more area than that of Hurricane Camille (1969), Mount St. Helens (1980), and the 1988 Yellowstone fires combined. A nine-county area experienced a loss of 70-90% of its older, taller timber (Janiskee 1990). The most extreme forest damage occurred within the area impacted by the eyewall (area of very strong winds surrounding the eye of the hurricane), and pine and hardwood species exhibited little differences in their resistance to wind damage (Hook and others 1991). Outside of the eyewall, there was generally less damage to the bottomland and swamp species than to pines (Hook and others 1991, Sharitz and Putz 1990), although in some areas oaks were damaged heavily. The major short-term effect to bottomland and swamp species was the loss of foliage and small branches. Sharitz and Putz (1990) also reported that trees that had previously suffered wind damage were more susceptible to new damage.

In one way, the point of landfall and subsequent damage will be very beneficial to the scientific world. Directly in the path of the storm was the Francis Marion National Forest and the Santee Experimental Forest (Figure 3)

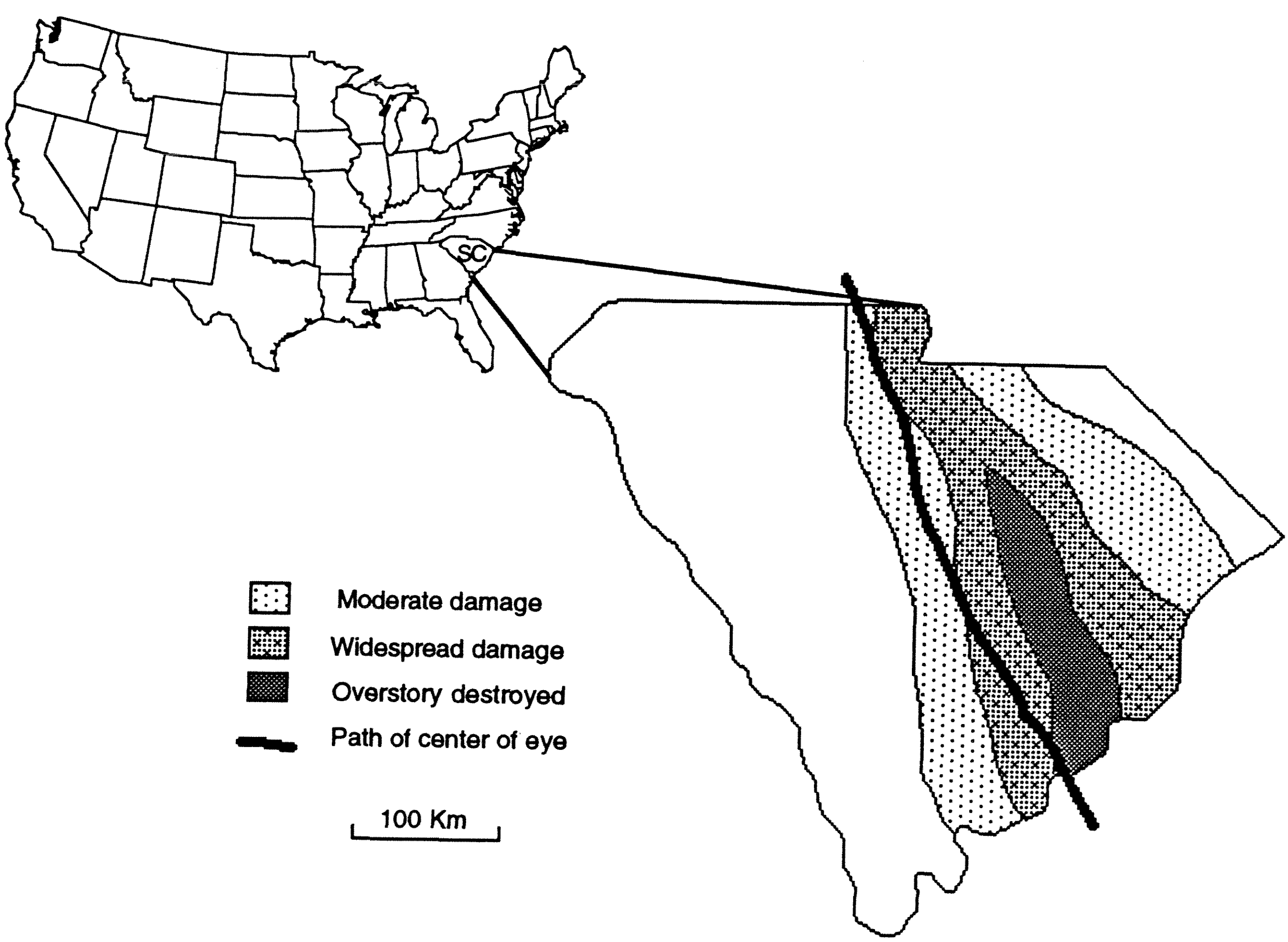

Figure 2--Map of South Carolina showing the path of Hurricane Hugo and the area of damage.

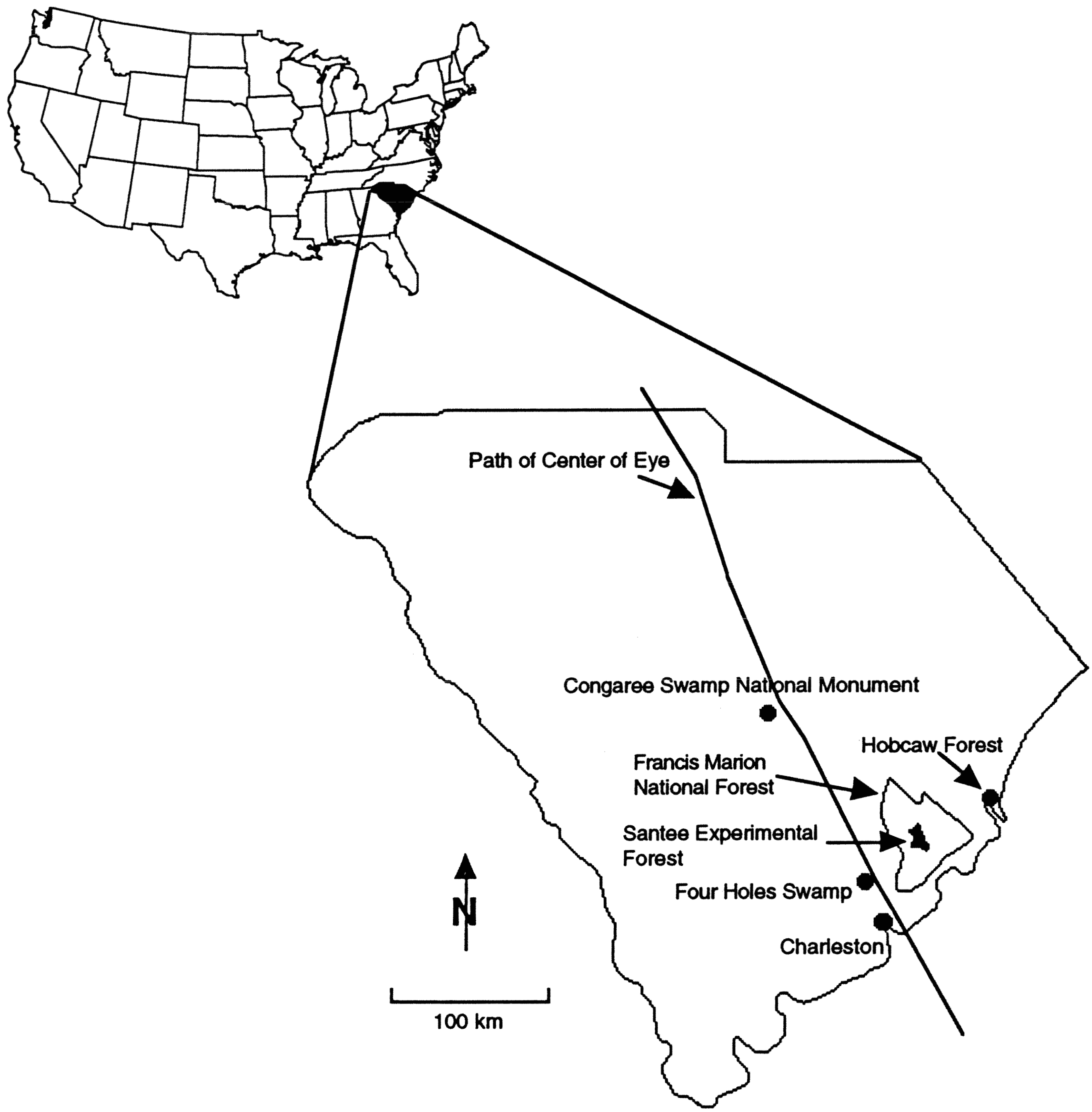

Figure 3--Map of South Carolina showing the location of areas discussed in text in relation to the path of Hurricane Hugo.

where forest management/resource studies have been underway for over 50 years. Since the storm, the U.S. Department of Agriculture Forest Service has implemented a program of research to learn about the storm's effects on the forest and to develop appropriate means to restore this ecosystem. Projects include:

- recovery of wetland functions in watersheds,
- ecophysiological and hydrologic studies of wetland forests and forest tree species impacted by tidal surge,
- mitigation of salvage logging effects on wetland soils and wetland site productivity,

- characterization of storm stress effects on trees and subsequent attack by insects and disease,
- recovery of wildlife populations, and
- wetland hardwood ecophysiology, restoration ecology, and silviculture.

Hobcaw Forest, just 90 km northeast of Charleston, South Carolina, is another area of active research since the 1960's. Post-Hugo research efforts by Clemson University faculty are focusing on the recovery of wetland forests after inundation by storm surge. Studies include seedling and watershed response to saltwater, natural and artificial regeneration of impacted areas, productivity and nutrient cycling studies, soil and hydrologic changes, and modeling efforts. Other efforts in the state include long-term study plots in the Congaree National Swamp Monument (Rebecca Sharitz, Savannah River Ecology Laboratory, Aiken, South Carolina, pers. comm.) and Four Holes Swamp (Norman Brunswig, National Audubon Society, Harleyville, South Carolina, pers. comm.).

CONCLUSIONS

Hurricanes occur frequently and are thus a recurring aspect of coastal forest development, but their impacts have not been studied extensively. Only now are scientists beginning to recognize the importance of natural catastrophes as critical to the dynamics of ecosystems (Boucher 1990). When considered in the broader context of the functioning of coastal ecosystems, hurricanes could be considered a periodic disordering stress which causes alteration of the biological and physical structure, elimination of some habitats and creation of others, and high material fluxes (Conner and others 1989). Since coastal forests have developed in areas prone to hurricanes, it is likely that these forests have developed mechanisms to reestablish themselves rapidly following disturbance, as has been suggested for rain forests (Boucher 1990). Research efforts initiated after Hurricane Hugo will help provide a better understanding of how coastal forests respond to and recover from large scale disturbance.

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IMPACT AND RECOVERY OF GULF COASTAL FORESTS FROM HURRICANE CAMILLE[1]

William Colvin[2]

[Hurricane Camille] was a killer. She rammed onshore in the Bay St. Louis/ Pass Christian Area with winds in excess of 200 miles an hour. And she was pushing a 30-foot wall of water that wiped away hundreds of beautiful old beachfront homes and thriving businesses for a full two blocks back from the beach north of Highway 90. Before she lost hurricane force wind status, she would leave light to heavy damage across 15 of the state's 82 counties (Figure 1).

Amazingly, the great majority of our coastal highway live oaks "stood tall" through those fierce winds. They were stripped of all their leaves--many of them were debarked over a high percentage of their trunks--objects of all kinds were entangled in their branches or stuck into their main bole.

In the ten days immediately after Camille hit, we (Mississippi Forestry Commission) had as many as 35 forestry crews performing vital clearing work along the coast, all the way from the Louisiana line to Biloxi. Well over 400 man days were used. I well remember that the work became extremely dangerous at times, especially in areas with downed power lines criss-crossing the woods. People were hooking portable generators into their house wiring and electricity was bleeding back into the main cross-country lines. It's a miracle that some of our people working to clear those lines weren't electrocuted!

Camille spawned a dozen or more tornadoes as she traveled inland. I particularly remember seeing several quarter-mile-wide paths crossing I-59 in Pearl River County. One funnel wiped out a tung nut orchard. In fact, the winds of Camille destroyed practically all of south Mississippi's tung orchards. But I visited the same area just two weeks ago to get a few "after" slides, and came upon Tung Ridge Ranch. A man from New York has begun an effort to re-start the tung oil business in Mississippi. They are planting several hundred acres back to tung trees and hope to bring that industry back to life--at not more than about 25 percent of its pre-Camille size. Keeping production at a reduced level will help hold prices at a level that will make the business profitable in today's world of synthetic paint additives, say those entrepreneurs. They are currently paying two dollars per bushel for tung nuts collected by local people from remnant trees left along hedgerows and protected places after Camille.

Before we leave Hancock Tower [in Hancock County], here's one more before/after sequence. This first shot was taken looking due west from the tower over the top of the quonset hut. As far as you could see, there were trees on the ground. I have no sure answer to why those trees you see standing were left by the wind. We looked closely at the base of some of these trees trying to figure it out. Apparently, trees on deep, sandy soils send their roots deeper for moisture and were anchored better--just a theory--who knows? It was interesting to see a thing we nicknamed the "zippo effect" at the base of many of these residual trees. You could stick a zippo lighter (the wide way) down below ground level next to these trees--apparently this "wallowing out" around the base of the tree was caused by the winds fiercely whipping the trees in all directions. I'm sure you could find the same thing here in the Hugo area. Did this tear the root system apart? Apparently not to the extent

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[1]Editor's Note: This article is a synopsis of the author's slide presentation at the 72nd Annual Meeting of the Appalachian Society of American Foresters held at Greenville, SC, January 20-22, 1993.
[2]William Colvin, Mississippi Forestry Commission, Jackson, MS.

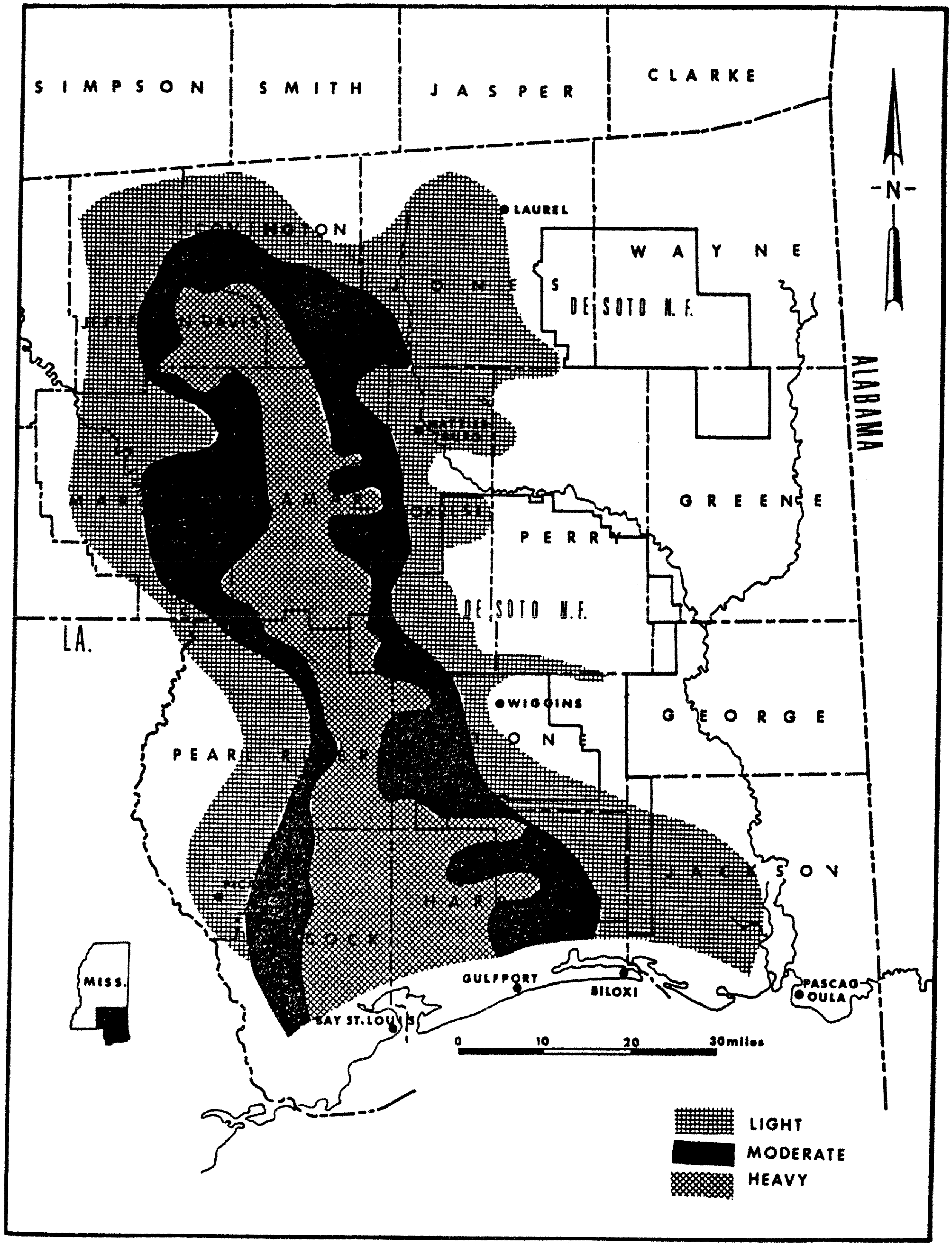

Figure 1--The extent of Hurricane Camille.

that it couldn't develop replacement roots to maintain the balance between the crown and the roots. Remember, these trees also lost some crown to the winds.

I should note here that many landowners were so discouraged by the timber destruction wrought by Camille that they waited a long time to replant. Many didn't replant, choosing instead to let the ravaged area revert to woods pasture or to sell their property to real estate speculators.

[Figure 2 illustrates the] extent of the overall timber losses we suffered from Camille. In 1967, we had about a billion cubic feet of pine growing stock in the nine counties hit hardest by Camille and about 435 million cubic feet of hardwood. Ten years later the forest survey shows we had only 868 million cubic feet of pine and apparently our hardwood component had jumped to about 612 million--talk about a hardwood problem! Another decade later, we see pine growing stock making a comeback and hardwood dropping back somewhat. The 1987 survey (combining the figures for nine counties) shows that we are back above our pre-Camille stocking of pine growing stock with hardwood growing stock continuing to increase.

GROWING STOCK
Nine Hurricane Camille Damaged Counties

Survey Year	Pine (million cu. ft.)	Hardwood (million cu. ft.)
1967	999.3(70%)	434.8(30%)
1977	868.3(59%)	612.3(41%)
1987	1,044.7(62%)	631.0(38%)

Figure 2--Forest growing stock in Hurricane Camille damaged counties.

I've watched that area be healed by time and by landowners with vision who picked themselves up after the hurricane (some sooner than others) and did what it took to get their timberland back into production. As I drove through the lower half of those nine hardest hit counties a couple of weeks ago, I searched hard for a scene that would show clear signs of Hurricane Camille's savagery in 1969. I honestly could find none. All those 1969 vintage trees that had been bowed severely, snapped or twisted off, had long since either been salvaged, straightened back up on their own, or been harvested. As far as the Gulf Coast forest is concerned, I think it is fully recovered.

East of these nine Camille-scarred counties, where slightly less damaging Hurricane Frederic visited us in 1979, you can still find a few areas (particularly in the hardwood types) that show the effects of that storm. I fully expect that by the turn of the century, you won't be able to see any appreciable signs of Frederic's meanness either.

[Figure 3] shows the timber harvesting that has taken place in the nine-county area I've been discussing. I've included 1968 as a base year. The Camille effect shows up first, of course, in 1969 calendar year harvest records. It stays up around an average of 185 million board feet of sawtimber until five years after Camille, then drops back to the pre-Camille level and below in 1988 and 1990. I think maybe a lot of "alive, but at-risk" sawtimber was being cut from 1970 to 1974. This would have raised our salvage figures somewhat, but we stopped keeping track of salvage after August 1970, so we don't know for sure just how much. I suspect that the closing of several sawmill operations in the Gulf Coast area in recent years is being reflected in those 1988 and 1990 figures.

TIMBER HARVEST 1968-1990
Nine Hurricane Camille Damaged Counties

Year	Sawlogs (mm bd. ft.)	Pulpwood (cords)
year	(mm bd. ft.)	Pulpwood
1968	140.7	454,921
1969	191.8	738,976
1970	185.8	893,597
****	*****	***
1974	142.0	459,697
1978	144.5	479,990
1988	136.2	732,370
1990	125.0	891,640

Figure 3--Timber harvest in Hurricane Camille damaged counties.

Pulpwood harvesting since Camille has followed a similar pattern, peaking a little earlier, in 1970, and then dropping sharply down to pre-Camille levels in 1974, then rising to new heights in 1988 and '89 as raw prices surged and many stands planted immediately following Camille reached full pulpwood and two-by-four (chip and saw) size.

That's enough with the numbers. They tell a deceptively simple story of forest recovery. I certainly don't claim to have thoroughly looked at all the complex factors that went into the compilation of these figures. It would take months of research to really factor in all the reasons for these totals. Suffice it to say that forest disasters like Camille and Frederic and Hugo are no match for the healing hand of nature, the determined action of professional foresters with know-how, coupled with the will to recoup-and-recover of the great majority of landowners.

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DAMAGE ASSESSMENTS

SHORT-TERM PLANNING AND RESPONSE TO FOREST DAMAGE[1]

Wray E. Freeman[2]

Abstract--The South Carolina Forestry Commission prepared for Hurricane Hugo by issuing information on care of storm-damaged trees, by checking heavy and communications equipment, and by helping to staff Emergency Preparedness offices the night of the storm. During the immediate aftermath, personnel and equipment cleared roads for traffic and an aerial forest damage survey was conducted. Long-range efforts included application to FEMA for fire prevention/control funding assistance and formation of the Governor's Forest Disaster Salvage Council.

Preparation for Hurricane Hugo's impact to South Carolina actually began several days prior to the storm's arrival. As soon as weather forecasts indicated the storm was likely to come ashore in South Carolina our Information and Education Section prepared and distributed to coastal districts a brochure on handling storm damaged yard trees entitled YOUR TREES AFTER HUGO. Additionally, we checked all motorized and communications equipment to see that it was well protected and as functional as possible. We also reviewed the agency's responsibility regarding our role in Emergency Preparedness and pre-selected personnel to be assigned to field and state headquarters of the Emergency Preparedness offices.

On late Thursday, September 21, 1989, Hugo hit South Carolina. As it moved inland, our communication system became spotty and it became obvious we were experiencing an extremely destructive and far-reaching storm.

By daylight on the 22nd, Commission personnel living in the storm's path began assisting the public at the local level. In spite of suffering damage to themselves, we estimate some 155 Commission personnel with 89 tractors (fire suppression units) were assisting. At the same time the state headquarters office began to mobilize personnel from four districts, two state forests and two nurseries. Dispatch of these personnel began almost immediately and continued through the next few days. Also, a Commission fixed-wing plane was dispatched to determine road conditions to help determine job assignments.

Within two days the agency had roughly 240 people (40 percent of its workforce) working in the recovery effort. Most of this effort involved opening roads and highways to allow travel. This road work had been pre-assigned to the Commission in the State's Disaster Plan.

In our early dispatch of personnel into the storm's area, several mistakes were made. We did not fully recognize that food, water, shelter and fuel would be scarce to unavailable in many areas. We had to do some rapid regrouping in order to get our personnel the items to allow them to be self sufficient. The main lesson learned is that you do not want to impose on the local population in any way during this type situation.

Many of our personnel worked in the area for several weeks. Everyone did so willingly and felt that they were highly appreciated by the local population.

[1] A presentation at the 72nd Annual Meeting of the Appalachian Society of American Foresters held at Greenville, S. C., on January 20-22, 1993.

[2] Assistant State Forester, South Carolina Forestry Commission, P.O. Box 21707, Columbia, S. C 29221.

One major assignment the Commission assumed was to conduct a survey to determine damage to the timber resource. This survey began approximately eight hours after the storm passed through and was completed in four days.

Acting State Forester Jack Gould declared a Forest Disaster on Saturday, the 23rd, which gave the Commission official authority to (1) conduct a damage survey, (2) apply Commission resources on both public and private lands, (3) develop a salvage and utilization plan, and (4) coordinate all forestry interests.

To conduct the timber damage survey we had used four-passenger high-wing aircraft carrying a pilot and two observers. The planes flew north-south flight lines predetermined on county maps (scale 1" = 1 mile) at eight-mile intervals. Three damage classes (light-5%, moderate-25%, and heavy-60%) were used for softwood and three for hardwood (light-10%, moderate-35%, and heavy-70%). As the planes flew the lines, using Loran-C guidance, the observers documented damage. By late Monday we completed the required flying and computed the data using a computer program set up by one of our staff foresters. This data was used to determine a total damage percent for each county. This percent was applied to the 1986 South Carolina Forest Inventory Analysis (FIA) data for that county. A comparison of the survey results with an FIA survey completed several months following the storm is as follows:

	Commission Survey	FIA Survey
Acres Impacted	4,435,363	4,505,700
Hardwood Sawtimber (MBF)	3,456,595	3,984,000
Softwood Sawtimber (MBF)	3,304,666	6,319,000
Total damage value[3]	$1,040,890,335	$1,181,457,000

It is very obvious that our Commission Survey badly underestimated the softwood sawtimber. We became aware that this had probably happened as we spent time on the ground following the aerial survey. In view of the rapid need to get damage figures we did not take enough time to determine correct damage categories. Overall, however, we feel our technique is a good system when you are faced with "cruising" 4.5 million acres in less than four days.

On Monday, day four, Acting State Forester Gould and the Chairman of the South Carolina Foresters Council, Ken Bailey, set up a meeting of the Council for the following Thursday. This Council is made up of representatives from industry, the U. S. Forest Service, Soil Conservation Service, the S. C. Forestry Association, Consulting Foresters, Clemson University and the Forestry Commission. This group gave Gould a broad segment of the forestry community that he could call upon to address the problems caused by Hugo.

On Tuesday Governor Carroll Campbell used the timber survey damage information in a Press Conference. This gave clout to the fact that the forest land suffered a major loss. Up until this time it had been difficult to get the attention of the news media away from the immediate coastal problems.

On Wednesday the 27th, we had our first encounter with the Federal Emergency Management Agency (FEMA). We recognized we had three major problems: (1) an immediate problem with timber salvage and utilization, (2) within a few weeks or months we could encounter the most severe forest fire situation ever encountered in the South, and (3) over the long haul we had a massive reforestation effort on our hands. With the help of the U. S. Forest Service and the Governor's office, we negotiated for well over a month before FEMA finally agreed to assist us with our forest fire effort. They came through in a major way and have continued to assist into our fourth fire season. They have supported a massive fire prevention campaign, two fixed-wing airtankers, additional observation aircraft and the construction of roughly 4,000 miles of firebreaks located in high risk areas.

On Thursday the 28th, the Foresters Council met. Out of the efforts of this group the Governor was persuaded to declare an Executive Order creating the Governor's Forest Disaster Salvage Council. This Council, with Scott Wallinger as Chairman and Mac Lupold as Executive Director, coordinated a massive effort to utilize as much of the impacted resource as possible.

SUMMARY

I don't think anyone or any group can ever totally prepare and respond to an

[3] Value damage includes pulpwood and damage to precommercial stands.

emergency like Hurricane Hugo. We in South Carolina did a number of things well and came up short in others. In summary, when faced by a disaster of this type, I suggest the following:

1. Get all communications up to speed and be prepared for backup systems prior to the storms.

2. Count on the situation being worse than predicted.

3. Assume utility services in the impacted area will be out an extended period.

4. Have a generic Forest Disaster Plan in advance.

5. Have an active body like South Carolina's Foresters Council.

6. Get the Governor's Office involved in the situation as rapidly as possible.

7. Prepare personnel dispatched to assist in the early on recovery effort to be self-sufficient. This may include food, water, fuel and basic shelter.

8. Be prepared to work night and day for an extended time.

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SALVAGE OF STORM DAMAGED TIMBER[1]

H. M. Lupold[2]

Abstract--All timber salvage efforts following natural disasters, including Hugo, should address these issues: (1) realistic damage assessment, (2) obtain broad-base support, (3) representative organizational structure, (4) quick response database of businesses and technical data, (5) identify usable material in damaged trees, (6) logging techniques and equipment modifications, (7) weather effects after storm, (8) use of wet log storage, (9) communications effort maybe the most important task, (10) government relations, (11) value timely statistics and attitude monitoring and (12) salvage time is limited. After nine months, 387 million cubic feet had been salvaged of the 3.5 billion estimated damaged (15.5% versus goal of 25%). Over 100% of the pine goal was salvaged with only 12% of the hardwoods. Good forest management is a mediator of damage exposure and salvage value received. Both state and federal sources of funds to support the Hugo salvage function were non-existent. The Hugo timber salvage was performed in the woods by many thousands of landowners, consultants, land managers, procurement foresters, loggers, equipment suppliers and primary wood-using industries working together.

INTRODUCTION

The salvage of Hugo-damaged trees in 1989-90 for the maximum volume and value to the forest landowners for conversion into solid wood and paper products in South Carolina ceased just nine months following the storm. I believe the long-term salvage effort on nearly 1/3 of SC's forested acreage is still in its infancy. For the most part I will address the actual nine months of timber salvage, but reserve the right to make a few comments on the future, the fact that good forest management pays and forestry's communication/education status with the general public. I want to thank John Purvis for including the ETV tape on the salvage in his presentation. You now have a feel for the woods condition and the magnitude of the problem. This allows me time to critique what we did and perhaps you might think about your own situation and possible forest disaster/salvage contingencies.

DAMAGE ASSESSMENT

To best relate the salvage efforts, I have selected twelve topics to discuss in some detail. The first of these is the "damage assessment" which Wray Freeman has so well presented. The outstanding thoroughness and timeliness of the SC Forestry Commission data assisted in gaining political, industry, agency and other forest community support. The volume, location and extent of damage assisted in forming the salvage committees, communication message, individual industry procurement policies, forest management approaches, salvage goals, and on and on. Certainly without the facts, an effective salvage program will never succeed.

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[1] A paper presented at the 72nd Annual Meeting of the Appalachian Society of American Foresters held at Greenville, SC, on January 20-22, 1993.

[2] H. M. Lupold, Manager, Manufacturing Services, Wood Products, Federal Paper Board, Co., Inc., Riegelwood, NC. Executive Secretary, Governor's Forest Disaster Salvage Council, 1989-90.

STRONG SUPPORT BASE

Hugo's $1 billion plus timber loss mandated the highest political support by using the Governor's Office to open as many doors as possible. Without a "strong support base", my second salvage consideration, the consolidation of effort that may best serve the landowners and primary wood-using industries is lost. When you focus on a specific geographic area and consumer products, activities must be handled through a governmental sanctioned entity as far as anti-trust issues. An attorney was present from the State Consumer Affairs Office at most of our meetings. The salvage phase in the woods and at the mills necessitated land manager, logger and industry involvement because these functions are not part of the daily activities nor expertise of the governmental agencies. The SC Forestry Association assumed the lead role in organizing, monitoring and financing the Salvage Council's efforts.

ORGANIZATIONAL STRUCTURE

The extent of damage dictates the type of salvage structure required, be it an intensified use of existing groups or a formal structure with full-time emphasis and/or personnel. "Organizational structure" then, is the third salvage point. The objective of the Salvage Council was to recover the maximum volume and value to the forest landowners. To accomplish this the council formed four working committees: Utilization, Information, Statistics and Monitoring and Governmental Affairs.

"Move the Wood" - Utilization Committee - Comprised landowners, managers, consultants, loggers, industry--solid wood and paper mills--hardwood and pine, equipment suppliers, railroad and trucking experts and several wood technologists. At one meeting 31 of the 32 members were present. Fantastic interest and support. Four subcommittees were developed specifically for the salvage effort. Utilization concentrated on the logging and milling activities within the salvage area and throughout SC. The 10 or so key people that usually control 80-85% of a state's procurement volume must be part of these committees. Out-of-state insured that sawmills and pulp mills in other states knew of the salvage problems, opportunities, plans and export potentials. Transportation concentrated on log trucks, rail, overseas shipping and barge methods. Storage placed emphasis on wet storage of logs and looked at rough green and finished lumber storage.

"Information Out" - Information Committee - Basically used the Communications committee of the SCFA. Used existing committee structures when possible. We supplemented with PR personnel from the Farm Bureau, ASCS, SCS, Clemson and SC Dept of Agriculture. Most of the daily activities were centered at Clemson Extension with a full-time writer who focused on the public and other interest group media.

"Remove Barriers" - Government Affairs Committee. Comprised the SCFA Governmental Committee with the addition of the 2 Senators and 2 Representatives appointed to the Salvage Council.

"Information In" - Statistics and Monitoring. Utilized personnel at the SC Forestry Commission, plus industry and consultants to track weekly salvage volumes, wet storage status and opinions from the field of salvage progress.

The Executive Committee performed most of the detail activities using a smaller group, represented by the committee chairmen. Funding was provided up-front by the SC Forestry Association and later $17,000 of the $25,000 expended was reimbursed from various Hugo relief funds in the Governor's Office. Expenses of the Forestry Commission for mailings, office space and phone, and at Clemson Extension for media expense were borne by each of these groups.

DATABASES/TECHNICAL LITERATURE

Most of the committee early functions depended upon obtaining information or technical data from a variety of groups and then distributing this data to the same or other groups about all facets of the salvage. No comprehensive computer database of all these organizations existed. My 4th point concerns "organizational and individual databases and technical literature libraries". To put it bluntly, will some entity step forward and take on the responsibility to prepare a standard format where all the forestry/wood product organizations and landowners throughout the southeast can be included and whatever sort is required can be quickly retrieved. This would have saved us 4 to 5 weeks. Research data and reports on past salvages need to be compiled and located in each state.

WHAT CAN BE USED?

One of the first questions asked is, "what can be used" by the sawmills, plywood plants and pulp mills, this being my 5th and longest discussion point about the salvage. In the woods damaged trees were usually found in three basic conditions:

- **Blowdowns**, with some of the root ball still in place,
- **Snap offs**, at 3' to into the tops, and
- **Leaners**, of all angles.

From Camille (Mississippi-Alabama) in 1969, the latest damage comparison to Hugo, those involved advised they were able to leave their blowdowns until last, and most lived through the summer with salvage up to a year later. With Hugo, pine blowdowns began to die in mid to late spring. Hardwoods were not far behind. Perhaps the roots were more severely stretched and damaged, the downing impact so much greater than with Camille. We were really counting on the blown over hardwoods to live for 2-3 years.

The completely broken-off trees, mostly pine, were reduced in most instances in value from sawtimber to pulpwood. Snags and broken tops could be used for sawlogs, if all the broken section and any other visible defects were cut out. A rule of thumb from Camille sawmillers held true in Hugo: on broken ends follow the visible split to its end and then go an additional 4'-6' and cut the stem. Even with this trim-back procedure, the chance of splits, shake and timber or compression breaks were possible. In the video, Chip Ingram showed you the results of a compression or timber break.

A reduction in delivered prices for logs at the mill discounted for the chance of splits and breaks occurring in the lumber. Since hurricanes occur in the fall, blue stain and insects do not become a problem until spring. Toward the end, the pine pulpwood utilization indicators were--if the brown needles did not drop off or the bark fall off when you hit it with your foot, then use it.

Most of the leaners were living when the USFS survey categorized the damage/risk classes 2 and 3, which were the least severe. Today, I see few leaners still living. If so, the damage value could reach $2 billion. The current Forest Service survey in progress will quantify what type tree ultimately dies from a hurricane of Hugo's intensity.

Nearly 30 separate mailings over the 9-month salvage were sent by the Executive Secretary with outstanding assistance from the Forestry Commission to over 500 persons or groups advising all of the current information possible about the salvage. About 400 different buy-sell-want type interests were advertised in the "classified" listings as submitted to the Council. The Council encouraged wood-using industries within the damaged area, and in Georgia and North Carolina when possible, to divert from cutting non-damaged stands and concentrate on the salvage. Concerns of various land-owners around the Francis Marion were discussed with the USFS with the intent to minimize the private land-owners salvage problems in that area.

The 27% salvage results of Camille were reviewed in an effort to establish a Hugo goal. Hugo involved seven times more volume. Several industry procurement personnel participated in evaluating the potential salvage volumes using two different approaches:

1. by analyzing what could be done from the woods and logging side with maximum out-of-state/export consumption and normal weather conditions, and

2. looking at the salvage from a manufacturing capacity, 2 years pine and 15 years hardwood on the ground.

A blend of these two analyses determined the pine and hardwood levels, a 25% salvage goal of the total cubic feet.

Most of us felt just after the storm, as Eddie Drayton mentioned in the video, that the hardwoods could have lasted 2 to 3 years since so many were blown over with a good portion of the root system still intact.

LOGGING

"Logging", item #6, was a completely new chapter in timber harvesting as evident in the video. Tree shears were almost useless. Crews needed a chain saw per man to trim and cut through the entanglement to get to each snag, leaner or broken top. Production rates were reduced 1/2 to 1/3 of normal cut and skid. This resulted in a second reduction factor in landowner stumpage. A high percentage of SC loggers were concentrated in the salvage area and the reduced productivity could not support the full manufacturing capacity. The lumber, plywood and paper markets were never affected by Hugo and remained fairly strong during the salvage period and the bottom did not occur until late 1990. To meet the favorable market and mill capacities, additional out-of-state loggers were secured. Tying up a logger for your specific needs was the name of the game. The legal road weight on log trucks was raised from 80,000# to 90,000# and was extended by the Governor two times until March 15th ("Hugo Timber Haul" sticker in video). Some of Hugo's broken mess could have been logged on the drier sites using short-wood crews, but the paper mills had converted almost completely to tree length with only a few out-of-state operations taking the 5' lengths. Only a few shortwood woodyards were reactivated. Shortwood rail cars were in excess. Be prepared for change--Camille, 20 years earlier, was a short-wood operation. The hardest hit mills from Hugo logging were the single species hardwood operations that usually depend on a large logger to perform separations on the log deck for their needs.

WEATHER CONDITIONS

One factor controls the volume, species and length of time in a salvage more than any other, and that is the "WEATHER", point #7. It also controlled the attendance at this meeting, most mills have few to no logs. Hugo was considered a dry hurricane, very little rainfall prior to and during the storm. Once the family concerns and basic infrastructure of services and access were restored, the rains had set in and the 15 inches in September and October fully saturated soils throughout the coastal plain. Few trees remained to suck up water during the normal October to December growth period. With loggers at half capacity due to the twisted mess, the rain-soaked soil severely limited usable logging sites. This limited logging capacity was apparent from November through January. Here again, if the timber could not be logged, it was worth nothing and on sites that could be, the landowner experienced additional stumpage discount. Landowners with deep sandy soils fared much better than the wet-site forest owners. As late as May and June, loggers were unsuccessful in harvesting tracts with 10 to 20 MBF/acre due to soils still saturated. The black-water swamps were flooded much of the 9-month salvage period; and as is the normal case, once the red rivers subsided, some logging occurred in the Congaree, Wateree, Santee and Pee Dee Rivers which were really hit hard with blowdowns. These flooded swamps are the primary reason hardwoods were limited to only a 3.3 percent salvage performance. Pine reached 40 percent in 9 months (of the total CF damaged). We worked closely with SCS to clear drainage ditches. For forestry's benefit they did not move fast enough, nor complete enough distance. Most projects stopped before they got to the forested acreage.

The combination of twisted damage and rain-soaked soils, despite the more than doubling of loggers in the area, limited the delivery of logs to primary mills to the extent they never created any excess until spring. Only 8 percent of the salvage was shipped out-of-state during the first three months and limited wet storage was initiated. Despite exerted efforts to ship logs, rough green lumber and chips out-of-state or for export, the weather essentially restricted the logged volume for local or SC consumption. Since SC's state ports are not traditional log, pole and lumber facilities, the port charges at two to three times Savannah and Mobile discouraged export, plus they were not willing to give up container space for wood products. Extra wide tires to improve flotation, helicopters (video), horses, oxen, etc. were all tried to escape the wet ground. By April we began to discourage the use of out-of-state loggers.

If the rains weren't enough, then the 80-degree weather in March and 90-degree in April told the tale that ended the salvage earlier than Camille. The final salvage chapter always ends with stain and borers in both the pine and hardwoods. The warm spring accelerated the stain presence and essentially ceased the salvage in June. Today, stain in lumber, although accepted in the SPIB grade rule, is not accepted by the treaters and the homeowner, DIY market from an appearance standpoint.

WET STORAGE OF LOGS

When your loggers aren't bringing in excess logs you tend not to think about "wet storage", emphasis #8. Most east side mills have had limited experience with wet log storage and therefore respond at the last possible moment. In late December all the technical publications in print on wet storage and a summary of the SC situation was distributed. A seminar with DHEC and USFS experts was held in January. DHEC variance allowed for immediate use of a properly designed site with subsequent reporting. This saved a normal 6 months application time.

By April 46 potential sites had been identified to store 150 million BF and 63,000 cords pine and hardwood and if fully filled would be worth $30 million at pre-Hugo values. Several excellent studies since Hugo by Clemson and the USFS are available on wet storage design and product placement and in lumber and veneer quality. These publications should be selling at a premium since many mills in the Carolinas are talking about wet storage capability in late 1993 and 1994. Log storage is really a simple operation--the key is, to store only good quality logs!!!!

In 1938, after the New England hurricane, 63 log pond sites were leased by the government to hold 500 million BF of timber to be purchased for resale to industry at a later date. That storm had the same volume of white pine damaged as Hugo with southern pine. We were totally unsuccessful in obtaining any federal or state funding for log storage or for loggers.

If a tremendous surplus of logs had been available in early 1990, I believe our log-storage situation may have been completely different. A more visible response would have been made to satisfy this opportunity to provide value to the landowners and have logs for processing. You must place emphasis and pressure on areas with specific problems and support with factual impacts. The Santee Cooper lakes and sites on Francis Marion National Forest were investigated as potential government funded projects.

COMMUNICATIONS

My 9th point is "Communications". Clemson Extension provided special emphasis and funding toward the communications effort. Several technical publications were prepared about damaged timber and landowner meetings were held throughout the area. Special feature articles were released to the news media. It's sad when the newspapers no longer want to publish the plight of the landowner who may have lost tens and even hundreds of thousand of dollars, but jump at the opportunity to present something new or a single incident like horse logging. SC ETV assisted in several programs and video features. As hindsight, I believe the Council as a whole could have done more in these areas:

- participated on more radio and TV talk shows,
- weekly face-to-face contact with newspapers from Charleston to Charlotte,
- feature writers need to be located in the salvage area at least in the case of a major storm like Hugo,
- stronger message to private landowners to seek professional advice, and
- stronger appeal to the general public, if that's possible.

GOVERNMENT AFFAIRS

"Government Affairs", item #10, obtained the higher truck weight and DHEC log storage variance early on. Attempts in Congress for legislation on reforestation, a CRP program, a casualty tax basis allowance, forest survey expense and storage funding failed to pass just prior to Thanksgiving. Several tours of the salvage were made for the Governor, Legislative Committees, FEMA and the USFS Washington office. FEMA was never supportive of specific funds for salvage operations. We did assist the Forestry Commission in its efforts for fire prevention and presuppression. Other attempts in Congress failed on a special crop loss (for timber) provision and further casualty tax allowances (most landowners had no basis in their timber and the loss was 100% out-of-pocket). With a shortage of state funds, the General Assembly never could justify allowances for a state casualty tax loss provision, ITC for reforestation, or specific funding for the salvage council.

Just yesterday at a Forestry Association meeting, we discussed possible forest disaster (hurricanes, tornadoes and excessive wet weather) legislation that would automatically fall in place for low-interest loans and maybe a 25- to 50-basis casualty loss allowance. A timber salvage program should not sit back and wait on special government funding. All available state efforts will be toward restoring the normal infrastructure. The salvage, as evident of the lack of success we had in obtaining special funds or tax provisions, actually boils down to landowners, managers, loggers and primary manufacturers working together.

STATISTICS AND MONITORING

"Statistics and Monitoring", point #11, is essential to track and evaluate the salvage progress. The adjusted volume evaluated all mills reporting, including out-of-state, with an 85 percent hard number participation. Industry finds this type information very useful during the salvage. I've included so far several statistical findings, here are some others:

- After 9 months, salvaged 387 million CF of 2.5 billion damaged, 15.5%. 62% of our 25% goal. The USFS Survey will tell the real story--volume damaged, salvaged and what type risk condition ultimately dies.

- 10.1 percent shipped out-of-state

- Softwood sawtimber
  797 MMBF 100% goal
  Softwood pulpwood
  2.1 million cds 107% "
  Hardwood sawtimber
  64 MMBF 10% "
  Hardwood pulpwood
  508 thousand cds 15% "

- Source, minimal accuracy: Private 49%, industry, 13%, government 18%, unknown 20%.

LENGTH OF TIME

My final and 12th comment is "length of time". Damaged timber is a perishable product. All of the factors I've mentioned above are constantly closing in on your efforts. The Council tried to take a can do approach--no time for lengthy studies or reports, but rather each day inform as many people in the field as possible of the opportunities, possible solutions, where to go for advice, and status of the salvage.

GOOD FOREST MANAGEMENT A SALVAGE MEDIATOR

I have intentionally left out several salvage pointers because they relate directly to the status of forest management being practiced on any timber tract at the time of a disaster --not just Hugo. Good forest management is an ongoing mediator of damage exposure. Just think: problem free sales mean painted property lines with wide firebreaks; basic access; adequate culverts; maybe some gravel or ROC; sufficient drainage to remove excess water; being active in timber sales means buyer contacts with early negotiations maybe at 85-95% pre-Hugo prices, rather than less than 50% later; managed smaller acreage stands; less exposure; longer interval for thinned trees to stiffen; no slick-bark, old growth--a Hugo nemesis; performed control burning, hardwood reduction, good seed bed condition--thus adequate natural regeneration. Observe much of Francis Marion today and lower Colleton and Charleston counties from Gracie in 1959. Thus, limited salvage volume at reduced price. Bulk of stands remain to manage for excellent future markets. Good management pays!

IMMEDIATE NEEDS OF PEOPLE AND INFRASTRUCTURE GREATER THAN TIMBER LOSS

With Hugo the Council approached the Governor, the Legislature, the US Congress and the people of SC with these facts:

- $1 billion loss in timber and could possibly double when all the mortality is known, less than $100 million in salvage value.

- Over $10 billion of potential forest products sales of lumber and paper will rot in the woods of SC.

- SC's ultimate loss could exceed $40 billion using all the multipliers in the economy.

- The December Budget & Control Board estimate illustrated that timber was 75% of SC's unrecoverable Hugo loss.

These unbelievable facts did little to bring about any viable programs to assist the private landowner. Once the San Francisco earthquake occurred our efforts in Washington completely died.

It is critical that the public understands what we are all about, appreciates the wood and paper products they depend on daily, and we link the forest resource and our management activities to their need. The current efforts of the state Forestry Association and Commissions must be continued and expanded. With all disasters the immediate emphasis will be toward people needs and community infrastructure, not on forest salvage and renewal which are more long-term situations.

The Salvage Council did not cut a single tree or haul any loads of logs. This was done by the efforts of tens of thousands of landowners, consultants, loggers, mill people, equipment suppliers, etc. I thank all of them for their support to the Council.

Today we as foresters must take this tract called, "South Carolina" and type out the state's forest and ask the question what are we going to do with this one area comprising 36% of the state. It's a unique and different type of problem. Landowners and industry are going to suffer even more if we don't approach it as a special problem. The Foresters Council and/or the Salvage Council following the release of the new forest survey data must immediately address what most people fear as a worst case scenario for SC.

The statement of Scott Wallinger, chairman of the Salvage Council, about the salvage efforts in 1989 still apply today in 1993 to the current Hugo-damaged forest condition - "Seeking Unprecedented Solutions To Unprecedented Challenges".

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HOW TO EVALUATE AND MANAGE STORM-DAMAGED FOREST AREAS

Patrick J. Barry[1], Coleman Doggett[2], Robert L. Anderson[1], and Kenneth M. Swain, Sr.[3]

INTRODUCTION

Hurricanes, tornadoes, and ice storms strike somewhere in the South almost every year. They cause extensive forest damage by uprooting, wounding, bending, and breaking trees. Standing water, which often accompanies hurricanes, can cause additional stress and mortality. When one of these natural disasters occurs, it is important to have a plan for managing damaged timber.

Development of a storm damage management plan involves several systematic steps. As soon as possible, the area should be sketch mapped or aerial photographed. The next step is to ground check the damage to determine the need for salvage. Priorities for salvage will depend on location, amount and type of damage, and management objectives. This guide presents methods for managing storm-damaged trees to reduce growth loss, product degrade, and mortality. In the process, other factors such as threatened and endangered species must be considered. The information presented here will assist in setting priorities.

SURVEY THE DAMAGE

Two types of surveys, general and intensive, are needed to determine the extent of forest damage from a storm.

General surveys are designed to determine geographical area affected by storms. These are very quickly and easily done from the air. Using aerial survey techniques, damaged areas may be sketched on preexisting maps or photographs, or damaged areas may be aerially photographed. A planimeter or other device is then used to determine acres affected.

Intensive surveys are designed to collect information on volumes of timber damaged and on conditions of surviving trees. Volumes of storm-damaged timber are difficult to estimate with aerial survey techniques because damaged trees are broken and twisted together. It is also difficult to determine tree condition from the air. Consequently, intensive surveys usually require ground-based plots for acceptable accuracy. The number and size of plots are determined by desired accuracy, and by time and personnel constraints.

Tornado damage surveys are unique because the storm tracks are usually long and narrow with few surviving trees. Volumes of tornado damaged timber may be estimated by taking systematic plots on a transect parallel to the storm track but just outside the damage area.

NOTE TYPES OF DAMAGE AND TAKE ACTION

Breakage

Breakage is the most common type of storm damage. Its impact depends on the degree and pattern of damage as well as the tree species involved.

Breakage inevitably lowers timber values. Breaks are uneven by their nature and occur randomly along the tree bole. The random pattern lowers value since products are normally cut in specified lengths. Breakage also lowers value because difficulty in logging in broken timber slows productivity. Patterns are important when assessing breakage impact. When ice or strong gale-force winds break trees, break patterns are simple and limited

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to the area adjacent to the break-point. Hardwood trees are seldom killed by breakage. Even when tops are completely gone, new branches will sprout and the tree will recover. In hardwoods, the major problem is that breaks in the trunk or large branches (over 3 in. diameter) permit entry of stain and decay fungi. Stain will move vertically from the injury at a rate of 6 to 18 inches per year, and decay will follow the stain in 8 to 10 months.

Most species of pine will die if tops are completely broken and no live limbs remain. If three or more live limbs are left in the tops of loblolly or slash pines, the chance of survival is excellent (above 75 percent). One of the lateral branches in these trees will become the terminal, and in 8 to 10 years the only sign of breakage will be a sharp crook in the bole at the point where the break occurred. These trees will experience growth losses, however.

Recommendations
For hardwoods, trees with broken tops or branches over 3 inches in diameter should be salvaged during the next scheduled harvest. High-value trees such as those in recreation areas and in yards should be properly pruned to promote rapid healing.

For pines, if three live limbs or less remain, the trees should be harvested as quickly as practical.

Twisted Trunks
The cyclonic winds that are typical of tornadoes, and often accompany hurricanes, cause twisting and separation of wood fibers in the main stem. Logs from trees that have experienced this treatment may fall apart when sawn for lumber products. Trees twisted by cyclonic winds may appear normal, except that pines often have pitch flow along the trunk.

Recommendations
Trees with evidence of twist injury should be removed, since the problem will not disappear with time and considerable losses may be incurred during a later harvest.

Root Damage
If they are not salvaged promptly, uprooted trees probably will be degraded quickly by stains, decays, and secondary insects, such as *Ips* bark beetles, borers, powderpost beetles, and ambrosia beetles. The longer salvage is delayed, the greater the amount of degrade and weight loss from rapid drying. Degrade translates into a stumpage value loss. The amount of degrade that is acceptable to industry depends on the tree species and local markets. Table 1 shows the probable sequence of invasion by damaging organisms in storm-damaged timber.

Root-sprung trees will not die immediately, but will show decline symptoms over a period of several years. These trees may be invaded by root rot organisms and subjected to drought stress and insect attack. Root-sprung pines may be invaded by bark beetles and blue stain fungi. These pines can serve as prime habitat for the southern pine beetle and, if conditions become favorable, an outbreak could occur. They can also harbor high populations of turpentine beetles.

Recommendations
Trees with major root damage should be salvaged as soon as possible to avoid growth loss, product degrade, bark beetle attacks, and mortality.

Table 1--Sequence of invasion of damaging organisms in storm-damaged timber

Species	Year 1	Year 2
Pine	Bark beetles, ambrosia beetles, sawyers, blue stain fungi, soft rot fungi	Decay fungi
Oak and hickory	Wood borers, ambrosia beetles, stains, soft rot fungi	Sapwood decay fungi
Other hardwoods	Wood borers, ambrosia beetles, stains, soft rot fungi	Sap and heartwood decay fungi

Major Wounds

During storms, many trees sustain wounds caused by falling tops, adjacent uprooted trees, and major branch breakage. In hardwoods, wounds that do not penetrate more than 2 inches into the sapwood and have less than 144 square inches of surface area will have only localized stain, but little decay. Wounds that exceed these limits will have stains and decay that move at the rates described for broken branches. Pine trees with major wounds to the lower bole and larger roots may be attacked by bark beetles.

Recommendations

Trees with major wounds should be considered for removal during the next scheduled harvest, or they should be included in the salvage operation.

Bent Trees

Bent hardwoods usually are not attacked by insects or diseases because they are not in a stressed condition. Pine trees that are bent to the extent that cracks and resin flow occur may be invaded by bark beetles and disease-causing organisms.

Recommendations

Small trees (under 15 feet in height) usually straighten even after severe bending. Taller severely bent hardwoods should be removed during the salvage operation or the next scheduled harvest. Be sure to inspect large pine timber for pitch flow. Many large, green, standing trees may not be usable for veneer, poles, or lumber because of internal ring shake, splintering, and separation of the wood fibers. Often, the only external evidence of such damage is pitch or sap flow where the injury has broken the bark. These characteristics are often overlooked, and considerable losses are incurred during a later harvest.

Standing Water

In standing water, the dissolved oxygen is quickly depleted, so trees of most species are injured by prolonged flooding, particularly during the growing season. The loss of soil oxygen leads to root mortality and tree death. Trees weakened by standing water are often attacked by insects or affected by diseases.

Recommendations

Forest managers may wish to favor flood-tolerant trees and shrubs in areas subject to intermittent flooding. Tree species that can tolerate prolonged or intermittent flooding are noted in Table 2. Flood-tolerant shrubs include: buttonbush, sand plum, deciduous holly, and swamp-ironwood.

MANAGE TO REDUCE PEST-CAUSED LOSSES

Storm damage often increases the risk of pest outbreak by weakening the defenses of host trees. Pest infestations will not develop unless suitable host trees are available, so every effort should be made to remove concentrations of susceptible host trees. A well-planned and executed salvage operation can greatly increase a stand's resistance to pest attacks. To ensure effective salvage, we recommend the following approach:

1. Act quickly. Prompt salvage will help avoid losses from degrade and subsequent pest-caused mortality.

2. Measure carefully the extent of the damage before deciding on a salvage operation. A number of factors such as stand age, species, stocking, and management objectives will need to be considered.

3. Salvage the most severely damaged timber first. Concentrate on the pine stands, because they are more susceptible than hardwoods to pest outbreaks. On deep sandy soils where a stand will be left, the stumps should be treated for annosus root rot control. During salvage avoid damage to residual trees.

4. Complete salvage promptly and in one continuous operation. Bark beetle populations are more likely to build up in the slash and move into healthy trees if logging operations are prolonged or interrupted for periods of a month or more. (When salvage is delayed, a helpful guide is available for utilization of beetle-killed pine trees based on tree appearance. See Table 2.)

Table 2--Utilization guidelines for beetle-killed pine trees[1]

Product	Class A Trees with needles or no needles, but twigs attached	Class B Trees with no needles, most twigs and branches lost, and some broken tops	Comments
Appearance lumber[2]	Not recommended	Not recommended	Blue stain prohibits use.
Dimension lumber[2] (structural)	Can be used with caution	Not recommended	Should be kiln dried to prevent emergence of secondary insects. Low moisture content may dull saws and chipper knives faster than with sound wood and may require milder kiln schedule. Do not use where toughness is important.
Decorative lumber boards and paneling	Can be used	Can be used	Should be kiln dried.
Posts, poles, piling	Not recommended	Not recommended	Toughness and preservative treatability may be highly variable.
Plywood	Can be used	Not recommended	Adhesives and gluing practices may have to be adjusted.
Hardboard, particle-board, medium density fiberboard	Can be used	Can be used	Low moisture content may affect some production schedules. Should be mixed with sound wood.
Pulp	Can be used	Can be used	Blue stain and low moisture content may affect pulping process and chemical or energy requirements. Should be mixed with sound wood, particularly where strength is important.
Fuelwood	Can be used	Can be used	Low moisture content increases heat value.

[1] For more information on utilization of beetle-killed trees, see "A Guide for Using Beetle-Killed Southern Pine Based on Tree Appearance", by Michael P. Levi, USDA Agriculture Handbook 572.
[2] For more information on economics of producing lumber from beetle-killed pines, see "A Mill Operator's Guide to Profit on Beetle-Killed Southern Pine", by S.A. Sinclair, USDA Agriculture Handbook 555.

5. Follow the practices listed below to ensure that the residual material (slash) will dry quickly. Bark beetle infestations will not build up in dry material.

   - Cut all logs from seriously damaged trees to the minimum merchantable size and remove them from the area.
   - Lop and scatter all harvesting slash and tops into open areas when possible.
   - Scatter large accumulations of slash away from the bases of residual trees, and into direct sunlight if possible.
   - Sever downed trees from roots that could keep them alive.

6. Inspect large pines for pitch flow. Many large, green, standing pines may be unusable for veneer, poles, or lumber because of internal splintering and separation of the wood fibers. Often, the only external evidence of such damage is pitch flow where the bark has been broken.

7. Follow the ratings of species resistance to insects and diseases in Table 3 when planning the salvage of timber, especially hardwoods.

8. Consider deducting storm-damage losses on income-tax returns. Landowners can secure advice from local foresters, accountants, attorneys, or Internal Revenue Service agents concerning deductible losses.

9. Check for pest activity after salvage operations are finished. Make periodic surveys, either aerial or ground, of the residual stands to check for pest activity. These surveys may be required for up to 2 years. Trees that are turning yellow, have pitch tubes on the bark, or red boring dust around the base, are probably affected by insects, diseases, or both. These trees should be considered for control activities.

MANAGE TO REDUCE HURRICANE DAMAGE

Tree species vary in their ability to withstand hurricane winds and salt damage. Wind resistance depends on the interaction of five factors: strength of the wood, shape and size of the crown, extent and depth of the root system, previous moisture conditions, and shape of the bole.

No tree species has perfect wind resistance, but live oak, palm, pondcypress, and baldcypress are among the best, as shown in Table 3. These trees combine deep root systems with buttressed trunks (low center of gravity). The wood of live oak is exceedingly strong and resilient. The crown is usually widespread, but this does not seem to negate its strong points. Cypress has relatively weak wood, but its crown is so sparse and its foliage so limber that it is also extremely windfirm.

Shallow-rooted trees are easily uprooted, especially after the soil is saturated by heavy rains. Common shallow-rooted trees along the coast are dogwood, water oak, pecan, sweetbay, and red maple. Common deep-rooted trees are live oak, longleaf pine, and pondcypress and baldcypress.

Trees growing in sandy soils are more deeply rooted than trees growing in soils with an inhibiting clay layer or a high water table. Although rooting habits vary according to the soil profile, each species has a characteristic pattern. Another factor to be considered is the height of the tree. The taller the tree, the greater is its chance of breaking, especially if the bole has little taper. For this reason, tall, slim slash and longleaf pines are extremely vulnerable.

Table 3--Resistance of tree species to hurricane-related damage (in descending order of resistance)

Flood tolerant	Breakage	Uprooting	Salt	Deterioration by insect and disease
baldcypress	live oak	live oak	live oak	live oak
pondcypress	palm	palm	palm	palm
tupelo-gum	baldcypress	baldcypress	slash pine	sweetgum
sweetbay	pondcypress	pondcypress	longleaf pine	water oak
willow	sweetgum	tupelo-gum	pondcypress	sycamore
sweetgum	tupelo-gum	redcedar	loblolly pine	baldcypress
sycamore	mimosa	sweetgum	redcedar	pondcypress
river birch	dogwood	sycamore	tupelo-gum	southern red oak
cottonwood	magnolia	longleaf pine	baldcypress	magnolia
green ash	sweetbay	mimosa	sweetgum	tupelo-gum
red maple	southern red oak	southern red oak	water oak	sweetbay
pecan	water oak	magnolia	sycamore	hickory
mulberry	sycamore	slash pine	sweetbay	pecan
American elm	longleaf pine	loblolly pine	southern red oak	redcedar
persimmon	slash pine	sweetbay	hickory	red maple
silver maple	loblolly pine	water oak	mimosa	mimosa
water oak	redcedar	red maple	pecan	dogwood
swamp chestnut oak	hickory	dogwood	magnolia	longleaf pine
magnolia	red maple	hickory	red maple	slash pine
hickory	pecan	pecan	dogwood	loblolly pine

Open-crowned and lacy-foliaged trees, such as cypress and mimosa, offer less resistance to the wind, and thus are better able to survive. On the other hand, magnolia trees with their heavy, wind-catching foliage are windthrown more than their root system and bole structure would indicate. Palm trees offer little surface to the wind because they have almost no laterally extended crown and branches. This characteristic makes them fairly windfirm, despite their limited root systems.

Based on these observations, the following preventive measures are recommended to forest managers in hurricane-risk areas:

1. Keep a balanced mixture of size and age classes to prevent a complete loss. Young trees are rarely damaged, because they tend to bend with the wind; old trees tend to break or uproot.

2. Where feasible, stagger thinnings to limit exposure of the recently thinned areas. (During Hurricane Camille, recently thinned stands of pine with little taper were severely broken, while open stands and stands thinned several years earlier suffered less damage.)

3. Manage for well-spaced, thrifty trees and, as much as possible, develop a spread of age classes to distribute the risk of wind damage.

4. Consider planting longleaf pine in deep sandy soils, because longleaf has a deep taproot.

5. When planting slash and loblolly, use an 8- by 8-foot or wider spacing.

Winds often carry saltwater inland for a considerable distance. The leaves on trees saturated with saltwater turn brown and give the appearance of being burned. Most of these trees will not die and should not be cut. See Table 2 for resistance among tree species. The trees may lose their leaves and some growth, but most of them will grow new leaves and recover. Check trees closely in the spring after salt damage for adequate recovery or possible bark beetle attack. Trees should be harvested if they have been attacked by bark beetles or if they have not put on new growth in the first full growing season after the damage occurred.

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Damage to Forests

IMPACT OF HURRICANE HUGO ON THE SOUTH CAROLINA COASTAL PLAIN FOREST

Donal D. Hook[1], Marilyn A. Buford[2], and Thomas M. Williams[3]

Abstract--The impact of Hurricane Hugo on the Coastal Plain forest is described using data from two experimental forests. The Santee Experimental Forest experienced the full force of the eyewall, sustaining extreme wind damage. On Hobcaw Forest, northeast of the area impacted by the eyewall, major damage was done by salt with some wind damage. The largest and tallest trees of all species were more severely damaged than were smaller trees. Within the area impacted by the eyewall, 89% of the longleaf pine trees, 91% of the loblolly pine trees, and 86% of the bottomland hardwood trees were broken or uprooted. Outside the area of the eyewall, 17% of the longleaf pine, 52% of the loblolly pine and 20% of the bottomland hardwoods were broken or uprooted. Species differences in wind resistance were apparent outside the area affected by the eyewall.

INTRODUCTION

Hurricane Hugo came ashore across Sullivan's Island, South Carolina, at midnight EDST, September 21, 1989. When the storm made landfall, it was considered a Category 4 on the Saffir/Simpson scale. At the coast near Bulls Bay, estimated maximum sustained surface winds were 54 meters per second (ms^{-1}) (121 miles per hour (mh^{-1})) with possible extreme gusts to 66 ms^{-1} (147 mh^{-1}). The eye of the storm was approximately 50 km in diameter with the eyewall affecting an area approximately 100 km wide[4]. The center of the hurricane followed the path indicated in Figure 1, inflicting timber and property damage across 23 of South Carolina's 46 counties. Seven counties experienced extensive timber damage, 3 experienced moderate timber damage, and 13 counties suffered light timber damage. The storm was down-graded to tropical storm status after passing Charlotte, North Carolina, six hours after landfall, and ultimately crossed the Canada-United States border at Erie, Pennsylvania, 17 hours after landfall.

In South Carolina, approximately 1.8 million ha of forest land were damaged by wind and water. In comparison, the eruption of Mount St. Helens affected 60,750 ha and the Yellowstone fires of 1988 burned approximately 400,000 ha (Figure 2a,b). The amount of dead and downed wood is three times the annual harvest in the state. An estimated 32.3 million cubic meters (6.7 billion board feet (bf)[5]) of sawtimber was damaged or destroyed. This is enough wood to build approximately 660,000 average homes; enough to house almost the entire population of West Virginia or the city of Philadelphia (South Carolina Forestry Commission 1989). In comparison, the total harvest of lumber in the northern coastal plain of South

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[4] Powell, M.D.; Dodge, P.; Black, M. 1990. The landfall of Hurricane Hugo in the Carolinas. In preparation for Weather and Forecasting.
[5] A board foot (bf) is equivalent to a plank 1 inch thick and 12 inches square.

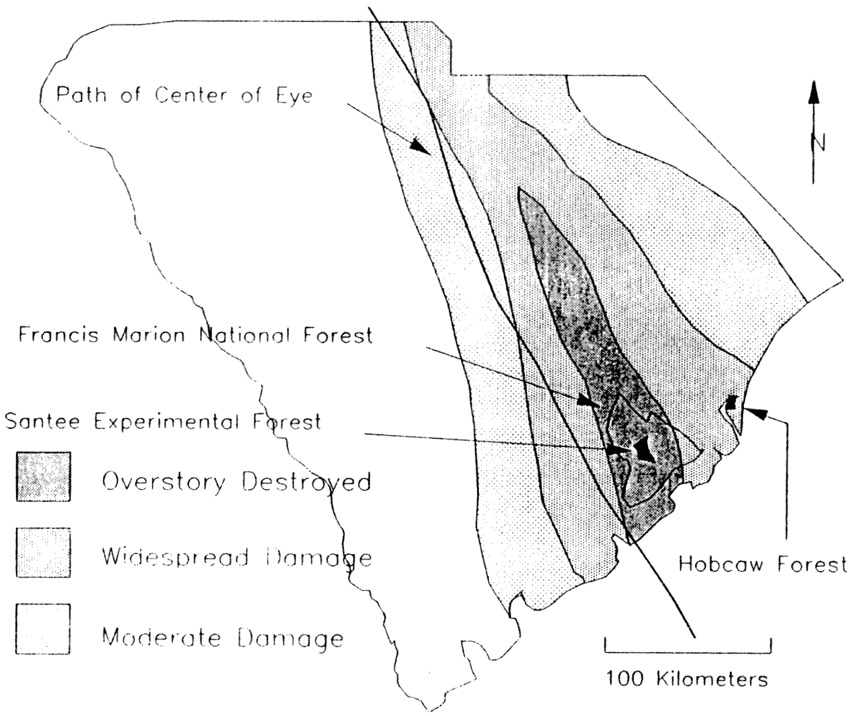

Figure 1--Map of South Carolina showing the path of Hurricane Hugo, the area impacted by it, and the locations of the Santee Experimental Forest and the Hobcaw Forest.

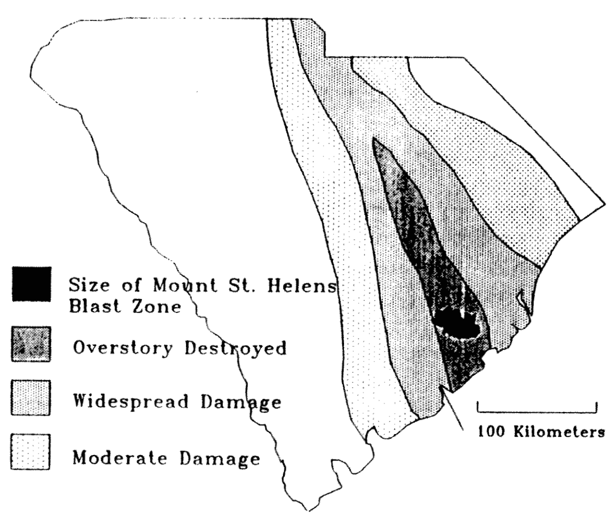

Figure 2a--Map of South Carolina showing the area impacted by Hurricane Hugo with the area impacted by the eruption of Mount St. Helens superimposed.

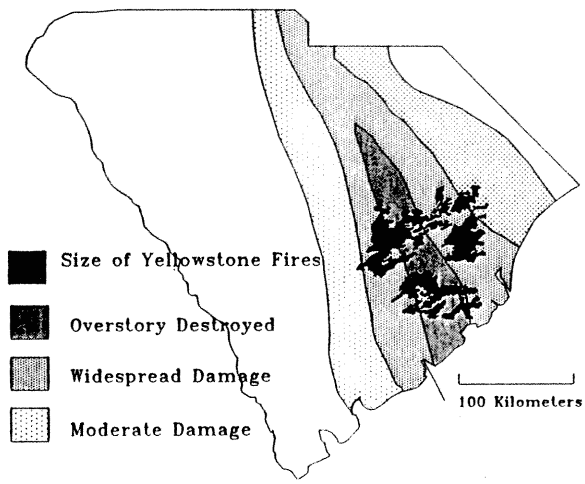

Figure 2b--Map of South Carolina showing the area impacted by Hurricane Hugo with the area impacted by the 1988 Yellowstone fires superimposed.

Carolina during the 20-year peak exploitation period 1909-1929, was approximately 30.8 million m^3 (6.4 billion bf)[6]. As of this writing, intensive efforts have resulted in the salvage of 39% of the pine and 3.7% of the hardwood downed or damaged by the hurricane in South Carolina.

The center of the eye passed within 8 km of the 101,000 ha Francis Marion National Forest (FMNF). Nearly the entire FMNF was affected by the winds of the eyewall. Most of the wind damage in a hurricane occurs as a result of short duration gusts (2-4 second), either the typical gusts associated with turbulence or the extreme gusts associated with the downdrafts from intense thunderstorms, most of which form in the eyewall and outer rainbands[7].

Throughout the region of severe damage, the sites of the extreme gusts described above are marked by areas 0.25 ha to 7 ha in size where every tree was broken or uprooted. These spots of total destruction extended inland for more than 150 km.

The Santee Experimental Forest (Santee) is located approximately 40 km from the coast, on the west side of the FMNF[8]. Hobcaw Forest (Hobcaw) is approximately 90 km northeast of Charleston, near Georgetown, SC, positioned along the coast and immediately to the west of the North Inlet salt marsh (Figure 1)[9]. The Santee and Hobcaw are sites of intensive forest research and offer a unique opportunity to examine the effects of a severe hurricane on the Coastal Plain forest. This paper describes the effect of a severe hurricane on the Atlantic Coastal Plain forest with specific examples from these two experimental forests.

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[6] Reference to timber harvest of 1909-1929.
[7] Powell and others. The landfall of Hurricane Hugo in the Carolinas.
[8] The Santee Experimental Forest is administered by the Southeastern Forest Experiment Station, Forest Service. United States Department of Agriculture, and serves as the primary outdoor laboratory for the Center for Forested Wetlands Research, Charleston, South Carolina.
[9] The Belle Baruch Forest Institute is managed by Clemson University and serves as an outdoor teaching and laboratory facility for all facets of forest environment research.

SANTEE EXPERIMENTAL FOREST

Land Use History and Description

During the eighteenth and nineteenth centuries, the area that is currently the Santee Experimental Forest contained parts of seven major plantations. Rice was the main money crop and the attendant diking structures and canals are still clearly evident on all the main creek bottoms on the forest. The remains of numerous tar kilns on the forest provide evidence of the extent of longleaf pine (*Pinus palustris*) and the importance of the naval stores industry which peaked between 1850 and 1880 (Frothingham and Nelson, 1944). Intensive timber removal began in the 1890's with the development of steam power, and continued for a period of 30 to 40 years throughout South Carolina and the southern forests. After the coastal forests were cut over, much of the land was abandoned or sold very cheaply. The U.S. Government purchased approximately 100,000 ha and President Franklin P. Roosevelt established the Francis Marion National Forest in 1936. In 1937, 2000 ha were set aside as the Santee Experimental Forest. The area was enlarged to its present 2452 ha in 1946.

In the 53 years prior to Hugo, 190 short- and long-term studies were conducted on the forest and over 400 articles were published on the results. Major research areas were prescribed burning, regeneration and management of bottomland hardwoods, natural regeneration of pine stands, coastal watersheds, and threatened and endangered species (red-cockaded woodpecker, in particular).

The soils of the Santee are primarily Alfisols and Ultisols with drainage ranging from very poorly to moderately well drained, and surface textures range from sandy loam to clay. The Alfisols generally occur in the drains and depressions and the Ultisols generally occur on the higher topographic positions.

The Santee is a mosaic of Atlantic Coastal Plain forest types. The forest types present on the Santee Experimental Forest are: (1) mixed pine-hardwood--typically a mix of loblolly pine (*P. taeda*), sweetgum (*Liquidambar styraciflua*), southern red oak (*Quercus falcata*), white oak (*Q. alba*), and red maple (*Acer rubrum*); (2) loblolly pine--often has a midstory or understory of sweetgum, red maple, and willow oak (*Q. phellos*); (3) longleaf pine (*P. palustris*)--often has an understory of turkey oak (*Q. laevis*) or blackjack oak (*Q. marilandica*); (4) mixed loblolly pine-longleaf pine; (5) upland hardwoods--white oak, southern red oak, and black oak (*Q. velutina*); (6) bottomland hardwoods--cherrybark oak (*Q. falcata* var. *pagodaefolia*), swamp chestnut oak (*Q. michauxii*), sweetgum, red maple, Water oak (*Q. nigra*), willow oak, green ash (*Fraxinus pennsylvanica*), yellow-poplar (*Liriodendron tulipifera*), Shumard oak (*Q. shumardii*), black gum (*Nyssa sylvatica*), and laurel oak (*Q. laurifolia*); and (7) creek swamp--baldcypress (*Taxodium distichum*) and water tupelo (*N. aquatica*). The area of each forest type is given in Table 1.

Table 1--Area by forest type on the Santee Experimental Forest and Hobcaw Forest.

Forest Type	Area (ha) Santee Experimental Forest	Area (ha) Hobcaw Forest
Mixed pine-hardwood	1017	635
Loblolly pine	702	840
Longleaf pine	46	629
Loblolly longleaf	195	407
Upland hardwoods	312	41
Bottomland hardwoods	152	307
Creek swamp	28	141

Damage

In the path of the eyewall, the Santee suffered extreme wind damage. Over 80% of the trees were destroyed and nine long-term studies accounting for 221 research years were prematurely terminated by the storm's passage. Prior to the hurricane, the volume of wood on an average ha in the experimental forest was 178 m^3 (15,000 bf/acre). Current estimates are that less than 24 m^3/ha (2000 bf/acre) were left standing after the storm (Photo 1). Table 2, based on a survey incomplete as of this writing, gives the proportion of each species in each of 7 condition classes: (1) no apparent damage, (2) broken stem (broken below the base of the live crown), (3) broken top (broken above the base of the live crown), (4) leaning more than 45°, (5) leaning 30-45°, (6) leaning 5-30°, and (7) uprooted. The results in Table 2 are based on a survey of 137 trees from

Photo 1--Devastation of an 85-year-old loblolly pine (*Pinus taeda*) stand resulting from Hurricane Hugo on the Santee Experimental Forest in South Carolina.

Table 2--Proportion of each species in each condition class.

Species	Condition Class						
	No Damage	Broken Stem	Broken Top	Lean ≥45°	Lean 30-45°	Lean 5-30°	Uprooted
Ash	80.0	0.0	0.0	0.0	0.0	20.0	0.0
Elm	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Hickory	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Ironwood	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Laurel oak	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Loblolly pine	22.2	44.4	22.2	0.0	0.0	11.1	0.0
Red maple	13.6	0.0	9.1	36.4	22.7	18.2	0.0
Red oak[a]	35.0	0.0	0.0	0.0	45.0	15.0	5.0
Sweetgum	54.7	10.9	6.3	7.8	15.6	4.7	0.0
White oak	0.0	0.0	0.0	0.0	0.0	100.0	0.0
Yellow poplar	16.7	33.3	0.0	0.0	0.0	0.0	50.0

[a] Cherrybark oak and Shumard oak.

12.7 to 50.8 cm dbh, and do not contain the larger size classes of any of the species. The larger size classes of all species suffered greater damage than did trees in the smaller size classes.

Using aerial photographs taken from an altitude of approximately 457 m, stem counts in mature stands were made to determine the proportion of loblolly pine, longleaf pine and bottomland hardwoods that were apparently undamaged, broken, and uprooted. The results are given in Figure 3. In these 80- to 110-year-old stands, this represents severe damage to approximately 124 of 166, 128 of 141,

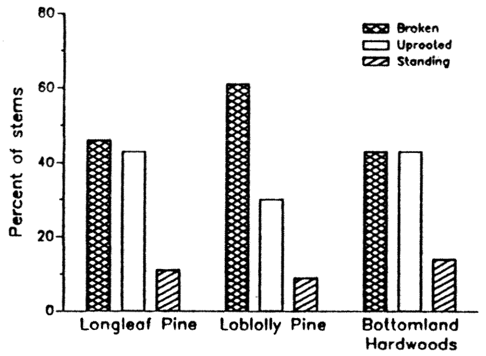

Figure 3--Percentage of longleaf pine, loblolly pine, and bottomland hardwood stems on the Santee Experimental Forest that were uprooted, broken, and standing after Hurricane Hugo.

and 67 of 77 trees/ha in the bottomland hardwood, loblolly pine, and longleaf pine groups, respectively.

In general, the tallest and largest (dominant) trees experienced the most severe damage. Those suffering less damage were primarily in the midstory and not in the dominant canopy. Loblolly pine suffered the greatest amount of stem and top breakage. Shumard oak, cherrybark oak, and yellow poplar are relatively large-crowned and shallow-rooted and did not lose their foliage in the wind. These combined factors contributed to the large number of uprooted stems of these species (Photo 2).

HOBCAW FOREST

Land Use History and Description

The Hobcaw Forest contained parts of 13 plantations during the eighteenth and nineteenth centuries. As with the Santee during this time period, rice was a major crop and evidence of its culture is still apparent. The Hobcaw forest was purchased in 1905 by Barnard M. Baruch and, because it was maintained as a hunting preserve and winter retreat, it was not heavily logged during the early twentieth century. The property was willed to the colleges and universities of South Carolina by Belle W. Baruch in the 1960's to be used for research and education in forestry, wildlife, and marine biology.

Research efforts on the Hobcaw Forest began in the late 1960's and since that time have focused primarily on insects, wildlife, vegetation, hydrology, and forest regeneration techniques. Major research efforts have been made on the ecology and management of feral hogs, red-cockaded woodpeckers, fox squirrels, and songbirds. In addition, an important effort quantifying the hydrologic inputs from a managed coastal forest into the relatively undisturbed North Inlet estuary has been undertaken.

The Hobcaw Forest is 3000 ha in size, and is primarily an old coastal pine forest. Pine and pine-hardwood stands occur on 2511 ha and contained 126,000 m^3 (26.1 million bf) of pine sawtimber and 35,900 m^3 (18,000 cords) of pulpwood based on a 1986 inventory. Hardwood stands occur on 489 ha and contained 15,000 m^3 (3.1 million bf) of hardwood sawtimber and 31,500 m^3 (15,800 cords) of pulpwood in 1986. The area in each forest type is given in Table 1 and the type descriptions are essentially those given for the Santee Experimental Forest.

Soils on the forest have developed on sandy former beach ridge topography. Ridges are predominantly Leon (Aeric Haplaquods) and Centenary (Grossarenic Entic Haplohumods) and intermediate swales are primarily Lynn Haven (Typic Haplaquods) and Rutledge (Typic Humaquepts).

Wind Damage

Preliminary estimates of losses due to wind damage were 19,900 m^3 (3.9 million bf) of pine sawtimber (10.9%), 1365 m^3 (684 cords) of pine pulpwood (4.5%), 4650 m^3 (912 thousand bf) of hardwood sawtimber (25.9%), and 15,130 m^3 (7576 cords) of hardwood pulpwood (39%). Wind damage was evaluated on the ground by 0.1 hectare strip plots located in each stand less than 20 ha and two plots in each stand over 20 ha for a total of 355 plots. In each plot all trees over 10 cm dbh (diameter at breast height--1.37 m above the soil surface) were tallied by species, diameter and one of eight damage codes: (1) undamaged, (2) defoliated, (3) bent, (4) branches broken, (5) top broken, (6) stem broken, (7) uprooted-leaning, and (8) uprooted-on the ground. Trees in the "stem broken" category have the main stem broken between the ground and the first limb. Those in the "top broken" category have

Photo 2--The remains of a red-cockaded woodpecker (*Picoides borealis*) colony site in a 100-year-old longleaf pine (*Pinus palustris*) stand on the Francis Marion National Forest in South Carolina after Hurricane Hugo.

the main stem broken between the first limb and the terminal shoot. Uprooted-leaning trees were uprooted but fell into another tree and did not reach the ground. Uprooted-on the ground trees were uprooted and fell all the way to the ground.

The ground survey was incomplete at the time of writing, but 119 plots were compiled to give preliminary indications of wind damage. The number of trees tallied in each species was proportional to the relative abundance of the species on the forest. Of the 4380 trees tallied, 2490 were loblolly pine, 520 were longleaf pine, 440 were sweetgum, 330 were laurel oak, 300 were black gum, 155 were water oak, 116 were live oak (*Q. virginiana*), 64 were southern red oak and 60 were cypress.

With the exception of longleaf pine, the resistance to wind damage, by species, was found to be similar to the general list of wind resistance found in Barry and others (1982). The proportion of stems undamaged ranged from highs of 73% in longleaf pine, 51% in live oak and 48% in loblolly pine to a low of 15% in water oak and 24% and 26% in southern red and laurel oak, respectively. Alternatively, the portion of broken or uprooted stems varied from a low of 0 in live oak and cypress to highs of 22% in water oak and 18% in southern red and laurel oak.

Tree species could be grouped by the mechanisms of resistance to wind damage. Live oaks have very strong wood and large spreading crowns. Limbs were broken on 34% of the stems and tops were broken on 7% of the stems. Average diameters of stems with broken limbs (33.8 cm) and broken tops (37.5 cm) were much larger than undamaged trees (22.1 cm). Defoliation was most common in cypress and black gum.

Fifty percent of the cypress and 64% of the black gum were defoliated. No cypress and only 2.3% of black gum were uprooted or broken. Average diameters of black gum with broken tops and stems was 42 cm compared to 28 cm for defoliated stems and 31 cm for undamaged stems.

Three species of oak with tall growth form (water, laurel, and southern red) were the most severely damaged. For all three species more than 75% of all stems were damaged. Six percent of each species had stems broken but water oak (which usually grows on more poorly drained soils) had 18% uprooted compared to 12% for the other two species. Average diameters of undamaged trees were smaller than those of damaged trees. For example, undamaged water oak, laurel oak, and southern red oak had mean diameters of 13.8 cm, 15.8 cm, and 17.3 cm, respectively, while uprooted and broken stems of water oak, laurel oak, and southern red oak had mean diameters of 22 cm, 25 cm, and 35 cm, respectively.

Longleaf pine resistance was better than would be expected from its rank in the list included in Barry and others (1982). Seventy three percent of all stems were undamaged and only 5.2% were broken and uprooted. Undamaged stems averaged 29 cm in diameter while broken and uprooted trees averaged 39 cm in diameter. These results may be due to the unusual condition of longleaf pine on the forest. All stands of longleaf are over 70 years old. All but a few of these stands were cut in the 1950's and 1960's and had residual basal areas of 9 to 18 m^2/ha (40 to 80 ft^2/acre) when the hurricane struck (Williams and Lipscomb, 1989). The longleaf pine trees on Hobcaw forest had been growing in open stands for 30 to 40 years prior to the hurricane.

Only 48% of loblolly pine stems were undamaged and those stems averaged 16.4 cm in diameter. Eight percent of all loblolly stems were broken and uprooted and those were twice as large, averaging 32 cm in diameter. Loblolly pine was the only species that had enough stems to examine damage in each diameter class. Undamaged stems decrease progressively from 60% of all stems in the 10-20 cm class to <25% in the 50-60 cm class. Conversely, the uprooted and broken stems increase from <5% in the 10-20 cm class to 30% in the 50-60 cm class.

Spatial distribution of wind damage to the forest has been evaluated with large scale (1:6000 rf) aerial photographs taken on October 12th. Under 8x magnification, individual broken and uprooted trees can be identified on these photographs. Each of the forest stands was classed as lightly, moderately, or heavily damaged as determined by the portion of the stems in that stand identified on the photographs as broken or uprooted. Heavy damage was restricted mainly to poorly drained bottomland hardwood and pine-hardwood stands and to pine stands that had been thinned within the last three years. Light damage was found in cypress ponds and closed canopy pine stands.

Tidal Surge Damage

Although wind damage was widespread, major damage was also done by salt, both windblown and carried by a storm surge approximately 3 meters above sea level. The hurricane struck the coast near the time of high tide. Most instruments on the eastern side of the forest were destroyed by the surge, but two water level recorders on shallow groundwater wells recorded elevations of the surge until floats emerged from the well tops. From the records and elevations of these two recorders it can be established the tide was from 3.0 to 3.2 meters above sea level from 2330 on September 21, 1989 to 0130 on September 22.

Mortality due to salt water infiltration from the storm surge accounted for a loss of 22,200 m^3 (4.6 million bf) of pine sawtimber (13%), 11,400 m^3 (5700 cords) of pine pulpwood (33%), 1050 m^3 (226 thousand bf) of hardwood sawtimber (6.4%) and 4200 m^3 (2100 cords) of hardwood pulpwood (10.7%). Tree mortality became apparent in early December. Mortality was most pronounced in closed depressions and along either side of drainages near the southern end of the forest. Wet weather prior to the hurricane limited the amount of salt water that directly infiltrated during tidal inundation. The records from the operating wells with water level recorders and charts recovered from those made inoperative show that the water table in the aquifer was near the surface in all the depressions and within a meter of the surface at the top of the ridges. Both the limited opportunity for immediate infiltration and the pattern of tree mortality suggest that infiltration of trapped water after the storm was the main mechanism of mortality. Along the southern end of the forest, ridges and swales of the relic beach ridge topography are pronounced. A series of north-south ridges extend from the western side of the salt marsh. Ridge tops are about 300 meters apart and are separated by swales about 50 meters wide and 1 to 1.5 meters below the adjacent ridges. Each ridge is about 1 meter higher in elevation than the ridge to its east. The surge covered three ridges on the southern end of the forest. As the surge receded each ridge drained rapidly to the east. However, water within the swales was blocked by the next ridge to the east and drained slowly to the south in channels clogged with uprooted trees.

In December, groundwater conductivity was measured on three transects of piezometers across a ridge swale watershed in the area covered with salt water. Conductivity in groundwater beneath the swale ranged from 10 to 15 millimhos/cm while along the eastern ridge values of 3-5 millimhos/cm were recorded. Franscois (1980) found many pine species could not survive when conductivity of soil water exceeded 5 millimhos/cm and very few plants could tolerate values higher than 10. On this one watershed the pattern of high salinity groundwater and tree mortality were similar.

FUTURE PROBLEMS

The greatest risks to the remaining trees are fire and insect attack. Normal amounts of fuel in the coastal plain forest are approximately 4-16 metric tons/ha. In the wake of the hurricane, fuel loads are in excess of 135 metric tons/ha[10], greatly increasing both the danger of a large fire and the difficulty of suppression.

Surveys of the FMNF show that insect infestation of the down and damaged trees is occurring. Table 3 shows the extent of infestation by 3 southern species of *Ips. spp.* bark beetles. Southern pine beetles (*Dendroctonus frontalis*) are beginning to be found in insect traps in the impacted area[11]. Attacks of these insects are fatal. On the area of Hobcaw Forest impacted by the storm surge, large numbers of trees not killed by salt intrusion are now dying from attacks by southern pine beetle and *Ips*.

SUMMARY

Within the eyewall, where winds were 43 to 66 ms^{-1}, there was little difference between the wind resistance of longleaf pine, loblolly pine, and bottomland hardwoods, with 89%, 91%, and 86% of the trees broken or uprooted, respectively. However, on Hobcaw Forest, about 100 km from the center of the eye, 73% of the longleaf pine was undamaged, 48% of loblolly pine was undamaged and 80% of the bottomland hardwoods were undamaged. Species resistance to wind damage was not meaningful within the area impacted by the eyewall of this Category 4 hurricane. Outside of the eyewall, however, species resistance to wind damage greatly affects the composition of the remaining forest.

Table 3--*Ips. spp.* bark beetle activity on the Francis Marion National Forest as of mid-April, 1990.[a]

	Tree Damage Category			
	Green Trees	Broken Tops	Bole, Top Removed	Windthrown
Number trees sampled	0	52	45	23
Number infested trees	0	52	42	23
Percent infested	0	100	93	100

[a] Trip report on bark beetle and other pest activity in Hugo damaged timber, Francis Marion National Forest, South Carolina. Patrick J. Barry, State and Private Forestry. May 18, 1990.

ACKNOWLEDGMENTS

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[10] South Carolina Forestry Commission. Hurricane Hugo Update. April, 1990.
[11] Barry, Patrick J. Trip report on bark beetle and other peat activity in Hugo damaged timber. Francis Marion National Forest, South Carolina. United States, Department of Agriculture, Forest Service, Southeastern Area State and Private Forestry, Pest Management, May 18, 1990.

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ASSESSMENT OF HURRICANE DAMAGE TO THE SANTEE EXPERIMENTAL FOREST AND THE FRANCIS MARION NATIONAL FOREST WITH A GEOGRAPHIC INFORMATION SYSTEM

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INTRODUCTION

The Santee Experimental Forest (SEF) experienced the full force of the eyewall of Hurricane Hugo and sustained extreme wind damage (Hook and others 1991). Preliminary estimates indicate that 80 percent of the trees on the experimental forest were blown down or damaged to the extent that they will not recover. Aerial photographs made immediately after the storm and subsequent measurements on a few plots show that the tallest and largest (dominant) trees were damaged most. Those trees in the midstory and young regeneration suffered less damage. Loblolly pine (*Pinus taeda*) appeared to suffer the greatest amount of stem and top breakage of any species on the forest. In contrast, losses of large-crowned hardwood species, such as Shumard oak (*Quercus shumardii*), cherrybark oak (*Q. pagoda*), and yellow poplar (*Liriodendron tulipifera*), were primarily due to uprooting.

Although reports are available on hurricane damage for other regions of the East and South, very little is available for the Carolinas. Furthermore, Hurricane Hugo was a category 4 storm and affected a larger area and downed more timber than any previous natural catastrophe in the U.S. (Hook and others 1991). Thus, a unique opportunity exists to study the effect of a major storm on the forests of this region and help unravel the role that hurricanes play in shaping the forests of this region.

Geographic Information Systems (GIS) were not available to help assess past hurricane damage. However, the newly acquired GIS of the Francis Marion National Forest (FMNF) proved to be helpful in making management decisions on Hugo recovery actions on the forest (Rivenbark 1990). Research has not fully explored the role that GIS can play in assessing damage, analyzing management choices, and evaluating the impact of hurricanes on the ecology of coastal forests (Mead and others 1990). This study attempted to determine the ability of GIS to analyze relationships between or among site, stand, management conditions, and approximate wind velocities as they related to damage classes on the SEF and FMNF. Since considerable historical and scientific data were available for many sites on the SEF, there was an opportunity and need to capitalize on this information to determine how prior site and stand characteristics influenced the level of hurricane damage to specific forest types.

This study was limited to the SEF and selected forest types on the FMNF. Existing information on stand characteristics, species, soils, hydrology, and past management activity was used to determine if they were related to stand damage classes within the eyewall and progressively away from the eyewall to the northeast on the FMNF. This information allowed us to evaluate, in an indirect way, the factors that played significant roles in predisposing the forest to hurricane damage in relation to wind forces. Near the center of the eyewall, there was almost total destruction of all age classes.

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Influence of individual stand conditions and soil/site differences appeared to be expressed as the distance from the eyewall increased to the northeast and wind speed decreased. The purpose of this study was to determine if GIS technology could effectively ferret out soil characteristics, prior stand conditions, hydrology, and prior management activities that influence the resistance of coastal forests to hurricane damage.

MATERIALS AND METHODS

Low level aerial photographs of the SEF were taken and delineated for cover type, size and density by private contractor. This photography and its interpretation were used to help build a GIS database for the SEF. Pre-Hugo aerial photo stand delineations were digitized in Arc/Info®, a vector-based GIS software and, along with the USDA soils and the USDI National Wetlands Inventory maps, were overlaid with post-Hugo aerial photo-delineations. An improved wetlands map was created by GIS overlay of digitized color-infrared aerial photos with a Global Positioning System (GPS)-augmented, field-corrected wetlands map, which was then "rubber-sheeted" to conform to the compartment and hydrology base maps. Photo delineation of pre- and post-Hugo stands, photo estimation of stand density and product size classes and regression prediction of number of trees and basal area per acre, and timber volumes, done under separate contract, were used to develop a GIS database of stand damage based on difference in pre- and post-Hugo stand condition. GIS was used to evaluate the pre- and post-Hugo aerial photo stand cover type delineation. Once the wetlands had been delineated, overlaid and mapped, the data were entered into the existing GIS database for the SEF and used for analytical purposes to evaluate soil, stand, and previous management influence on hurricane damage. The GIS software, Arc/Info®, was used in conjunction with existing data on stands, soils, hydrology, prior management activities and wind speed to assess the following:

1. spatial distribution of stand damage in relation to physical and chemical soil characteristics of delineated and mapped wetland landscapes on the SEF.
2. species and stand characteristics that predispose stands to hurricane damage along a wind gradient on the FMNF.
3. effect of prior stand management/condition on hurricane damage.

Specifically, for the SEF, stand, soils, wetlands, and hurricane wind field maps of the SEF were digitized into Arc/Info® and overlaid such that a large database (4500 entries) was created of the spatial coincidences of these factors. A revised, small-scale wind field map of Hugo on South Carolina, created from aerial damage surveys by T. Fujita of the University of Chicago (Powell and others 1991), was provided by the U.S. Forest Service Laboratory in Charleston, SC. Soils information and series polygons were digitized from USDA Soil Conservation Service county soil maps of the study area. In addition, compartment maps of an on-the-ground, post-Hugo damage assessment of the SEF, also provided by the Charleston Laboratory, were point-digitized into the Arc/Info® database. This assessment was an extensive ground sample consisting of 0.1 acre plots done along transects on approximately 3 x 5 chain (66 feet) grids resulting in a theoretical digitized resolution of 1.5 acres. Thiessen Polygon Logic was used with Arc/Info® to convert the ground points (plot centers) to a "cover type" polygon map equivalent to a "stand" map. We felt that this gave a better resolution, damage assessment and stand coverage than the post-Hugo photo delineations by the contractor.

Stand damage was based on loss in basal area (difference in pre- and post-Hugo) as derived from the ground sample plots and separated into three classes of damage, light, medium and heavy. Relationship of the variables was examined by correlation analysis to provide a preliminary evaluation of the influence of predisposing site, stand, and wind speed factors. Stand variables examined were cover type, product size, basal area, and stand condition including density and size of trees (USDA Forest Service 1988). Soil variables used were standard soil series characteristics, e.g., surface texture and thickness, drainage class, depth to mottling, hydricity, and flooding propensity, frequency and duration. Wind speeds were spatially interpolated directly from the digitized wind field map using a 5th order polynomial in TIN®, an Arc/Info® module. These interpolated wind speed values were assigned to the existing soils polygons in which they were located. There was little variation in wind speeds on the SEF, most exceeded 100 miles per hour (mph). Also, resolution of the small-scale wind field map was low, approximately ± 10 chains.

Subsequent to this analysis of the SEF damage, we received an extensive Arc/Info® digital data set of the FMNF from the South Carolina National Forest Management Headquarters in Columbia. This data set was very large, producing 27,000 samples after overlaying the stand and soils maps with the interpolated wind speeds across the Witherbee and Wambaw Districts of the FMNF. Much of the same data as obtained for the SEF was included in the FMNF database, except that it was already digitized and polygonized into stand format with soil polygons within the stands. This data set had already been assigned stand damage classes based on differences in pre- and post-Hugo trees and basal area per acre. Only the pine cover types, mainly loblolly and longleaf (*P. palustris*) pine, and the poletimber and sawtimber size stands had been examined and assigned a damage class. Removal of all non-pine stand samples from the data set left about 15,000 samples. Again, a preliminary correlation analysis of the data was performed to evaluate variable performance and rogue nonessential variables.

Examination of the data revealed that there were many multiples of the same damage and stand condition class with different soil and wind speed values, thus, greatly diluting the influence of these variables on damage class. We consolidated all variables at the stand level, averaging continuous variables (soil surface thickness, depth to mottling, wind speed, etc.) and taking the mode of discontinuous variables (drainage class, texture, flooding frequency, etc.). These steps resulted in about 11,000 samples remaining, which were now simple stand polygons, with single values for all variables to be used in the analysis. The consolidation also more closely matched the resolution of the wind speed data.

Discriminant Data Analysis

The first step in the data analysis consisted of some minor editing and simple statistics. Means, correlations, and other summary statistics were run by damage classes, by forest types, by soil/site variables, wind speed and stand conditions (SAS 1989). We determined that discriminant analysis would be the appropriate method by which to characterize the damage classes (Afifi and Clark 1990, SAS 1989). By using the initial summary statistics and stepwise discriminant analysis, the following variables were selected for development of the discriminant function:

Stand condition (STCN)
Soil surface texture (SURFTEX)
Soil surface thickness (SURFTHK)
Soil depth to mottling (DEPMOT)
Ratio of soil surface thickness to depth to mottling (THKMOT = SURFTHK/DEPMOT).

The data set was stratified by wind speed into three wind speed classes and a separate discriminant function developed for each class. The wind speed classes are as follows: low = 77-91 mph; medium = 92-105 mph; high = 106-120 mph.

It was very difficult to discriminate between the light and medium damage classes on the FMNF using the available data. Accuracies of classification ranged from 61 to 69 percent when all three damage classes were used. The heavy damage class was always classified with accuracies greater than 90 percent, but the light and medium damage class accuracies were no more than 50 percent. Since the Wambaw District stands had not been assigned a medium damage class, pooling the light and medium damage classes resulted in considerable improvement in the accuracy of classification between a "heavy damage" class and a "light damage" class.

The FMNF data set was divided into two parts, one for fitting the discriminant function and the other for cross-validation of the resulting model (Afifi and Clark 1990). Separate discriminant functions were then developed for each wind speed class and checked for accuracy. In cross-validation the discriminant function is computed for a set of samples, then used to classify a different set of samples to estimate the proportion of samples correctly classified. The FMNF data were divided by extracting every other sample, resulting in about 5,000 samples each in the two new data sets, one to be used to develop the discriminant function, the other for cross validation.

RESULTS

Santee Experimental Forest

A GIS database was developed in Arc/Info® for the SEF and its forested wetlands and conveyed to the Forestry Sciences Lab in Charleston where one of the authors assisted in its installation on the resident Arc/Info® system. Having GPS-located ground points available greatly improved the wetlands mapping process. Pre- and post-Hugo photo stand delineations were compared by overlaying in Arc/Info®. The results indicated that the contractor had a 20 percent error or difference between pre- and post-Hugo aerial photo delineations of cover types or stands. The error consisted mostly of post-Hugo delineation of hardwood cover types as pine cover types, with very few pine stands being delineated as hardwood on the post-Hugo photos. Part of this error resulted from using different delineation criteria with the post-Hugo photos. The post-Hugo delineations, which were very difficult to begin with because of the heavy damage (loss of overstory), were altered with GIS overlay to conform to the pre-Hugo stand/cover type delineations and used to develop the GIS database of the SEF. It would have been helpful if the photo-delineation of post-Hugo conditions could have been done with the aid of a GIS-generated, pre-Hugo overlay to outline the former stands and note their pre-Hugo cover type.

The ground damage assessment of the SEF was overlaid onto the stand coverage and reconciled with the other sources of spatial information, such as the USDI Fish and Wildlife Services' NWI wetlands delineation, resulting in a well-delineated digital database to spatially analyze. Results of the initial correlation analysis, however, indicated no damage predictive capability of any stand or soil variable, as correlation coefficients were all less than 0.14. Stepwise regression analysis produced R-square values less than 0.02. Although disappointing, these results were not surprising in view of the extensive, heavy damage that occurred throughout the SEF. Wind speeds were at eyewall velocities (≥ 105 mph) throughout the SEF after Hugo's landfall (Hook and others 1991), and probably overwhelmed any inherent resistance to damage.

Francis Marion National Forest

Initial results of correlation analysis of the GIS-overlaid data from the Witherbee and Wambaw Districts of the FMNF were encouraging. At least one variable, stand condition class, a Forest Service characterization of the size and density of the trees (USDA Forest Service 1988), stood out as a good damage predictor variable. During stepwise regression analysis, variation in stand condition accounted for 48 percent of the variation in stand damage; no other variable accounted for more than 1 percent of damage variation. Initial stepwise discriminant analysis (Afifi and Clark 1990, SAS 1989) not only highlighted stand condition as a good predictor of damage, but also resulted in 90+ percent accuracy of predicting high damage. However, no separation of the light and medium damage classes was feasible as accuracies were 50 percent or less. After the light and medium damage class samples were combined into a "light" damage class, the discriminant functions immediately improved to a 93 percent accuracy.

After further refining the data sets by stratifying into 3 wind speed classes and rerunning the stepwise discriminant analysis, overall classification accuracy was 95 percent for the low and medium wind speeds and 85 percent for the high wind speed. In addition, variables other than stand condition, e.g., soil surface thickness and texture, and depth to mottling, became statistically significant contributors to classification accuracy.

The following discriminant functions were computed for each wind speed class. The notation follows Afifi and Clark (1990).

Wind Speed Class	Discriminant Function Coefficients
High	$Z = 1.16246\ (\text{STCN}) - 0.00427\ (\text{SURFTEX}) - 0.04389\ (\text{SURFTHK}) + 0.03250\ (\text{DEPMOT}) + 0.54477\ (\text{THKMOT}),\ C = 9.67983$
Med	$Z = 3.10135\ (\text{STCN}) - 0.07802\ (\text{SURFTEX}) - 0.02894\ (\text{SURFTHK}) + 0.05451\ (\text{DEPMOT}) + 0.09913\ (\text{THKMOT}),\ C = 27.22875$
Low	$Z = 2.73050\ (\text{STCN}) + 0.06318\ (\text{SURFTEX}) + 0.01501\ (\text{SURFTHK}) + 0.01184\ (\text{DEPMOT}) + 0.02835\ (\text{THKMOT}),\ C = 23.91123$

For a new sample stand, the procedure is to calculate a Z-value for each wind speed class, compare the Z-value to C; if Z is greater than the appropriate C then the sample is classified as "light damage" class, otherwise the sample is classified as "heavy damage" class.

The average error rate using the cross-validation procedure with wind speed classes was 9.4 percent. Incorporating the wind speed classes in the computation of the discriminant functions resulted in a 3.7 percent increase in accuracy. The reduced errors (< 5 percent) in the low and medium wind speed classes, which ranged from 77-91 mph and 92-105 mph, respectively, indicate that, as suspected, at less-than-eyewall velocities, the soil and site variables interact with the stand condition to improve prediction of damage class. The damage prediction error for the high wind speed class is nearly 15 percent, which indicates an increasing potential for a hurricane to overwhelm the influence of stand, soil and site variables in resisting damage with winds exceeding 105 mph. Summary statistics (Tables 1-3) indicate that sparse sawtimber was damaged most, immature poletimber was damaged least and, of the soil variables, only surface thickness differed enough to have influenced stand resistance to wind damage at all windspeeds.

DISCUSSION

Assessment of forest damage caused by Hurricane Hugo was greatly facilitated by the development of an Arc/Info® GIS-database for the SEF and FMNF. GIS overlay made it possible to assign wind speed and soil attributes to stands and evaluate their effects on damage resistance. The initial analysis of the SEF data indicated that wind speed at or near the eyewall of the hurricane was so great and damage so extensive that any inherent damage resistance features of the SEF stands, such as prior stand condition, soil/site variables, or the effect of small differences in wind speed had little or no mediating effect on the destructiveness of the high winds. The resolution of the database was sufficient to have detected any relationship between damage and stand factors if it existed, as stands and soil polygon data were at a resolution of at least ± 3 chains (198 feet) and more likely were closer to the 30 meter (α 100 feet) resolution of the digital soils data.

The availability of the existing FMNF GIS database of stand condition class and stand damage was very helpful and initial correlation analysis indicated that pre-Hugo stand condition was a strong predictor of resistance to wind damage. Overlay of soils and wind speed data made it possible to examine their effects on wind damage resistance of stands. Discriminant analysis resulted in excellent initial prediction of stand resistance to wind damage (85 percent accuracy). Stand condition continued to be the best predictor of stand resistance to hurricane wind damage ($R^2 = 0.70$). Reducing the damage classes to light and heavy and adding wind speed classes, improved overall damage prediction from 87 percent to 92 percent accuracy. As wind speed increased, damage became more random, i.e., overall prediction of damage was less accurate (86 percent) in the high windspeed class.

The average stand condition incurring heavy damage across all wind speeds was 6.14 or sparse sawtimber (Table 1). Nearly 90 percent of all heavily damaged stands were sparse sawtimber (Table 2). The average stand condition incurring light damage across all wind speeds was 10.83 or very close to immature poletimber (Table 1). Over 80 percent of all lightly damaged stands were immature poletimber or sawtimber (Table 3). It is obvious that larger, more widely-spaced pine sawtimber stands suffered the most damage from Hugo among the pine stand condition classes examined (Figure 1). It is equally as obvious that smaller, more closely-spaced pine poletimber stands were resistant to damage from Hugo's winds (Figure 1). It is probable that the wedging or lifting effect of the denser, shorter, immature poletimber-sized stands deflected the wind force upward and over them, while the mutual support of stems at close intervals provided some degree of protection from breakage or uprooting. Stem flexibility might also have contributed to resistance to damage, especially that of wind breakage.

Some of the soil/site variables might have differed enough to have caused some stand wind damage resistance (Table 1). Soil surface thickness, depth to mottling, and surface thickness/depth mottling differ

Table 1. Mean pre-Hugo stand and site variables for wind speeds and damage classes used in the analysis of pine stand wind damage during Hugo on the Francis Marion National Forest.[1]

WINCLS	DAMAGE	STCN	SURFTEX	SURFTHK	DEPMOT	THKMOT
Summary Stats for 1/2 Data Set Used for Fitting Model						
High	HD	6.1 **	2.6 NS	14.1 *	13.5 NS	1.0 NS
High	LT	10.0	2.5	15.4	14.0	1.0
Med	HD	6.1 **	2.8 *	11.8 **	12.7 NS	1.0 **
Med	LT	11.2	2.6	15.1	13.0	1.2
Low	HD	6.2 **	3.0 NS	10.1 **	9.8 **	1.2 **
Low	LT	11.0	2.8	13.1	12.9	1.3
Summary Stats for 1/2 Data Set Used for Cross-Validation						
High	HD	6.1 **	2.6 **	14.5 **	13.4 *	1.0 **
High	LT	10.2	2.3	16.4	14.6	1.0
Med	HD	6.1 **	2.9 **	11.9 **	12.1 *	1.1 *
Med	LT	11.2	2.6	14.3	13.2	1.1
Low	HD	6.2 **	2.8 NS	10.9 **	11.0 **	1.2 **
Low	LT	10.9	2.9	13.0	12.2	1.3

[1] STCN = stand condition class; STCN 6 = sparse sawtimber; STCN 10 = mature sawtimber; STCN 11 = immature poletimber
NS not significantly different at the .05 level of probability within wind class
* significantly different at the .05 level of probability within wind class
** significantly different at the .01 level of probability within wind class
SURFTEX = soil surface texture class; 1-8, sandy through clayey textures
SURFTHK = soil surface thickness; range = 1-50 inches
DEPMOT = soil depth to mottling; range = 3-50 inches
THKMOT = soil surface thickness/depth to mottling; range = 0.05-3.00

Table 2. Distribution of heavily damaged longleaf and loblolly stands among wind speed and stand condition classes on the Francis Marion National Forest after Hugo.

Covertype	Wind speed Class	No. Stands Heavily Damaged	Distribution (%) Sparse Poletimber	Sparse Sawtimber
Longleaf (3,396)	High	701	7.8	84.1
	Med	127	9.4	88.1
	Low	671	0.3	93.9
	SUBTOTAL	1499	4.6	88.8
Loblolly (7,446)	High	1199	7.0	91.6
	Med	1114	2.9	93.7
	Low	1191	15.4	79.6
	SUBTOTAL	3504	8.5	88.2
Both (10,842)	TOTAL	5003	7.3	88.3

Table 3. Distribution of lightly damaged longleaf and loblolly stands among wind speed and stand condition classes on the Francis Marion National Forest after Hugo.

Covertype	Wind speed Class	No. Stands Lightly Damaged	Distribution (%) Stand Condition Code[1] 10	11	12	All
Longleaf (3,396)	High	553	15	49	31	95
	Med	545	5	38	57	90
	Low	799	30	20	49	99
	SUBTOTAL	1897	18	33	46	95
Loblolly (7,446)	High	602	0	52	20	72[2]
	Med	1158	7	38	51	96
	Low	2182	12	45	39	96
	SUBTOTAL	3942	9	44	40	92
Both (10,842)	TOTAL	5839	12	40	42	93

[1] Stand condition codes are defined as follows: #10 - mature sawtimber; #11 - immature poletimber; #12 - immature sawtimber

[2] About 28% of the lightly damaged loblolly stands in the high wind class were in stand condition classes 5 and 6, sparse pole and sawtimber. No explanation for this anomaly has been forthcoming.

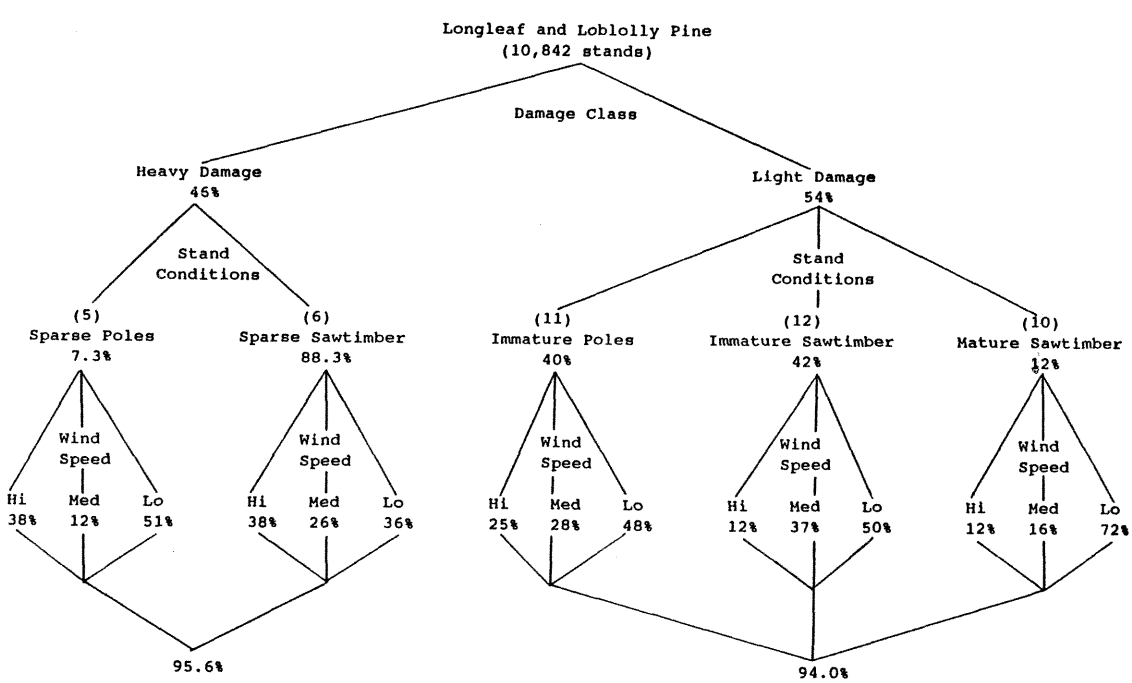

Figure 1. Distribution of loblolly and longleaf pine stands among damage and prior stand conditions after Hugo on the Francis Marion National Forest.

significantly between the high damage and low damage classes at low and medium windspeed (Table 1). Surface texture, a class variable, should not be considered in the same light as the other variables, as the small difference in values, though statistically significant, would provide no real difference in texture of the soil to contribute wind resistance to the stand. In addition, the small difference in any of the soil variable means at the highest windspeed could not have made any real difference in damage incurred. However, as much as 2-3 inches difference in soil surface thickness and depth to mottling at low and medium wind speeds may have actually contributed some wind resistance to the FMNF pine poletimber and sawtimber stands during Hugo. It is hoped that, eventually, damage classes will be assigned to the rest of the forest cover types on the FMNF so that a GIS-based assessment of the relationship between stand, soil, and site variables can be done for the hardwood stands, especially the bottomland and wetland stands.

ACKNOWLEDGMENTS

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HURRICANE HUGO DAMAGE ASSESSMENT OF BOTTOMLAND HARDWOODS IN SOUTH CAROLINA

Kenneth Pittman, R. C. Kellison, and Russ Lea[1]

Abstract--Of the 1.732 million acres of bottomland hardwoods in the 23-county area affected by Hurricane Hugo, 1.329 million acres suffered storm damage. However, the hardwood growing stock on the area was reduced by only six percent, from 5.1 to 4.8 billion cubic feet, from immediate mortality. Delayed mortality of hardwoods is expected to reduce the growing stock to an accumulated total of 20 percent which is comparable to the immediate mortality of softwoods. Trees of increasing diameter were more subject to windthrow than those of smaller size. Trees most subject to severe damage (windthrow) were the oaks, red maple, and yellow-poplar. The gums, occupying the swamps, were least damaged. Regardless of species, the stands most severely damaged were those of medium stocking; i.e., from 60 to 69 percent stocked. Recommendations are given for managing the damaged stands.

INTRODUCTION

Hurricane Hugo, packing winds of 135 miles per hour, struck the mainland at Charleston, SC on September 21, 1989. Travelling northwestward, it wreaked havoc to all within its path until it exited the state at Rock Hill during the morning hours of September 22 (Figure 1).

Aerial and ground surveys by the South Carolina State Commission of Forestry showed there to be major damage to the forests in a 23-county area within the path of the storm (Figure 2). The surveys paved the way for timber salvage, fire- and pest-control measures and regeneration planning, but they did not provide quantitative data to show how the timber supply would be affected over the next several decades. That responsibility accrued to the Forest Inventory and Analysis (FIA) Research Work Unit at the Southeastern Forest Experiment Station, USDA Forest Service, Asheville, NC. The survey conducted between February and June 1990 had the following objectives: (1) determine the volume of hurricane-related mortality and damage, (2) assess damage to merchantable and submerchantable pine plantations, and (3) quantify needed stand treatments resulting from the storm (Sheffield and Thompson 1992).

As the objectives signify and as the results verify (Sheffield and Thompson 1992), primary interest was on the pine resource, now and in the future. The hardwood data were further restricted because, in the summary results of Sheffield and Thompson (1992), the inventory of upland hardwoods was amalgamated with the bottomland hardwoods. Enough data exists, however, for us to quantify needed stand treatments (objective #3) for the bottomland hardwoods in the 23-county area.

METHODS

The post-Hugo (1990) inventory consisted of revisiting the 2,530 permanent plots in the 23-county area that had been the basis for the sixth survey in 1986 of South Carolina's forest inventory (Figure 3). Only 730

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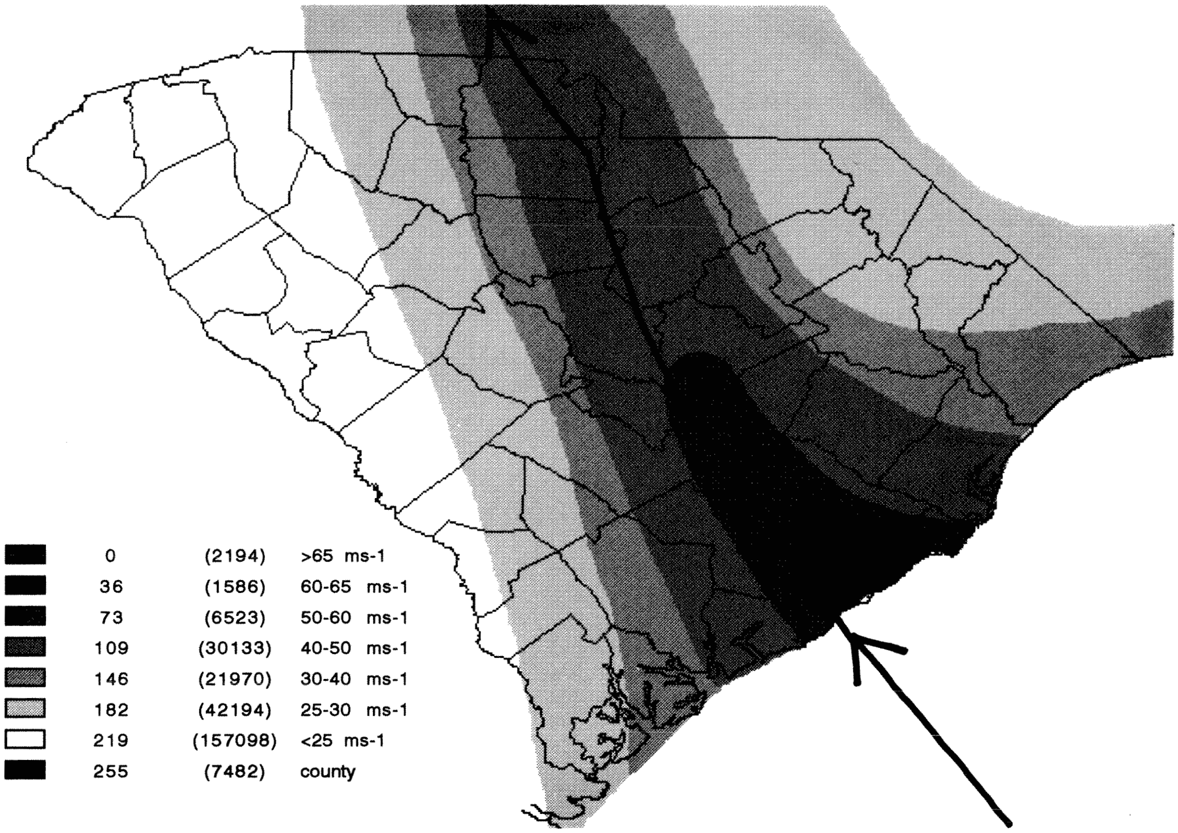


Figure 1--Peak winds (after Fijita damage directions; Powell, Dodge, and Black).

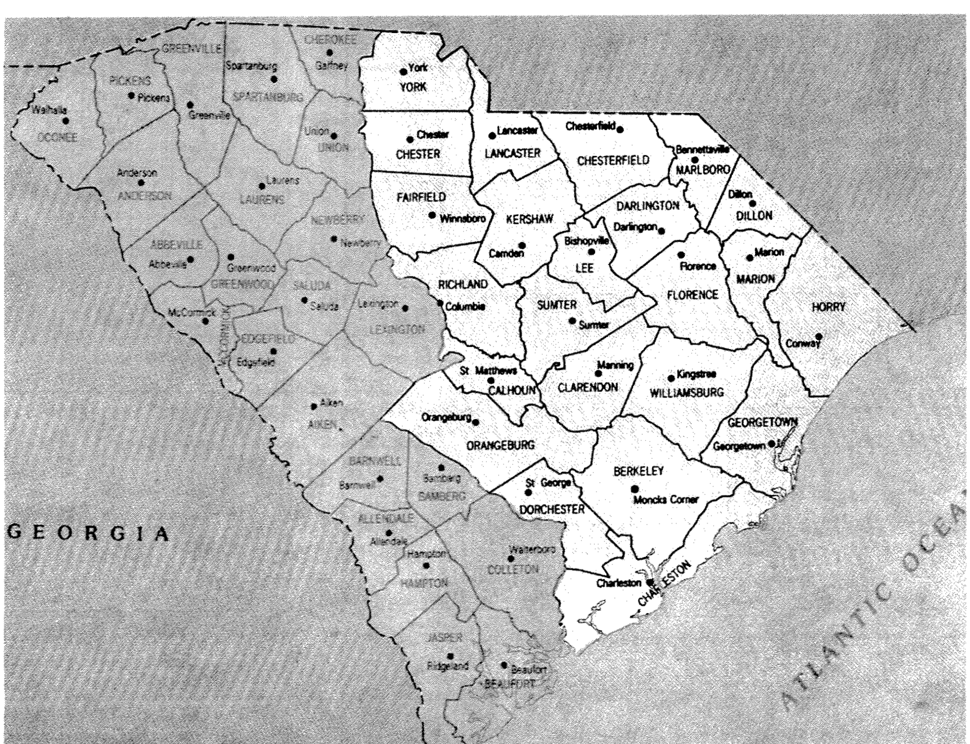


Figure 2--South Carolina counties.

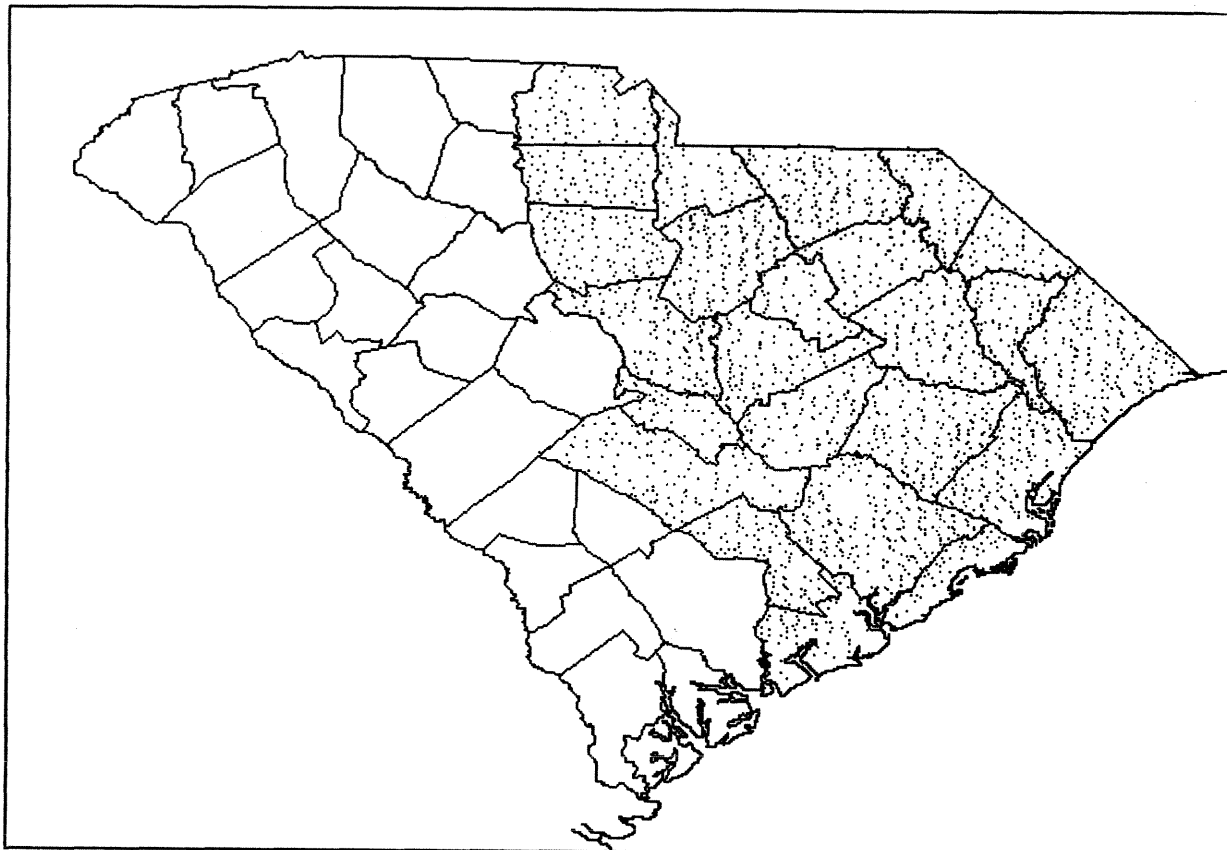


Figure 3--FIA plots for 23 SC counties.

of the plots were located in bottomland hardwood stands (FIA forest site types 60--oak/gum/cypress, and 70--elm/ash/cottonwood) (Figure 4), and all of those were in natural stands because commercial hardwood plantations do not exist in the area (Figure 2). FIA sample plots are based upon a 10-point cluster design. In most cases, five points are installed in a single forest condition using a basal area factor of 37.5 square feet per acre to sample trees 5.0 inches dbh and larger. Trees less than 5.0 inches diameter at breast height (dbh) are tallied on 1/300-acre fixed plots at each of the point centers. More detailed information about standard FIA field sampling procedures is available (Tansey and Hutchins 1988; USDA Forest Service 1991).

In the natural hardwood stands, the post-Hugo field crews accounted for each tree that was 3.0 inches dbh and larger in 1986. This procedure provided assurance that any tree that had grown large enough to have merchantable volume by 1990 (5.0 inches dbh and larger) would be evaluated. Each tree was assigned to one of six categories: (1) live, without hurricane damage; (2) live, with hurricane damage; (3) dead, hurricane related; (4) dead, not hurricane related; (5) cut, not associated with the salvage of damaged stands; or (6) cut, associated with hurricane salvage or cleanup operation, regardless of whether the tree was utilized for a product. Live trees with hurricane damage were assessed for volume loss, percentage of crown missing, lean and bend, root damage, degree of damage to the tree bole, and salt burn (Sheffield and Thompson 1992).

These assessments served as the basis for developing damage/risk classes for the trees on each plot that had not been killed outright by the hurricane. The classes reflect the likelihood of tree survival and present (or potential) value degrade. The categories were:

Class 1. High-risk tree with a high probability of dying in the near

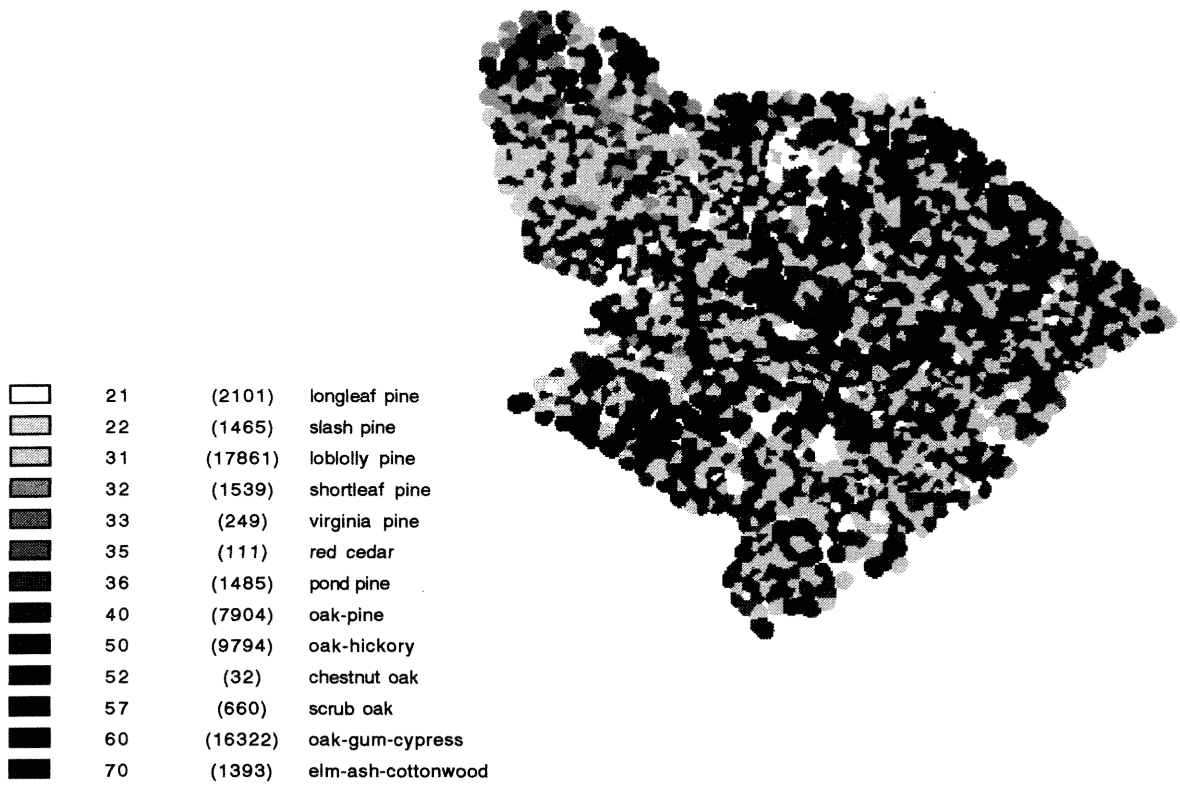


Figure 4--Forest type.

future. Damage and value loss are severe enough that this tree should not be retained in the stand.

Class 2. Moderate-risk tree with elevated risk of mortality; serious current or potential loss of value; retention in the stand is questionable.

Class 3. Low-risk tree that has a high probability of surviving, though not as high as an undamaged tree. Damage and value degrade are minimal. These trees should be retained in the stand in most management scenarios.

Class 4. Healthy. No obvious hurricane damage. A tree with hidden or internal damage was included in this category.

A complete assessment of current stocking and hurricane damage in very young natural stands was hampered because trees less than 3.0 inches dbh were not measured or sampled in 1990. Field crews did assess treatment opportunities in these stands, reflecting the degree of damage. The treatment opportunities included salvage cut, regeneration, thinning, and no action.

AFFECTED AREA AND VOLUME

Of the 6.5 million acres of timberland in the 23-county area, 4.5 million acres suffered significant storm damage. Of this total, 1.732 million acres were in bottomland hardwoods of which 1.329 million acres (77 percent) suffered storm damage. Within the damaged area, 267,000 acres had stocking reduced below manageable levels from Class #1 injury. This area is enlarged to 380,000 and 491,000 acres when Class #2 and Class #3 injury is included. In summary, no damage occurred on 403,000 acres, mortality without salvage was complete on 87,000 acres, salvage was effected on 17,000 acres, 491,000 acres had stocking levels reduced below manageable levels from Class #1, #2 and #3 damage, and 734,000 acres had damage levels below Class #3.

On a volume basis, the inventory of the combined upland and bottomland hardwood growing stock was reduced from 5.1 to

4.8 billion cubic feet (6 percent). Since the data were combined in the analysis and were not available as independent sets the assumption for this report is that the hurricane damage was comparable for both upland and bottomland forest types. The 6 percent hardwood loss is small in comparison to the loss of softwood growing stock where the comparable value is 21 percent, from 4.8 to 3.8 billion cubic feet (Sheffield and Thompson 1992). The reasons for the reduced hardwood loss are: (1) low salvage cutting--49 million cubic feet compared to 376 million cubic feet for softwoods, and (2) softwood species died more quickly following windthrow, bole breakage and crown destruction. Many of the hardwood trees--even those severely damaged--continue to show signs of life for years afterward. Some of them will eventually succumb, and others will badly degrade over the years. The estimate is that about 20 percent of the hardwoods will suffer hurricane-related mortality, comparable to the 21 percent of softwood mortality associated with Hurricane Hugo damage (Sheffield and Thompson 1992).

DAMAGE CHARACTERISTICS OF BOTTOMLAND HARDWOOD STANDS

I. Physiography

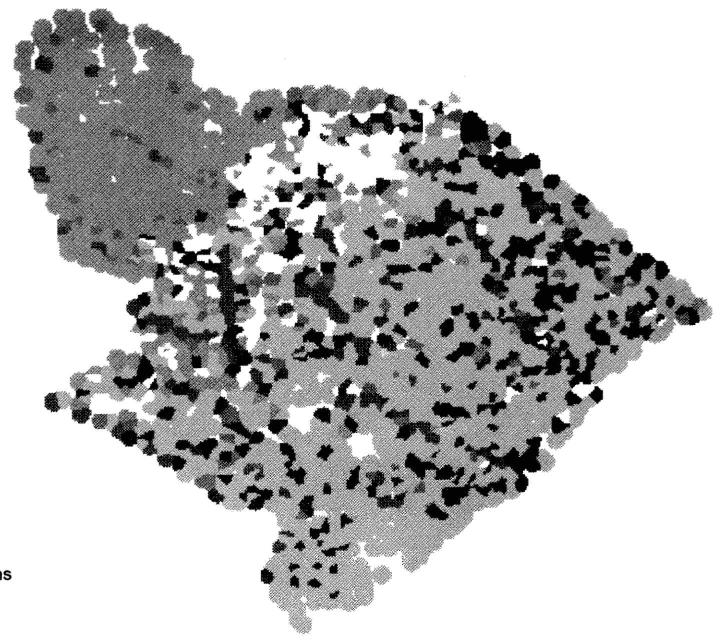
By the very nature of the hurricane, greatest damage was done nearest the coast (Figures 4, 5 and 6). Peak winds of greater than 65 m s^{-1} were encountered in northern Charleston and southern Berkeley counties. An expanded area in the same two counties experienced winds of 60 m s^{-1}. A third zone of slightly less intensity (50 m s^{-1}) encompassed nearly all of Charleston and Berkeley counties, northern Dorchester, southeastern Orangeburg, southern Clarendon, southeastern Calhoun; it pinched out in southern Sumter county. The three other bands of winds (40, 30, and 25 m s^{-1}) paralleled one another until they exited the state (Figure 1). Despite these well-defined wind zones, damage to the timber by physiographic class cannot be closely correlated because of the inclusion of bottomland and upland hardwoods into a single category.

II. Tree Size/Diameter Class

More damage was associated with trees of increasing size of hardwoods, as measured by dbh, than for softwoods (Table 1). The 1990 inventory was calculated from the more complete 1986 inventory in which adjustments were made for net growth, and regular and Hugo removals. The results for cubic volume are similar to those for sawtimber volume, so only the percentages for cubic volume are shown in Table 1. Reference is made to Sheffield and Thompson (1992), page 45 for comparable percentages on sawtimber volume. In interpreting Table 1, it is emphasized that the mortality of softwoods averaged 21 percent across the range of diameter classes whereas that for hardwoods averaged only 6 percent. Among the live softwood trees, however, no trend is evident, by diameter class, in the percent of healthy trees or in those of Damage Class #1, #2 or #3. In contrast, the percentage of healthy hardwood trees decreases sharply from 78 for the 6-inch class to 54 for the 21-inch and larger class. Similarly, no trend is evident in the damage classes (Class #1, #2, #3) of softwoods whereas a distinct change is seen for hardwoods, especially for damage classes #1 and #3. The apparent reasons for these results are that the larger-crowned hardwood trees are less subject to stem breakage and more subject to wind-throw--often without immediate mortality--than are their softwood counterparts. In addition, the root systems of bottomland hardwoods will, on average, be more shallow than either upland hardwoods or softwoods. We were unable to test for this phenomenon in this exercise because the data of the two forest types were combined.

III. Species

In addition to diameter class, some species were more subject to hurricane damage than other species. This phenomenon is in contrast to the softwoods where the predominant pines of the area (loblolly, longleaf, pond and slash) of a given size and age class all suffered about the same mortality--from 25 to 30 percent. The exception to this conclusion about softwoods is that baldcypress and pondcypress suffered only about 3 percent mortality. Those species are similar to many of the smaller-crowned hardwoods in that they can withstand tremendous wind forces without suffering stem breakage or wind throw. However, extreme epicormic branching has since been observed on these species, indicating that they were greatly stressed by the hurricane winds.



	2	(4505)	deep sands
	3	(26)	xeric
	4	(27182)	flatwoods
	5	(14909)	rolling uplands
	7	(2059)	narrow floodplains
	8	(3316)	broad floodplains
	9	(544)	mesic
	10	(2361)	deep swamps
	11	(2845)	small drains
	12	(2125)	bays and wet
	13	(1044)	hydric

Figure 5--Physiography.

	10	(413)	1.0 high damage
	13	(18)	1.3
	15	(409)	1.5
	16	(383)	1.6
	17	(269)	1.7
	18	(157)	1.8
	19	(238)	1.9
	20	(717)	2.0
	21	(251)	2.1
	22	(635)	2.2
	23	(461)	2.3
	24	(448)	2.4
	25	(1357)	2.5
	26	(527)	2.6
	27	(868)	2.7
	28	(1207)	2.8
	29	(503)	2.9
	30	(2566)	3.0
	31	(890)	3.1
	32	(1704)	3.2
	33	(1365)	3.3
	34	(1354)	3.4
	35	(1834)	3.5
	36	(2080)	3.6
	37	(1938)	3.7
	38	(2251)	3.8
	40	(33866)	4.0 no damage

Figure 6--Damage classes.

Table 1--Status of living softwood and hardwood trees following salvage operations in 1990, by diameter class, for 23 counties in South Carolina affected by Hurricane Hugo.

Diameter class (inches)	Healthy trees		Class #1[a]		Class #2		Class #3	
	Stwd	Hdwd	Stwd	Hdwd	Stwd	Hdwd	Stwd	Hdwd
	percent							
5.0- 6.9	68	78	13	8	13	7	6	7
7.0- 8.9	71	75	12	11	12	8	5	6
9.0-10.9	73	72	12	11	8	8	5	9
11.0-12.9	72	71	14	10	6	7	5	12
13.0-14.9	72	73	14	11	7	6	7	10
15.0-16.9	72	64	15	14	7	7	6	15
17.0-18.9	69	62	15	14	9	7	7	17
19.0-20.9	74	60	13	13	7	9	6	18
21.0 & larger	66	54	17	14	11	11	6	21
All classes	71	68	14	12	9	8	6	12

[a] Class #1. High-risk tree; salvage.
Class #2. Moderate-risk tree; harvest to prevent degrade.
Class #3. Retain in stand though some degrade is likely.

The hardwood species most subject to damage were the oaks, especially red oaks (Table 2). The observation is that those species were more common to the bottomlands (first bottoms and terraces) where they were likely of a larger diameter class, with concomitant large crown), and had a more shallow root system than their upland counter-parts because of a year-round high water table. Red maple also showed a propensity for severe wind damage. That damage is primarily of the wind-throw type since that species is common to the wet flats of bottomlands where it is characterized by a shallow root system.

Yellow-poplar also suffered higher than average damage, as did ash (*Fraxinus* spp.). Both of these species or species groups encountered stem breakage as the major source of damage, as opposed to wind throw. Yellow-poplar is noted for its low density wood (average specific gravity of about .42 for old-growth trees, as opposed to about .60 for both red and white oaks), with its poor strength properties. The wood of ashes is known for its resiliency, but it is also brash, meaning that when enough force is applied for breakage that it shatters parallel to the grain. Baseball bats exhibit both of these characteristics which is why ash is preferred as an implement in our national pastime.

Two classes of bottomland trees that suffered least damage were bay/magnolia and tupelo/swamp black gum. Even though unique to water saturated soils, these species have deep root systems and, thus, they encountered almost no windthrow. The relative resistance of tupelo/blackgum to wind damage is similar to that of bald cypress which is a common associate in the hydric soils of the Lower Coastal Plain.

IV. Stand Density (Stocking)

Hurricane damage to bottomland hardwoods appears to be worse in stands that were intermediate in stocking, as opposed to both high and low stocking (Table 3). For example, 43 percent of the stands that were identified as being 100 percent stocked at the time of Hurricane Hugo maintained that level of stocking following the storm. Similarly, stands that were stocked at the 30-39, 40-49, and 50-59 percent level before Hurricane Hugo retained stocking at that level 49, 46 and 50 percent of the time. Conversely, stands with 60-69 percent stocking maintained that stocking in only 28 percent of the cases. To a lesser extent, stands with 70-84 and 85-99 percent stocking were also less able

Table 2--Status of hardwood species following salvage operations in 1990 for 23 counties in South Carolina affected by Hurricane Hugo.

Species	Healthy trees	Class #1[a]	Class #2	Class #3
	----------percent----------			
Select white oaks	71	11	4	14
Select red oaks	63	10	5	22
Other white oaks	65	10	11	14
Other red oaks	58	12	9	21
Hickory	69	6	8	17
Red maple	58	12	13	17
Beech	66	--	19	15
Sweetgum	71	14	7	8
Tupelo/black gum	78	11	6	5
Ash	64	13	10	13
Cottonwood	70	15	11	4
Yellow-poplar	60	13	8	19
Bay/magnolia	85	--	5	10
Sycamore	74	6	4	16
Elm	77	11	4	8
All species	69	10	8	14

[a] Class #1. High-risk tree; salvage.
Class #2. Moderate-risk tree; harvest to prevent degrade.
Class #3. Retain in stand though some degrade is likely.

Table 3--Percentage comparison of the areas (acres) supporting different stocking classes at pre- and post-Hugo inventories for bottomland hardwoods in 23 South Carolina counties.

Pre-Hugo Stocking (percent)	Post-Hugo Stocking (percent)								
	0-14	15-29	30-39	40-49	50-59	60-69	70-84	85-99	100+
0-14	100								
15-29	30	70							
30-39	12	39	49						
40-49	15	17	22	46					
50-59	12	8	10	20	50				
60-69	6	12	15	14	15	28			
70-84	7	8	12	8	12	13	39		
84-99	5	6	8	9	5	10	20	36	
100+	5	3	4	3	4	4	13	20	43

to hold that stocking compared to densities at both lower and higher levels. The respective values for those two classes were 39 and 36 percent.

MANAGEMENT PRESCRIPTIONS

Physiographic Class

Using the convention of the FIA Research Work Unit, the physiographic classes supporting bottomland hardwood in the 23-county area of South Carolina are as follows:

Narrow Floodplains

Floodplains less than 1/4 mile in total width along rivers and streams. They include natural levees and first bottoms. These sites are normally well drained but are subject to occasional flooding during periods of heavy or extended precipitation. Associated species include sycamore, sweetgum, yellow-poplar, green ash, willow oak, southern red oak and, further inland, black walnut.

Broad Floodplains

Floodplains 1/4 mile or wider along rivers and streams. They include natural levees, first and second bottoms and terraces. The mineral soils common to these sites are normally well drained but are subject to annual flooding, especially during periods of heavy or extended precipita-tion. Species associated with this class include cottonwood, sycamore, sweetgum, green ash, red maple, and cherrybark oak, and toward the fringes (terraces) water, willow, overcup and swamp chestnut oak.

Deep Swamps

Low, wet, flat forested areas, usually quite large in extent, which are flooded for long periods of time except during periods of extended drought. They are often associated with sizeable streams forming in the Lower Coastal Plain. Soil and moisture conditions are generally quite favorable for forest growth of selected species such as tupelo, swamp black gum, red maple, green ash, sweetgum, yellow-poplar and water, willow and laurel oak. Organic soils are common to these areas.

Small Drains

Narrow, streamlike, wet strands of forest land often without a well-defined stream channel. These areas are poorly drained or flooded throughout most of the year except during periods of extended drought. They often serve as drains for the adjacent higher ground, distal from the adjoining stream. Associated species include bald cypress, swamp black gum, sweetgum, green ash and red and loblolly bay. They are characterized by organic soils.

Bays and Wet Pocosins

Low, wet, boggy sites characterized by peaty or organic soils. Common species associates of these sites include swamp black gum, green and Carolina ash and loblolly and red bay. Pond pine is also common to these areas.

Other Hydric

Includes areas of standing water in which there are inlets and outlets during stages of high water. Examples of these areas include oxbow lakes and cypress ponds. The predominant tree species are bald cypress, pond cypress and tupelo gum.

Forest Types

The species groups recognized by the FIA Research Work Unit for the bottomland hardwoods in the 23-county area affected by Hurricane Hugo are Oak-Gum-Cypress and Elm-Ash-Cottonwood. Seven forest types are identified within the first group and four in the second (USDA Forest Service, FIA Research Work Unit, 1991). Their description follows:

Oak-Gum-Cypress

Swamp chestnut oak-cherrybark oak
Swamp chestnut oak and cherrybark oak comprise a majority of the stocking. Associates include ash, hickory, white oak, shumard oak, black gum, sweetgum, American elm, winged elm, yellow-poplar, and American beech. The locations are alluvial flood plains of major rivers, usually in the Coastal Plain, where the soils are moist but seldom covered with standing water.

Sweetgum-water oak-willow oak Sweetgum and water, willow and laurel oak, either singly or in combination make up this type. Associates include green ash, red maple, blackgum, over-cup oak and occasionally bald cypress. The Coastal Plain and lower Piedmont sites are low and moist which are representative of drains, poorly drained flatwoods, and swamp margins.

Sugarberry (hackberry)-American elm-green ash The three species comprise the majority of this forest type. They are joined by water oak, willow oak, laurel oak, sweetgum, water hickory and boxelder. The type is common on imperfectly drained soils of the first or second bottom of major rivers and streams in the Coastal Plain.

Overcup oak-water hickory These two species comprise a majority of the stocking. The associates include green ash, hackberry, American elm, and red maple. The type is common to the Coastal Plain where it is found in poorly drained sloughs and depressions of first and second bottoms of rivers and primary streams.

Cypress-water tupelo Bald cypress and water tupelo comprise the majority of the type. Associates include green ash, red maple, swamp black gum, and sweetgum. The type is common to the Coastal Plain where flowing water is present for the better part of the year. The associates would be found on the periphery of the water body, or on hummocks or ridges within the confines.

Sweetbay-black gum-red maple The associates of this species combination would include Atlantic white cedar, sweet bay, pond pine, slash pine and titi. The organic soils supporting this forest type which is unique to the Coastal Plain remain saturated through-out the year.

Elm-Ash Cottonwood Group

River birch-sycamore The type, common to the Upper Coastal Plain, Piedmont and low mountains, is most frequently found along stream margins, on recently disturbed land. River birch often forms pure stands in such situations with sycamore occurring as scattered trees which will eventually dominate. Associates include ash, sweetgum, red maple and yellow-poplar.

Cottonwood This species infrequently occurs as a pure stand, but more commonly occurs in mixture with willow, white ash, green ash and sycamore. It is most commonly found on point bars and secondarily on recently disturbed, moist soil along streams and sloughs. It is most common to the Coastal Plain, but occurs in mixture with other species in the Piedmont and low mountains.

Willow This species group almost always occurs in pure stands, often on point bars, and on recently disturbed soils adjacent to streams and sloughs where the surface water drainage has been adversely altered. On such sites, it often serves as a pioneer, giving stability to the site until other tree species of longer life become established. A common pioneer associate is swamp cottonwood.

Sycamore-pecan-American elm A mixed stand of the three species is sometimes observed, but a more common phenomenon is for a pure stand of either sycamore or pecan to occupy the site. Both species find their niche on abandoned bottomland fields or along logging roads where there has been recent disturbance. Sycamore is more common to the Piedmont and low mountains, on soils of good internal drainage. The latter two species are common to the Upper Coastal Plain on imperfectly drained soils.

PRESCRIPTION

Data collected and analyzed by the USDA Forest Service FIA Research Unit show almost no trends in the severity of hurricane damage to the bottomland hardwoods of the 23-county area of South Carolina. This conclusion applies specifically to the seven forest types that comprise the Oak-Gum-Cypress Group and the four that comprise the Elm-Ash-Cottonwood Group. A number of these forest types commonly occur within one or more of the six physiographic types (narrow floodplains, broad floodplains, deep swamps, small drains, bays and wet pocosins, and other hydric) within the area. No consistency was found in the damage of a forest type either within or among physiographic types.

There is evidence that the severity of damage was worse on trees of large size, i.e., greater than 15 inches dbh (Table 1) and on species such as the red and white oaks, red maple and yellow-poplar (Table 2). As a result of their large size, the select red and white oaks were thought to be more prone to damage because of their proportionally larger crowns and because they more often occupy fine-textured, imperfectly drained soils which are conducive to development of shallow root systems.

Evidence also exists that stands of optimal stocking for tree growth and development were more subject to hurricane damage than those classes that would be considered understocked or overstocked (Table 3). A greater percentage of the stand area was reduced to the next lower levels of stocking when the pre-Hugo stocking was from 60 to 99 percent. The 60 to 69 percent class appeared to be especially vulnerable. The cause of this phenomenon probably lies in the partial harvests of many of the bottomland hardwood stands, an undesired but ongoing practice where the best trees are removed at periodic intervals.

With the general lack of trends in tree damage across physiographic and forest types, definitive prescriptions for timber stand improvement are left wanting. However, the following observations and recommendations should be helpful to the timberland owner in upgrading affected bottomland hardwood forest.

1. The deep swamps, small drains, bays and wet pocosins and "other" hydric physiographic class offer the least opportunity for timber stand improvement. Even though considerable stem and crown breakage occurred in these types, relatively little windthrow was encountered. The lack of wind-throw is the result of the crown architecture of the species (columnar and single stemmed) and the deep rooting habit of the species.

   The year-round water saturated soils of these physiographic classes will largely prohibit ready access of wheeled or tracked logging equipment for anything much less than complete harvest of the timber. Therefore, little economic opportunity exists for upgrading these stands.

2. The narrow floodplains of the Coastal Plain, Piedmont and low mountains offer the greatest opportunity for timber salvage as well as for timber stand improvement. These lands are generally accessible from the high banks. In addition, the soils within the floodplain are without standing water for all but a few weeks a year.

   The recommendation is to identify the older stands of marginal stocking for first entry. If the stands are severely damaged, the recommendation is to clearcut the timber, leaving only those trees that will have wildlife value but in low enough quantities that the ensuing seedling and sprout regeneration is not adversely affected. For stands less severely affected, i.e., where residual stands exist of 40 ft^2/ ac basal area or more, salvage harvesting should be conducted as soon as practical to remove the affected timber. The harvest should be scheduled during autumn to take advantage of existing seed crops, and to benefit from optimum traffic conditions that result from normal low rainfall of this season of the year.

3. The broad floodplains offer similar opportunity for regeneration and timber stand improvement as do the narrow floodplains. The exception is that trafficability will be more restricted during the rainy seasons. Priorities for treatment of these areas are to concentrate on the older and poorly stocked portions of the stands, especially where large diameter oaks, and to a lesser extent, ash and yellow-poplar, make up a large component of the stand.

   The prescription for managing the damaged stands of this physiographic class perhaps carries more urgency than do the narrow floodplains. The reason is that the understory, shade-tolerant species composition common to this class, i.e., ironwood, dogwood, redbay, American holly, and to a certain extent sugarberry, elm and boxelder, will benefit from the effects of the storm at the same time that the desired overstory species have been killed or variously damaged. In most salvage operations, whether a clearcut or a partial harvest, the understory species will have to be controlled to allow the light-demanding, overstory species to regenerate and develop. Control of the undesirables can be accomplished in a number of ways. Chain-saw felling, girdling, shearing and surface-applied or injected herbicides are proven methods of control.

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HURRICANE HUGO WIND DAMAGE TO SOUTHEASTERN U. S. COASTAL FOREST TREE SPECIES

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Abstract--One percent of Hobcaw Forest, a 3077 ha tract in South Carolina's lower coastal plain, was inventoried with fixed area plots within four months after the eye of Hurricane Hugo passed 97 km south of the forest. Results of this sampling confirmed our hypotheses that the amount and nature of hurricane wind damage differed among the tree species sampled. Approximately 73 percent of the 16,870 trees inventoried were either not damaged or had light crown damage. Longleaf pine (*Pinus palustris*) was less damaged than loblolly pine (*Pinus taeda*) or pond pine (*Pinus serotina*). Bald cypress (*Taxodium distichum*) suffered light crown damage. Upland oaks were more heavily damaged than the pine species. Live oak (*Quercus virginiana*) was less damaged than laurel oak (*Quercus laurifolia*) and water oak (Quercus nigra). Those tree species commonly found in the lower coastal plain (longleaf pine, bald cypress, and live oak) suffered less damage than species with larger natural ranges.

INTRODUCTION

On September 22, 1989, the eye of Hurricane Hugo came ashore 20 km east of Charleston, SC with estimated maximum sustained winds of 222 km/hr and a barometric pressure of 93.4 MPa in Charleston (Purvis and others 1990). It proceeded northwest (Figure 1). In Georgetown, 97 km north of Charleston, the mean wind speed was estimated to be 87 km/hr with gusts of 138 km/hr (Purvis and others 1990).

Hobcaw Forest, 7 km southeast of Georgetown, was less damaged than forests closer to the hurricane's eye, but it was enough damaged to determine the sensitiv-ity of several coastal plain tree species and size classes to hurricane winds. This report summarizes the results of an intensive survey of tree damage in Hobcaw Forest immediately following Hurricane Hugo. The objective of the survey was to quantify hurricane wind damage to common tree species of Hobcaw Forest to test the hypothesis that the damage was not similar among species and among size classes within species. We hypothesized that loblolly (*Pinus taeda* L.) and longleaf pine (*Pinus palustris* Miller) would exhibit different kinds of wind damage because of foliage and branch morphological differences, and that pond pine (*Pinus serotina* Michaux) and loblolly pine would be damaged in similar ways, because they are morphologically similar. Bald cypress (*Taxodium distichum* (L.) Richard) has deciduous foliage and fine branches, unlike the other conifers, which could contribute to its previously observed ability to withstand strong winds. Water oak (*Quercus nigra* L.), laurel oak (*Quercus laurifolia* Michaux), and southern red oak (*Quercus falcata* Michaux) grow taller, have an excurrent canopy, and would be more wind damage sensitive than live oak (*Quercus virginiana* Miller) with its deliquescent canopy.

METHODS

The study was conducted on the 3077 ha Hobcaw Forest (33 20′ N, 79 15′ W) which occupies the southern tip of the Waccamaw Peninsula in Georgetown County, South Carolina (Figure 1).

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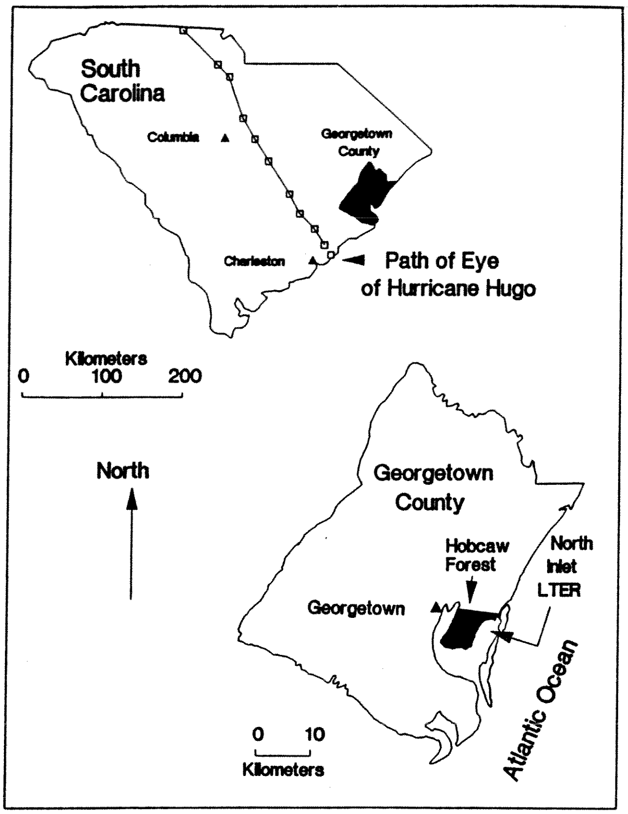

Figure 1--Location of Hobcaw Forest in Georgetown County and South Carolina.

The Georgetown area climate is characterized by mild winters and hot humid summers. Monthly mean January and August temperatures were 8°C and 23°, respectively, and mean annual precipitation was 1300 mm for the period 1951-1980 (NOAA 1981).

Local topography is dominated by a series of Sangamon Age beach ridges with elevations ranging from 3-8 m above mean sea level (MSL) on the western side of the forest and 1-2 m above MSL on the eastern side (Williams and Lipscomb 1981). Hobcaw Forest soils are sandy throughout, excessively to moderately well drained on the western side, and moderately to poorly drained on the eastern side (Stuckey 1982).

Fifty-two arborescent species (nomenclature follows Radford and others 1968) occur in Hobcaw Forest (Barry 1968). Ridges are dominated by either longleaf pine with some shortleaf pine (*Pinus echinata* Miller) occurring on older ridges, or by a mixture of oaks (*Quercus* L.) and hickories (*Carya* Nuttall). Inter-ridge areas are flat and support a mixture of loblolly pine, pond pine, or longleaf pine. Ephemeral streams drain inter-ridge areas and are bordered by forests of sweetgum (*Liquidambar styraciflua* L.), ash (*Fraxinus* L.), elm (*Ulmus* L.) and blackgum (*Nyssa sylvatica* var *sylvatica* Marshall). The top of the forest canopy averages 21 m high (unpublished data, Baruch Forest Science Institute). Pre-hurricane forest structure and composition resulted from repeated logging (Williams and Lipscomb 1983) and prescribed burning (Komarek 1981).

From November 1989 to May 1990, we sampled hurricane damage to trees in 293 of the 362 Hobcaw Forest stands delineated in 1965 for forest management purposes (unpublished data, Baruch Forest Science Institute). (Stands without minimum-sized [see below] trees or in which timber was salvaged were not sampled.) Stands varied in size from 0.6 ha to 44 ha and each had a relatively homogeneous canopy composition. Within each stand we inventoried a randomly located, 100 m by 10 m plot by recording species, diameter at breast height (dbh), and damage class of all live, woody stems greater than 10 cm dbh. If 25 trees were not in the 0.1 ha plot, it was extended until 25 trees were inventoried in each plot. If a stand was larger than 20 ha, two plots in it, of at least 25 trees each, were inventoried.

We visually estimated wind-related tree damage and assigned trees to one of the following damage classes, listed in order of increasing severity of damage:

1. Undamaged: Bole unbent and vertical with little crown damage;
2. Bent: Roots intact, lower bole vertical, upper bole not vertical;
3. Limbs broken: Many limbs broken, terminal leader intact:
4. Defoliated: Sparse foliage, with brown or dying foliage;
5. Top broken: Many limbs broken, terminal leader broken;
6. Broken: Bole broken between ground and crown base;
7. Uprooted: Tree partially uprooted with bole leaning;
8. Downed: Tree partially uprooted with bole lying on ground.

These damage classes were grouped as follows for discussion purposes: undamaged trees, (class 1); light damage, bole bent or limbs broken (classes 2,3); moderate damage, defoliated or top broken (classes 4,5); heavy damage, broken, uprooted or downed (classes 6,7,8).

Basal area and stem density were calculated on a plot basis and averaged over 329 plots. An R X C G-test (Sokal and Rohlf 1981) was used to determine pooled differences and homogeneity of number of stems among damage classes. Chi-square tests of independence in R x C contingency tables (Everitt 1977) were used to compare stem distributions among damage classes between two species. An alpha of 0.05 was used for all tests.

RESULTS

We tallied 16,870 stems in 329 0.1 ha plots which is 1.08 percent of the area of Hobcaw Forest. Average plot density was 506 stems ha^{-1} and average plot basal area was 25.3 m^2 ha^{-1}.

Severity of Damage

Percents of stems in damage classes are summarized in Table 1. Approximately 73 percent of the trees sampled were not damaged (24%) or were lightly damaged (49%). Moderately damaged and heavily damaged trees were 16 percent and 11 percent of the total, respectively. With the exception of live oak and swamp tupelo, hardwoods suffered more wind damage than did pines. Longleaf pine was the least damaged of the pines with 87.7 percent of the stems not damaged or lightly damaged, compared to 73.5 percent for loblolly pine and 65.5 percent for pond pine. Approximately 84 percent of the bald cypress stems were not damaged (11.2%) or were lightly damaged (73.0%). Laurel oak, the most common upland hardwood, had 19.4 percent of the stems in the heavy damage group compared to 7.8 percent for longleaf pine and 9.0 percent for loblolly pine.

Table 1--Variation by percent of stems for types of damage suffered by tree species in Hobcaw Forest, South Carolina, during Hurricane Hugo. The table shows the percent of stems in each damage class for each of the major tree species, and the percent of stems of each major species of the total number of stems of all tree species in the samples. Damage classes are grouped as shown into damage groups for discussion in the text.

	Damage Group								
	Un-damaged	Light Damage		Moderate Damage		Heavy Damage			
Species	Un-damaged	Bent	Limbs broken	De-foliated	Top broken	Bole Broken	Up-rooted	Downed	Percent of total
Longleaf pine	46.7	1.1	39.9	3.4	1.1	1.8	2.9	3.1	6.7
Loblolly pine	27.3	4.4	41.8	9.7	7.8	2.6	5.3	1.1	47.0
Pond pine	27.7	2.4	35.4	2.9	4.8	6.3	12.1	8.3	1.2
Bald cypress	11.2	1.3	71.7	5.6	6.6	1.6	1.0	1.0	1.8
Blackgum	15.3	1.4	48.7	25.4	5.5	2.3	1.1	0.4	4.7
Sweetgum	14.9	5.8	49.3	12.7	15.8	4.0	3.4	4.2	8.7
Swamp tupelo	5.4	0.6	86.0	0.3	6.3	0.9	0.6	0.0	2.1
Laurel oak	15.7	11.4	41.9	5.4	6.3	6.2	7.0	6.2	5.0
Live oak	27.1	1.0	46.6	15.9	5.3	1.9	1.1	1.3	2.8
Water oak	15.9	8.6	43.2	6.7	5.4	4.7	8.4	8.0	2.7
Average	23.9	4.2	44.8	8.6	7.4	3.5	5.0	2.7	

Live oak and swamp tupelo had a larger percent of stems not damaged or lightly damaged than water oak and laurel oak, which had a larger percent of stems heavily damaged (Table 1). Twenty-seven percent of the live oak stems were undamaged compared to 16 percent for both water oak and laurel oak. Swamp tupelo had the highest percent of stems lightly damaged (86.6%).

Stem Number Distribution Among Damage Classes

Table 2 summarizes the results of the G-test for stem count distribution among damage classes. The heterogeneity test indicated that at least one species did not fit the damage distribution for all species combined. Individual G-test statistics indicated that 12 of 14 species tested did not fit the overall damage distribution.

Chi-square tests indicated similarities between damage distributions of pairs of species. Among conifers, damage distributions between loblolly pine and pond pine were not significantly different. Damage distributions of laurel oak and water oak were not significantly different and the distributions of live oak and southern red oak were not significantly different. The damage distributions of southern red oak and hickory (primarily *Carya tomentosa* [Poiret] Nuttall) were not significantly different as also indicated by the G-test (Table 2).

Non-significant differences between damage distributions of a pine and hardwood were live oak and loblolly pine and longleaf pine and southern red oak. All other pairwise tests of apparently similar damage distributions resulted in significant chi-square statistics indicating different distributions.

Basal Area Distribution Among Damage Classes

Table 3 summarizes the percent basal area distribution among damage classes for the more abundant species sampled. Because basal area integrates both dbh and stem density this analysis gives a better picture of tree biomass damaged than does the analysis based on stem counts.

Among the pines, the percent of basal area in the heavy damage group was 42.6 percent for pond pine, compared to 11.2 percent and 16.8 percent for longleaf pine and loblolly pine, respectively. Longleaf pine had approximately twice the basal area undamaged than did loblolly (39.4% and 19.3%, respectively).

Live oak was one tenth as damaged in terms of basal area as either laurel or water oak. Only 3.3 percent of the live oak basal area was in the heavy damage group compared to 32.1 percent for laurel oak and 34.6 percent for water oak. The following species had more basal area in the light damage groups than in the other groups: swamp

Table 2--G-test statistics for stem counts among damage classes testing the following hypothesized percent distribution among damage classes 1-8, respectively: 24.5, 4.2, 45.6, 8.5, 7.5, 3.0, 4.5, 2.2. The hypothesized distribution was the damage distribution for all species (** = P < .01).

Tests	df	G	Species	df	G
Pooled	7	3.3	longleaf pine	7	376.2**
Heterogenity	91	2189.9**	loblolly pine	7	139.7**
			pond pine	7	58.1**
Total	98	2193.2**	bald cypress	7	87.7**
			blackgum	7	274.9**
			sweetgum	7	276.2**
			swamp tupelo	7	518.9**
			ash	7	84.8**
			hickory	7	2.4
			laurel oak	7	179.6**
			live oak	7	62.4**
			southern red oak	7	6.3
			water oak	7	91.3**
			turkey oak	7	92.4**

tupelo (88.5%), bald cypress (84.3%), live oak (66.7%), sweetgum (60.1%), and blackgum (53.4%).

Damage as a Function of Tree Diameter

In general, the larger dbh trees were heavily damaged and smaller dbh trees were either not damaged or lightly damaged. Loblolly pine typified this pattern, except that the moderately damaged trees were about the same dbh as the undamaged and lightly damaged trees (Figure 2). Longleaf pine was unique among the pines in that the smallest trees had heavy crown damage, and the undamaged and lightly damaged trees were intermediate in dbh.

Laurel oak and water oak were similar in terms of kinds of damage suffered by trees of different sizes (Figure 3). The smaller dbh trees were either undamaged or bent. The larger dbh trees had the top broken or were in the heavy damage group. The smallest live oak trees were bent, and the undamaged live oak trees were larger than the bent trees. Like laurel oak and water oak, the larger live oak trees had the top broken or the bole broken. However, uprooted live oak trees were larger than uprooted laurel oak and water oak, and downed live oak trees were smaller than downed laurel oak and water oak.

DISCUSSION

We considered the sum of the percent basal area in the undamaged and lightly damaged groups (undamaged, bent, and limbs broken damage classes of Table 3) for a species to be an index of that species' ability to resist hurricane wind damage. Those species with 80 percent or more basal area undamaged or lightly damaged are, from least to most damaged, swamp tupelo, bald cypress, longleaf pine, and live oak.

Likewise, we considered the sum of the percent basal area in the heavy damage group of damage classes (bole broken, uprooted or downed of Table 3) for a species to be an index of a species' sensitivity to hurricane wind damage.

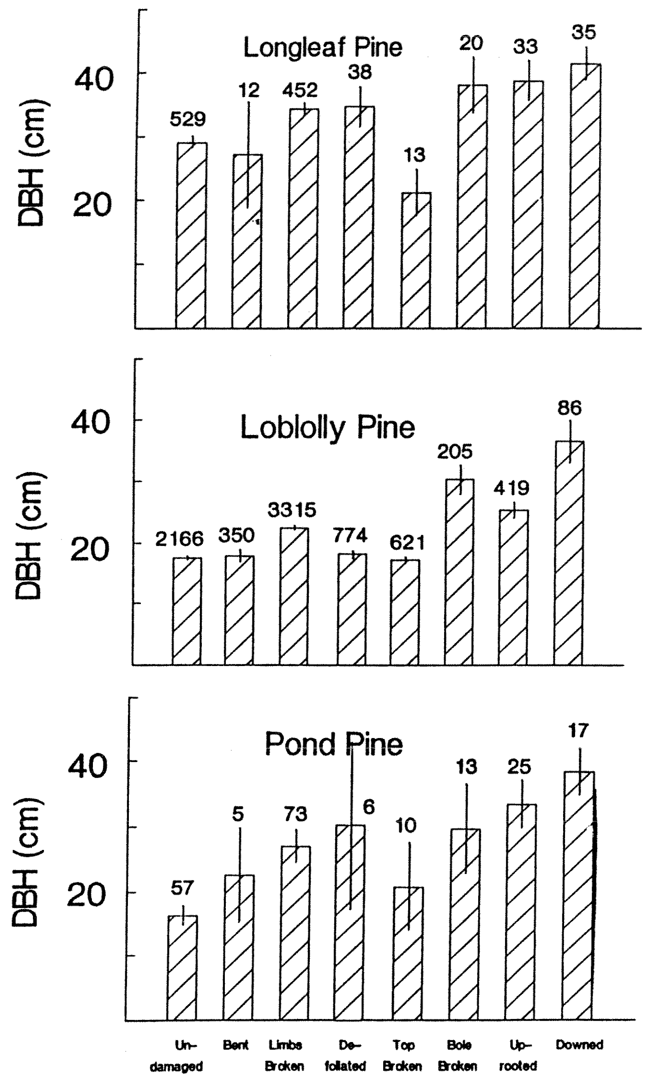

Figure 2--Average dbh of pine stems by damage class. Damage classes were grouped as follows: undamaged trees (damage class 1); light damage, bole bent or limbs broken (classes 2,3); moderate damage, defoliated or top broken (classes 4,5); heavy damage, broken, uprooted or downed (classes 6,7,8). Shortleaf pine did not have any stems in five of the eight damage groups and was not included in the figure. Error bars show two standard errors above and below means. Sample sizes are indicated above error bars.

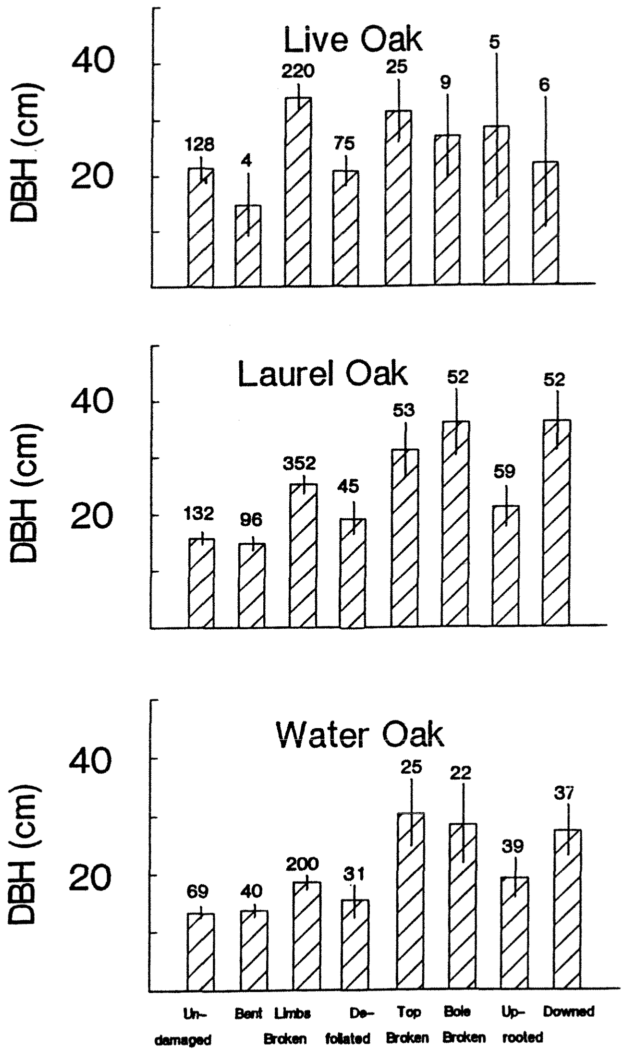

Figure 3--Average dbh of oak stems by damage class. Damage classes were grouped as follows: undamaged trees (damage class 1); light damage, bole bent or limbs broken (classes 2,3); moderate damage, defoliated or top broken (classes 4,5); heavy damage, broken, uprooted or downed (classes 6,7,8). Species with less than 100 stems inventoried are not included in the figure. Error bars show two standard errors above and below means. Sample sizes are indicated above error bars.

In order of decreasing basal area in the heavy damage group, pond pine, water oak and laurel oak had 43 percent, 35 percent and 32 percent of their respective basal area heavily damaged. From the hurricane wind damage resistance and sensitivity indices, the more abundant species encountered in this study can be classified as either resistant or sensitive, and other studies support this classification.

Touliatos and Roth (1971) reported that live oak, pond cypress (*Taxodium ascendens* Brongn.) and bald cypress had very high wind resistance. They also reported that loblolly pine, longleaf pine, southern red oak, and water oak had low resistance to breakage, which agrees with our data of Table 3.

This differential resistance of southeastern United States forest species to wind damage was also reported for tornado-generated high winds (Glitzenstein and Harcombe 1988). They reported that 73 percent, 73 percent, and 66 percent, of the surviving southern red oak, water oak, and sweetgum, respectively, were badly damaged compared to 1.6 percent of the loblolly pine and 0 percent of the longleaf pine. They also reported that destruction of individuals in the larger diameter classes significantly reduced the average diameter of intact trees. These same patterns of differential species sensitivity to wind damage and higher sensitivity of larger trees to wind damage were reported for a southeastern U.S. Fagus-Magnolia forest (Harcombe and Marks 1983). Tropical tree species also exhibit differential resistance to hurricane wind damage and suffer more damage in the larger diameter classes (Lugo and others 1983, Putz and others 1983).

Wind damage integrates species, site, and stand characteristics which prohibits direct assignment of a single cause of damage to an individual species. However, resistance and sensitivity to hurricane wind damage of the more abundant species of this study were associated with morphological and anatomical properties of the species. The resistance of swamp tupelo and cypress was probably related to the presence of buttressed boles (Touliatos and Roth 1971, Putz and others 1983), and the deciduous habit of cypress greatly reduced the surface area exposed to high winds. We noticed that cypress foliage was browning, as it does before leaf fall, just before the hurricane struck. The damage resistance of longleaf pine could be related to firm anchorage provided by the large taproot and widespread lateral root system. Our excavations of longleaf pine root systems (unpublished data, Baruch Forest Science Institute)

Table 3--Variation by percent of basal area for types of damage suffered by tree species in Hobcaw Forest, South Carolina, during Hurricane Hugo. The table shows the percent of stem basal area in each damage class for each of the major tree species, and the percent of stem basal area of each major species of the total stem basal area of all tree species in the samples. Damage classes are grouped as shown into damage groups for discussion in the text.

	Damage Group								
	Un-damaged	Light Damage		Moderate Damage		Heavy Damage			
Species	Un-damaged	Bent	Limbs broken	De-foliated	Top broken	Bole Broken	Up-rooted	Downed	Percent of total
Longleaf pine	39.4	0.9	44.3	3.8	0.5	2.4	4.0	4.8	12.1
Loblolly pine	19.3	3.2	48.5	7.2	5.2	5.7	7.9	3.2	39.6
Pond pine	10.5	1.7	37.7	4.2	3.3	8.1	18.5	16.0	1.5
Bald cypress	5.2	0.3	84.0	3.0	2.8	2.6	0.7	1.3	4.4
Blackgum	13.4	0.4	53.0	23.4	5.0	2.9	1.8	0.1	7.7
Sweetgum	8.9	2.8	57.3	11.9	15.0	4.0	3.2	7.0	7.0
Swamp tupelo	3.1	0.1	88.4	0.3	6.2	0.8	1.0	0.0	3.6
Laurel oak	5.7	3.7	45.4	13.2	0.1	13.6	5.6	12.9	6.2
Live oak	15.3	0.2	66.5	8.8	6.0	1.5	1.0	0.8	4.5
Water oak	6.2	3.6	38.4	4.3	12.8	10.5	8.5	15.6	2.0
Average	17.0	2.1	52.9	6.9	6.0	5.2	5.5	4.6	

indicated that longleaf pine taproots extended two meters vertically in the soil and the lateral root system extended up to six meters horizontally from the taproot. The resistance of live oak has been related to the low deliquescent canopy and high wood strength and resilience (Touliatos and Roth 1971). The crowns of the larger live oaks were level with or below crowns of associated laurel and water oaks.

The hurricane wind damage sensitivity of pond pine was probably related to its shallow root system, which developed in high water table soils. Pond pine had the highest percent of stems blown down (8.3%). A high percent of water oak and laurel oak stems were blown over (8.0% and 6.2%, respectively) which may be related to the observed shallow, diffuse root system. These oaks are tall at maturity (15-18 m, Harrar and Harrar 1962) and thus were more exposed to high winds than were smaller trees.

It is interesting to note that the more hurricane-wind-resistant species are commonly found in the lower coastal plain, where the frequency of hurricanes is higher than further inland. More wide-spread species, not particularly associated with the coastal plain, were more vulnerable. Longleaf pine, bald cypress and live oak trees commonly live at least a century (bald cypress trees live 400-600 years, Fowells 1965), and are commonly found in South Carolina's lower coastal plain (Radford and others 1968). With an average hurricane recurrence interval of 5.8 years (Purvis 1973), these trees would be exposed to 17 hurricanes during a 100-year lifetime. During the past 110 years four hurricanes as severe as Hugo struck South Carolina (Purvis 1973). Therefore, it is possible that hurricanes have exerted selection pressure on traits of some tree species that are common in forests frequently damaged by hurricanes.

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MAJOR STRUCTURAL DAMAGE PRESENT PRIOR TO HURRICANE HUGO IN OLD-GROWTH FOREST TREES AT FOUR HOLES SWAMP, SOUTH CAROLINA

M. J. Duever and J. M. McCollom[1]

Abstract--While measuring impacts of Hurricane Hugo, we assessed characteristics of trees that might have increased their susceptibility to damage. This included evidence of previous major damage, such as major branch loss and bent, uprooted, or broken boles. Previous damage varied from 21-91% as a function of species and from 25-75% as a function of site. For certain species previous damage was infrequent (21-29%), and these species showed low survival (0-2%) among trees affected by Hurricane Hugo. Other species exhibited a high frequency of previous damage (86-87%), and had a high percentage of individuals (80-100%) that survived despite being affected by the hurricane. Age was related to frequency of previous damage for most species. Different areas of the swamp have distinct disturbance histories as evidenced by sites in the same area having similar percentages of individuals with previous damage, regardless of habitat type and species composition.

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PATTERNS OF INITIAL AND DELAYED MORTALITY CAUSED BY HURRICANE HUGO IN FOUR OLD-GROWTH FOREST COMMUNITIES IN FOUR HOLES SWAMP, SOUTH CAROLINA

J. M. McCollom and M. J. Duever[1]

Abstract--Initial (Fall 1989) and delayed (Fall 1991 & 1992) mortality data were collected for 1233 trees >15 cm dbh in 16 plots damaged by Hurricane Hugo. Though 22% of the trees were killed, species composition two years after Hugo was quite similar to pre-hurricane conditions. The ratio of trees killed initially to all trees of a species showed a strong positive correlation with species arrayed along a topographic gradient. However, delayed mortality was much more equally distributed along the topographic gradient. Initial and delayed mortality patterns varied with type of damage incurred, such as major branch loss and bent, uprooted, or broken boles. Overall and initial mortality rates increased only slightly with diameter, while delayed mortality decreased slightly.

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HURRICANE HUGO EFFECTS ON OLD-GROWTH FLOODPLAIN FOREST COMMUNITIES AT FOUR HOLES SWAMP, SOUTH CAROLINA[1]

Michael J. Duever and Jean M. McCollom[2]

ABSTRACT--We assessed hurricane damage and mortality of 1233 canopy trees (≥6 in dbh) in sixteen plots within the old growth floodplain forest in Four Holes Swamp. Sixty percent of the trees sustained major damage, and 22% had died within two growing seasons as a result of the hurricane. Higher elevation Ridge Bottom forest plots sustained the greatest damage (81%) and highest mortality (47%), while the lower Cypress/Tupelo forest plots had the least (43% and 4%, respectively), and mid-elevation Hardwood Bottomland forests were intermediate (64% and 24%, respectively). Among the more common species in our plots, water oak (*Quercus nigra* L.) and spruce pine (*Pinus glabra* Walt.) had the largest percentage of individuals damaged (≥93%), and baldcypress (*Taxodium distichum* (L.) Rich), blackgum (*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.), water tupelo (*Nyssa aquatica* L.), and Carolina ash (*Fraxinus caroliniana* Mill.) had the smallest (≤47%). After two growing seasons, spruce pine had by far the greatest percent mortality (91%) of individuals alive at the time of the hurricane, and water tupelo and blackgum the lowest (1% and 3%, respectively). The dominant type of damage was main stem break (50% of affected trees). However, of the different types of damage, 70% of uprooted trees died and only 35% of the main stem broken trees died. Mortality among trees with major branch loss and bent stems has been less than 10%. Hurricane Hugo effects were not randomly distributed through the forest. While other factors may be involved, species present, and possibly community type, influence the kinds and degree of effects.

INTRODUCTION

In recent years there has been an increasing awareness of the role natural perturbations play in ecosystem dynamics. The concept that nature, undisturbed by man, 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 (Runkle 1982, Pickett and White 1985). 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 (Hook and others 1991, Whigham and others 1991). Documenting how these events interact with other natural processes to produce the earth's varied landscapes is critical to our understanding of how existing ecosystems have come into being and are likely to change in the future.

[1] Paper presented at the Seventh Biennial Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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Hurricanes represent one type of severe perturbation that produces major changes in natural landscapes (Sheffield and Thompson 1992, McCollom and Duever 1992). They are regular visitors to the southeastern United States, although there may be many years between visits to any particular area (Neumann 1987, Duever and others In Press).

On September 22, 1989, the eye of Hurricane Hugo, passed over National Audubon Society's Francis Beidler Forest in South Carolina, which contains the largest stand of old-growth baldcypress and water tupelo in the world (Brunswig and Winton 1978). An average of wind speeds estimated by Sparks of Clemson University for four cities (Camden, Sumter, Summerville, and Charleston) bracketing Beidler Forest along the hurricane's path place estimated mean hourly wind speed at 72 mph with gusts up to 115 mph (Purvis and others 1990). Rainfall associated with the hurricane was 4-5 inches (Purvis and others 1990).

The 6000 ac sanctuary contains approximately 1700 ac of old-growth forested wetlands which is one of the last remnants of the undisturbed floodplain forests that once laced the southeastern coastal plain. As one moves up the approximately 5-ft topographic and moisture gradient within the floodplain, the major swamp forest types include cypress-tupelo swamp on the lowest sites, bottomland hardwood swamp at intermediate elevations, and a mixed hardwood-pine community on low ridges within the swamp (Porcher 1981).

Our initial Hurricane Hugo field studies in December 1989, included an overflight of Four Holes Swamp to assess damage to the forest. The strongest impression that resulted from this flight was of the patchiness of the storm's more severe effects. This led us to formulate a series of hypotheses as to the reasons for this patchiness. The first was that it resulted from random severe wind gusts. However, if the pattern of minor and major effects were not random, then they must be related to certain characteristics of these sites. In this paper, we will discuss hurricane damage to and mortality of canopy trees among the major community types and the more common canopy tree species present at Four Holes Swamp.

METHODS

Sixteen 0.5 ac plots were established in old-growth stands of the three major forested wetland habitats listed above. All trees 6 in dbh or larger were identified to species where possible, tagged, and diameters recorded. It was not possible to determine species for elms (*Ulmus* sp.) and ashes (*Fraxinus*) except for Carolina ash. Ordination and clustering analyses of plot and species data matrices using Cornell Ecology Programs DECORANA, TWINSPAN, and COMPCLUS (Duever and McCollom, 1992) were used to determine which plots should be grouped into community types and which species were most closely associated with those communities.

Trees affected by the hurricane were classified into four damage types, listed here from most to least severe: main stem broken, uprooting, major branch loss (branches broken off at or near main stem), or bent trunk. Trees sustaining several types of damage were assigned to the most severe type of damage category.

Data on mortality were collected following the hurricane and at the end of the first and second growing seasons after the hurricane.

RESULTS

Damage

Sixty percent of the 1233 trees over 6 in dbh in our plots were damaged by the hurricane (Table 1). Half of the damaged trees were in the break category. Uprooting and major branch loss each represented 22% of the damage, while bent trunks were uncommon.

The percent trees damaged at a site generally followed the topographic and moisture gradient, with more affected at drier sites. The highest elevation community, the Ridge Bottom, sustained damage to 81% of the trees (Table 1). Half of the tree damage was broken boles and one third of the trees were uprooted. This community had the smallest proportion of damaged trees with bent trunks or major branch loss.

Moving downslope, 64% of the Bottomland Hardwood community trees were damaged. Broken boles were less common in this community than in the other two communities, representing only 43% of damaged trees. Uprooting and major branch loss categories each claimed one quarter of

Table 1. Damage and Mortality in three old-growth floodplain communities from 16 plots at Beidler Forest Sanctuary, South Carolina.

Community	No. Plots	No. Trees Before	No. Trees 2 Years After	Damage Total	Break	Uprooted	Branches	Bent
Ridge Bottom	4	220	117	178	90	60	22	6
Bottomland Hardwood	8	612	467	393	166	95	98	34
Cypress/Tupelo	4	401	383	174	116	10	42	6
TOTAL	16	1,233	967	745	372	165	162	46

Community	No. Plots	No. Trees Before	No. Trees 2 Years After	Mortality Total	Break	Uprooted	Branches	Bent
Ridge Bottom	4	220	117	103	55	43	4	1
Bottomland Hardwood	8	612	34	145[1]	63	66	10	3
Cypress/Tupelo	4	401	383	18	11	6	1	0
TOTAL	16	1,233	967	266	129	115	15	4

[1] Three trees died that did not fit in any damage category.

the damaged trees. The Bottomland Hardwood community also had the highest proportion of bent trees, 9% compared to 3% in the other two communities.

At the bottom of the topographic gradient, the Cypress/Tupelo community had the lowest percent damaged trees, 44%. Two thirds of the damage to this community was due to broken boles, the highest proportion of any community. This community also had virtually no uprooting, with only 6% of the damaged trees falling into that category.

Species responded quite differently to the hurricane. Of the 14 most common species ($N \geq 15$), the two species which sustained the most damage were found mainly on the higher elevation sites. Over 90% of the water oak and spruce pine were damaged. The common species found mainly in the deeper parts of the swamp sustained the least damage. Carolina ash, blackgum, baldcypress, and water tupelo each had less than 50% damaged individuals (Table 2). The two most common species, water tupelo (N=215) and laurel oak (*Quercus laurifolia* Michx.) (N=214), sustained 47% and 66% damage, respectively.

For most species, the most common type of damage was broken boles. Of the more common species, water oak, pignut hickory (*Carya glabra* (Mill.) Sweet), American hornbeam (*Carpinus caroliniana* Walt.), and red maple (*Acer rubrum* L.) had about equal numbers of uprooted trees and broken boles. Swamp chestnut oak (*Quercus michauxii* Nutt.) and the elms had similar numbers of individuals among the three most severe damage types: broken bole, uprooting, and major branch loss. Baldcypress had more trees with major branch damage than all other damage categories combined. However, it must be remembered that our sampling strategy only recorded the most severe damage for each individual. Thus, other species that had broken or uprooted stems could also have lost major branches, but this information would not have been included in our records.

Mortality

Two years after the hurricane, 78% of the 1233 trees sampled were still alive (Table 1). Deaths occurring immediately after the hurricane included 13% of all trees (N=160). Subsequent mortality through the end of the second post-hurricane growing season included an additional 8% (N=101).

Though broken boles were the most common type of damage and accounted for the most mortality in terms of numbers, uprooting was most likely to be fatal, with 70% of all uprooted trees dying by the end of the second growing season (Table 1). Mortality among trees with either broken branches or bent stems was less than 10%. Mortality patterns in the three forested community types followed a pattern similar to damage along the topographic gradient. Mortality for all trees was lowest in the deeper Cypress/Tupelo community sites, ranging from 1-10% in the four study plots at the end of two growing seasons after the hurricane (Table 1). Midway up the topographic gradient, the eight Bottomland Hardwood sites had mortality between 9% and 42%. The highest mortality was at the higher elevation Ridge Bottom sites, ranging from 38% to 52% in the four plots.

Mortality was highest for trees in the main stem broken damage category in both the Ridge Bottom and Cypress/Tupelo communities, while in the Bottomland Hardwood community mortality was more equally divided between broken boles and uprooted trees (Table 1).

Total Mortality for individual species ranged from only 1% for water tupelo (N=215) to 91% for spruce pine (N=43) (Table 2). For species with $\geq$15 individuals, percent Total Mortality was highest for species most commonly associated with the Ridge Bottom community, the first five species listed in Table 2, and lowest for species most commonly found in the Cypress/Tupelo community, the last four species listed in Table 2.

The two most common conifers, baldcypress and spruce pine, died primarily of broken boles. Hardwood mortality was generally associated about equally with broken boles and uprooting. However, blackgum, water tupelo, and Carolina ash, which were common in the Cypress/Tupelo community, had so little mortality that it is difficult to ascribe it to any particular type of damage. Water oak, swamp chestnut oak, red maple, and ashes all died primarily as a result of uprooting. Swamp chestnut oak, American hornbeam, and elms had a relatively high percent mortality associated with major branch loss.

Two years after the hurricane, species composition of trees equal to or greater than 6 in dbh, viewed as the proportion of numbers of one species to another, was quite similar to prehurricane conditions. Exceptions were laurel oak whose numbers had decreased from 213 to 141, and particularly spruce pine, which had decreased from 43 to 4 live individuals.

DISCUSSION

The results of our analyses of canopy tree damage and mortality among the various community types and species present in the old growth forest at Four Holes Swamp clearly indicated that the pattern of storm effects did not result solely from random wind gusts. There was a consistent pattern of more severe damage and mortality on the higher Ridge Bottom sites and much less effect on the lower Cypress/Tupelo sites. Also, the species exhibiting the most severe effects were most common on the higher Ridge Bottom sites, and those with the fewest impacts were the species that were dominant on the lower Cypress/Tupelo sites.

Putz and Sharitz (1991) reported that the more severe effects of Hurricane Hugo on trees in the Congaree Swamp were associated with certain species and community types. Their slough community would be comparable with our Cypress/Tupelo community, and, as at Four Holes Swamp, was much less impacted by the storm than was the bottomland hardwood community. They found that bottomland hardwood species were equally prone to being uprooted or to suffering stem breakage, whereas in the slough sites stem breakage was more common than uprooting. This was the same pattern of damage that we found in Four Holes Swamp.

Gresham and others (1991) reported that Hurricane Hugo damage to the Hobcaw Forest along the South Carolina coast was largely a function of the species present. The species most and least affected were quite similar in our respective studies. They reported that baldcypress, water tupelo, and blackgum were the least affected species, and that pond pine (*Pinus serotina* Michx.), possibly comparable to spruce pine at Four Holes Swamp, and water and laurel oaks were by far the most affected species. They did note that several other upland species, including

Table 2. Damage and mortality for dominant species from 16 plots in the old-growth floodplain forest at Beidler Forest Sanctuary, South Carolina.

Dominant Species (N>15)[1]	No. Trees Before	No. Trees 2 Years After	Damage				
			Total	Break	Uprooted	Branches	Bent
Water Oak, *Quercus nigra*	47	25	44	17	21	3	3
Spruce Pine, *Pinus glabra*	43	4	40	31	9	0	0
Pignut Hickory, *Carya glabra*	26	16	19	10	7	0	2
Swamp Chestnut Oak, *Quercus michauxii*	24	11	17	4	7	5	1
American hornbeam, *Carpinus caroliniana*	47	27	31	12	13	5	1
Elm (American or Winged), *Ulmus* sp.	62	50	41	15	12	11	3
Sweetgum, *Liquidambar styraciflua*	115	97	63	28	10	22	3
Red Maple, *Acer rubrum*	65	60	50	18	18	11	3
Laurel Oak, *Quercus laurifolia*	214	141	141	51	39	30	21
Ash (all sp. but water ash), *Fraxinus* sp.	70	54	44	25	14	5	0
Blackgum, *Nyssa sylvatica* var. *biflora*	94	91	43	29	0	11	3
Baldcypress, *Taxodium distichum*	136	122	63	29	2	32	0
Water Tupelo, *Nyssa aquatica*	215	212	100	78	1	17	4
Carolina Ash, *Fraxinus caroliniana*	15	14	5	5	0	0	0
TOTAL for Dominant Species Only	1,173	924	701	352	153	152	44

Dominant Species (N>15)[1]	No. Trees Before	No. Trees 2 Years After	Mortality				
			Total	Break	Uprooted	Branches	Bent
Water Oak, *Quercus nigra*	47	25	22	7	15	0	0
Spruce Pine, *Pinus glabra*	43	4	39	30	9	0	0
Pignut Hickory, *Carya glabra*	26	16	10	4	5	0	1
Swamp Chestnut Oak, *Quercus michauxii*	24	11	13	3	7	3	0
American hornbeam, *Carpinus caroliniana*	47	27	20	7	8	4	1
Elm (American or Winged), *Ulmus* sp.	62	50	12	5	4	2	1
Sweetgum, *Liquidambar styraciflua*	115	97	18[2]	7	9	1	0
Red Maple, *Acer rubrum*	65	60	5	1	4	0	0
Laurel Oak, *Quercus laurifolia*	214	141	73	35	36	1	1
Ash (all sp. but water ash), *Fraxinus* sp.	70	54	16[2]	4	11	0	0
Blackgum, *Nyssa sylvatica* var. *biflora*	94	91	3	3	0	0	0
Baldcypress, *Taxodium distichum*	136	122	14	12	1	1	0
Water Tupelo, *Nyssa aquatica*	215	212	3	2	1	0	0
Carolina Ash, *Fraxinus caroliniana*	15	14	1	1	0	0	0
TOTAL for Dominant Species Only	1,173	924	249	121	110	12	4

[1] Species not listed, in order of dominance: overcup oak (*Quercus lyrata* Walt.), common persimmon (*Diospyros virginiana* L.), redbay (*Persea borbonia* (L.) Spreng.), loblolly pine (*Pinus taeda* L.), water-elm (*Planera aquatica* J. F. Gmel.), American holly (*Ilex opaca* Ait. var. *opaca*), sugarberry (*Celtis laevigata* Willd.), water hickory (*Carya aquatica* (Michx. f.) Nutt.), cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.), red buckeye (*Aesculus pavia* L.), and waterlocust (*Gleditsia aquatica* Marsh.).
[2] One tree died that did not fit in any damage category.

longleaf pine (*Pinus palustris* Mill.), loblolly pine (*Pinus taeda* L.), and live oak (*Quercus virginiana* Mill.), suffered relatively little damage. These genera at Four Holes Swamp tended to be among the more severely affected species, suggesting that vulnerability to hurricane impacts is related more to species than generic composition.

Whigham and others (1991) also observed a differential mortality among dominant tree species during the two years after Hurricane Gilbert passed over their study sites in Quintana Roo, Mexico. Mortality associated with the storm varied from 1.4 - 31.3% among the different species. More individuals died from breaks in both Quintana Roo and Four Holes Swamp but branch damage caused the second most mortality in Quintana Roo, while at Four Holes death due to uprooting was the next most common. If we look at percent mortality among the damage classes by dividing the number that died within a damage class by the total number in that damage class, results for the two studies are quite similar. For Quintana Roo and Four Holes Swamp respectively, uprooting produced the highest mortality (43%, 70%), trunks snapped produced 28% and 35% mortality, and major branch loss resulted in only 6% and 9% mortality. These similarities are quite surprising given that the species present on their tropical sites were much different from the temperate species we studied.

A variety of factors undoubtedly play a significant role in determining damage to and mortality of canopy trees from hurricanes. Among these factors, species present on a site appears to have a major influence on the kinds and degree of effects. Community type also appears to be closely associated with hurricane impacts. However, it is difficult to decide whether these effects are intrinsically related to integrated community characteristics or are more a function of specific aspects of the community, such as species present or substrate or hydrologic characteristics.

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HURRICANE HUGO EFFECTS ON MAJOR FLOODPLAIN FOREST COMMUNITIES AT FOUR HOLES SWAMP, SOUTH CAROLINA

Michael J. Duever and Jean M. McCollom[1]

Abstract--We assessed effects on trees (>15 cm dbh) in 100 X 20 m plots. Results show 56-66% of trees exhibited major effects in 3 plots (18% in another). Of affected trees, 35-49% were killed in bottomland hardwood plots but only 0-10% in cypress-tupelo plots, and 40-49% were directly affected by hurricane winds as opposed to falling trees in 3 plots (79% in another). Community type, soil type, and water depth were not related to degree of site impact. Upwind sites were more impacted than downwind sites, and sites adjacent to a clearcut along the upwind side of the swamp were most affected. Cypress, blackgum, sweetgum, and hickory had the smallest number of individuals affected (32-33%); laurel oak, red maple, elms, pines, and overcup oak the largest (66-80%); tupelo, chestnut oak, and ashes were intermediate (46-50%). Of affected trees, 100% of pines were killed; tupelo gum, blackgum, chestnut oak, and hickory had 0-2% mortality; while for others it was 25-36%. The dominant type of effect was stem breakage (61% of affected trees).

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HURRICANE HUGO IN A SOUTH CAROLINA OLD-GROWTH FLOODPLAIN FOREST: ENVIRONMENTAL EFFECTS

Michael Duever and Jean McCollom

Abstract--We assessed hurricane effects on trees (>15 cm dbh) in six 2000 m^2 plots. Numbers of individuals in a plot varied from 62 to 105. Results show 53-58% of trees exhibited major effects in four higher elevation plots, with 18 and 66% in two lower elevation plots. Of affected trees, 49% were killed on the highest site (ridge bottom), 21-35% on three intermediate elevation sites (bottomland hardwood), and only 0-8% on the lowest sites (cypress-tupelo). Of affected trees, 39-79% were directly affected by hurricane winds as opposed to falling trees at the various sites. Cypress, black gum, and sweetgum had the smallest percentage of individuals affected (33%-37%); red maple, pines, and overcup and chestnut oak the largest (65-80%); and tupelo, laurel and water oak, elms, hickory, and ashes were intermediate (45-58%). After one growing season, of affected trees 100% of pines were dead; tupelo, red maple, and black gum had 0% mortality; while for other species mortality was 20-43%. The dominant type of effect was main stem breakage (54% of affected trees), although of the different types of damage classes, 60% of uprooted trees died. Impacts were related (directly) to tree diameter and height, but not crown size. Our analyses to date indicate that Hurricane Hugo impacts were a function of community type, species composition, and tree size.

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HURRICANE DAMAGE TO AN OLD-GROWTH FLOODPLAIN FOREST IN THE SOUTHEAST[1]

Rebecca R. Sharitz, Milda R. Vaitkus and Allen E. Cook[2]

Abstract--The old-growth forests of the Congaree Swamp National Monument, an 8988 ha floodplain tract in South Carolina, were damaged by Hurricane Hugo in 1989. The effects of the hurricane on forest structure and species composition were examined in ten 1.0 ha plots established in the winter months following the storm. Trees and large saplings (stems $\geq$ 2.5 cm in diameter) were tagged and measured, mapped, and the nature and extent of the damage was recorded. Effects of the hurricane were greater in bottomland hardwood forest communities (37% of trees seriously damaged) than in adjacent forested sloughs (10%). Among the hardwoods, highest damage was sustained by several oak species (61%), especially laurel oak (*Quercus laurifolia* Michx.) and willow oak (*Q. phellos* L.). Broken boles and uprooted trees were common. Extensive branch loss occurred in sweetgum (*Liquidambar styraciflua* L., 24%) and ash (*Fraxinus* spp., 26%). In contrast, the dominant slough canopy trees, water tupelo (*Nyssa aquatica* L.) and baldcypress (*Taxodium distichum* (L.) Rich) sustained low damage (9% and 3% of the trees). Broken boles and severe branch loss occurred most frequently. Regeneration in the canopy gaps was dominated by early-successional species in the hardwood forests, but not in the sloughs. Thus, the structure of the bottomland hardwood forests was altered by the hurricane, but the slough communities were not greatly changed.

Introduction

Large-scale disturbances are important in shaping forest community structure, composition and successional processes. Early European travelers in the southeastern United States (such as Thomas Nairne in 1708) recorded the damaging effects of hurricanes to forests (Moore 1988), and recent studies of southeastern forests have examined the influence of hurricanes and tornadoes on stand composition and patch dynamics (e.g. Vogel 1980, Glitzenstein and Harcombe 1988, Platt and Schwartz 1990). Such storms are a normal, although episodic, part of the climatic regime of the South Atlantic Coastal Plain.

On September 21-22, 1989, Hurricane Hugo came ashore 20 km northeast of Charleston, SC. As the storm traveled inland, winds in excess of 155 km/hr struck the old-growth floodplain forests of the Congaree Swamp National Monument, causing significant damage (Putz and Sharitz 1991). Within the last 110 years, four other hurricanes as severe as Hugo were recorded in South Carolina (Purvis 1973) and many less severe storms have occurred. Several of these have tracked near the Congaree Swamp. Thus, it is likely that the structure of this forest, as well as other mature southeastern forests, may have been shaped by repeated wind-related disturbances.

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We have initiated a study of long-term forest community dynamics in the old-growth forests of the Congaree Swamp National Monument. Included in this research is an examination of the effects of Hurricane Hugo. Our objectives were to evaluate the hurricane damage to these mature forests, and to establish a baseline for study of forest recovery processes.

Methods

The Congaree Swamp National Monument encompasses 8988 ha of swamps and bottomland forests on the floodplain of the Congaree River in central South Carolina. It lies within the Coastal Plain, just southeast of the fall line. For many years much of the property was privately owned and was protected from logging. In 1976, the tract was acquired by the National Park Service as a National Monument. Large areas of the floodplain support old-growth forests that show little or no signs of logging or other recent human disturbance.

The forests of the Congaree Swamp National Monument are relatively diverse. In a 1975 survey of the vegetation, Gaddy and Smathers (1980) reported more than 45 tree species and distinguished 29 plant communities. The most extensive are a variety of mixed bottomland hardwood forests that are found on subhydric and mesic sites, and the baldcypress/tupelo forests that occur in hydric sites such as sloughs and large depressions. They described the forests as usually having 100% canopy coverage of old and middle-aged trees. Because the forests were allowed to grow undisturbed on optimum soil conditions, they contain an unusual number of large trees with canopy heights of 30-50 m. A number of state and national record trees were reported (Gaddy 1977).

During the winter months following Hurricane Hugo, we established ten 10,000 m^2 (1 ha) plots (each divided into 25 400 m^2 subplots) in different forest communities within the Monument. Six plots were located in bottomland hardwood communities and four in slough communities. Within each plot, all trees ($\geq$ 10 cm diameter at breast height, dbh) were tagged, their diameters measured, and their locations mapped. Trees were measured at 140 cm above ground except for those species that develop a pronounced butt swell. These were measured 200 cm above the ground or, if necessary, 50 cm above the top of the swell. In the sloughs, all saplings (2.5-10 cm dbh) within each plot were also tagged and measured. Because of the high densities of saplings in the bottomland hardwood communities, only five subplots within each 1 ha plot were sampled.

Hurricane damage to trees and saplings was classified by type and severity. Moderate to severe damage included loss of major branches, bending of the stem or bole, breakage of the bole (snap-off, considered more severe if the break was nearer to the ground) and uprooting (tip-up, partial or total). Throughout the forest, the canopy was opened by wind-induced defoliation and loss of small branches. This type of mild damage was not quantified.

Percent damage by diameter size class was examined using ANOVA in a randomized complete block design. The subplots were used as blocks and the total number of trees of all species in each size class was used as a weighting factor. A least-squares means procedure, followed by a Bonferroni contrast of least-squares means, was used to assess significant differences between diameter size classes (Miller 1986). All statistical analyses were performed using the Statistical Analysis System (SAS Institute Inc. 1989).

Seedlings and small saplings (all individuals 0-140 cm high or >140 cm high - <2.5 cm dbh) were examined in two of the bottomland hardwood and two of the slough plots. In each of these, 30 circular subplots (radius 3.26 m) were established, giving a total area sampled of 0.1 ha per plot. Seedlings and small saplings were inventoried at the end of the second and third growing seasons following the hurricane; only third year data are reported here.

Results

Pre-hurricane Forest Structure

The pre-hurricane structure of the forests can be inferred since the survey included all trees judged to have been alive at the time of the storm. The six bottomland hardwood plots were dominated by sweetgum in the canopy, along with sugarberry (*Celtis laevigata* Willd.), American elm (*Ulmus americana* L.), ash (chiefly green ash, *Fraxinus pennsylvanica* Marsh.) and oaks (laurel oak, willow oak, *Q. phellos* L.; swamp chestnut oak, *Q. michauxii* Nutt.; cherrybark oak, *Q. falcata* var. *pagodifolia* Ell., Shumard oak, *Q.*

shumardii Buckl. and water oak, *Q. nigra* L.) (Table 1). While never achieving high densities, the oaks were widely distributed throughout five of the six plots. Loblolly pine (*Pinus taeda* L.) was abundant in only one of the plots. The understory was characterized by holly (American holly, *Ilex opaca* Ait.), possumhaw (*I. decidua* Walt.), American hornbeam (*Carpinus caroliniana* Walt.), pawpaw (*Asimina triloba* (L.) Dunal.) and abundant red maple (*Acer rubrum* L.) and box elder (*A. negundo* L.).

Table 1. Dominant overstory and understory species in bottomland hardwood plots.

	Density (stems/ha)	
	Trees[1] (≥10cm dbh)	Saplings[2] (≥2.5-10cm dbh)
Overstory		
Liquidambar styraciflua	99.3	5.0
Celtis laevigata	32.0	20.0
Ulmus americana	25.5	4.2
Fraxinus spp.	13.8	1.7
Quercus spp.	28.7	9.2
Pinus taeda	6.8	0
Understory		
Ilex opaca	111.8	130.8
Ilex decidua	7.3	207.5
Carpinus caroliniana	53.7	65.0
Asimina triloba	1.2	116.7
Acer rubrum	14.2	15.0
Acer negundo	14.5	10.8
Other species	23.4	36.6
Total density	432.2	622.5

[1] based on 6 - 10,000m² plots
[2] based on 30 - 400m² subplots

Slough plots had a canopy of tupelo, either water or swamp tupelo (*N. sylvatica* var. *biflora* (Walt.) Sarg.), and baldcypress (Table 2). Scattered individuals of sweetgum were found, as well as laurel oak and overcup oak (*Quercus lyrata* L.). The understory was chiefly red maple and Carolina ash (*F. caroliniana* Mill.). Many of the maples, sweetgums and oaks grew on the slough edges or on elevated microsites that were less flooded.

Tree density was higher in the slough plots than in the bottomland hardwood plots, but the density of saplings was lower in the sloughs (Tables 1 and 2). The distribution of individuals of different sizes in the two forest communities also differed (Fig. 1). The bottomland hardwood plots were dominated by small diameter size class

Table 2. Dominant overstory and understory species in slough plots.

	Density (stems/ha)	
	Trees[1] (≥10cm dbh)	Saplings[2] (≥2.5-10cm dbh)
Overstory		
Nyssa aquatica	286.0	61.5
Nyssa sylvatica biflora	139.3	18.5
Taxodium distichum	89.5	8.0
Liquidambar styraciflua	20.0	21.5
Quercus spp.	14.0	12.8
Ulmus americana	3.0	4.0
Understory		
Acer rubrum	26.8	32.3
Fraxinus caroliniana	21.3	113.3
Planera aquatica	9.3	20.0
Ilex opaca	9.0	21.5
Carpinus caroliniana	8.8	7.0
Ilex decidua	0.3	9.5
Other species	6.7	48.9
Total density	634.0	378.8

[1] based on 4 - 10,000m² plots
[2] based on 100 - 400m² subplots

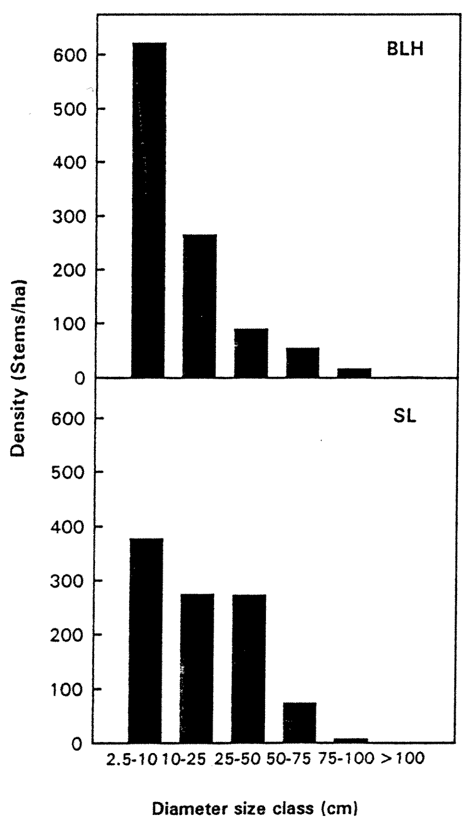

Figure 1. Density (stems/ha) by diameter class of trees and saplings in bottomland (BLH) and slough (SL) plots.

individuals; saplings comprised 59% of the stems per hectare. There were also some trees in the very large size classes with diameters greater than 75 cm. In the sloughs, 37% of the stems per hectare were saplings, and more than half (54%) were in small to intermediate size classes (10 to 50 cm dbh). There were fewer very large trees in the slough plots than in the bottomland hardwood plots.

Within each forest type, size distributions of the dominant canopy species also differed. For example, in the bottomland hardwood plots there were many more sweetgum trees than saplings (Table 1). In contrast, sugarberry and the oaks had higher proportions of saplings. There were several very large oaks of diameters greater than 100 cm. Importantly, the loblolly pines were all large trees with no saplings occurring. In the slough plots, tupelo saplings were abundant (especially water tupelo) but there were fewer saplings of baldcypress (Table 2).

Hurricane Damage

Damage from the storm was more severe in the bottomland hardwood forest communities than in the sloughs. A total of 36.7% of the individuals in the bottomland hardwood plots were moderately to severely damaged (Table 3), compared with only 10.0% of those in the slough plots (Table 4). In both forest communities, damage increased with tree size (Fig. 2). For example, 17% of the bottomland hardwood saplings (2.5-10 cm dbh) were damaged, compared with 60% of the largest trees (>100 cm dbh). In addition, the type of damage to the hardwood species tended to be more severe in larger individuals, many of which were broken off near the base or completely uprooted. In the sloughs, damage was relatively low (5-10% of the individuals) in all but the largest size class (Fig. 2). Most of the heavily damaged large trees in the sloughs had severe branch loss or snapped off boles.

In both forest communities, the type of damage differed by species. In the bottomland hardwood plots (Table 3), loss of branches was the most common form of damage to sweetgum in the canopy (23.6% of all individuals). Ash and elm in the canopy also lost many branches, as did the oaks. Between 11-18% of trees of all canopy species were snapped off. The oaks

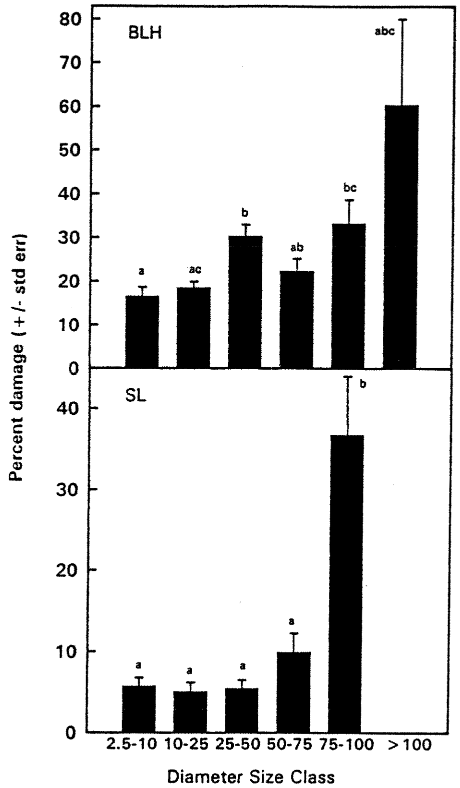

Figure 2. Mean percent damage (± standard error) by diameter size class to trees and saplings in bottomland hardwood (BLH) and slough (SL) plots. Different lower case letters denote significant ($p<0.05$) classes within BLH and SL plots, based on pair-wise comparisons.

sustained the greatest total damage (61.2% of all individuals), chiefly due to uprooting (28.9%) and snapping (17.0%). Of the pines, 12.2% were uprooted and 12.2% snapped off. Many of the understory trees were broken beneath damaged overstory trees. Red maple and boxelder sustained the greatest damage (about 25% of the stems snapped off).

In the slough plots, effects of the hurricane on canopy dominants was less severe (Table 4). In the two tupelo species, damage was 9.0-13.2%, and only 3.1% of the baldcypress were damaged. Most of the damage was in the form of branch loss or stem breakage. Sweetgums, oaks and elms tended to have higher percentages of tip-ups. The understory species, especially red maple, American hornbeam and possumhaw lost branches or were bent or snapped, probably due to large debris falling from the canopy.

Table 3. Percent damage to dominant overstory and understory species in bottomland hardwood plots.

	Percent Damage					
	Total damaged*	Branch loss	Bending	Snap off	Tip up	Projected mortal damage
Overstory						
Liquidambar styraciflua	44.5	23.6	1.2	11.0	8.5	9.5
Celtis laevigata	31.0	9.3	3.2	11.6	5.5	4.2
Ulmus americana	39.9	12.6	0.6	18.3	7.0	7.6
Fraxinus spp.	51.8	25.6	4.7	16.3	3.5	3.5
Quercus spp.	61.2	11.0	3.3	17.0	28.9	33.4
Pinus taeda	31.7	7.3	0	12.2	12.2	12.2
Understory						
Ilex opaca	23.3	4.7	6.4	6.9	4.9	4.1
Ilex decidua	32.8	7.5	11.3	12.0	1.7	7.2
Carpinus caroliniana	39.0	6.0	7.8	13.8	11.2	11.2
Asimina triloba	25.2	3.4	7.5	10.9	4.1	7.5
Acer rubrum	49.6	4.9	6.8	25.3	12.6	17.5
Acer negundo	44.0	8.0	3.0	25.0	6.0	8.0
Average for all species	36.7	10.4	5.4	12.3	7.9	8.6

* May include additional damage not shown in other columns.

Table 4. Percent damage to dominant overstory and understory species in slough plots.

	Percent Damage					
	Total damaged*	Branch loss	Bending	Snap off	Tip up	Projected mortal damage
Overstory						
Nyssa aquatica	9.0	3.9	0.8	4.2	0.1	0.4
Nyssa sylvatica biflora	13.2	4.7	1.9	6.2	0.2	0.5
Taxodium distichum	3.1	1.0	0	2.1	0	0.3
Liquidambar styraciflua	8.5	2.0	0.5	1.5	4.5	4.0
Quercus spp.	11.2	0	3.7	4.7	2.8	3.7
Ulmus americana	21.4	7.1	3.6	7.1	3.6	3.6
Understory						
Acer rubrum	19.1	7.6	4.2	4.7	2.5	2.5
Fraxinus caroliniana	10.3	3.2	2.2	4.3	0.6	2.4
Planera aquatica	8.6	2.6	4.3	1.7	0	0
Ilex opaca	2.5	0.8	0	1.6	0	0
Carpinus caroliniana	23.8	1.6	12.7	7.9	1.6	1.6
Ilex decidua	20.5	0	5.1	10.3	5.1	5.1
Average for all species	10.0	3.4	1.8	4.1	0.7	1.2

* May include additional damage not shown in other columns.

Projected mortality of injured trees was based on type and severity of damage. Trees broken off within 2 m of the ground and those completely uprooted were considered likely to die. In the bottomland hardwood plots (Table 3), the oaks had the highest level of projected mortality (33.4%). Most of this mortality resulted from uprooting. Pines also showed relatively high projected mortality (12.2%). This estimate is probably low, since many pines snapped off higher than 2 m will not survive. Other overstory dominants had much lower expected mortality (3.5-9.5%). Although half of the ash trees in the plots were damaged, only 3.5% are expected to die. In the understory, the most abundant species, American holly, sustained the least expected damage (4.1% mortality). Red maple had the highest projected mortality (17.5%), although this may be an overestimate as individuals completely tipped up have been observed to survive if a sufficient number of roots remain intact.

In the slough plots, estimated mortality of dominant canopy species was low (0.3-0.5% for baldcypress and the tupelos). Almost all of the mortality resulted from snapped boles (Table 4). Possumhaw had the highest projected mortality (5.1%) of the understory species. Only about 2.5% of the understory dominants, red maple and Carolina ash, are expected to die.

Forest Regeneration

An examination of the densities of seedlings and small saplings (advance regeneration) of the major species gives an indication of the recovery potential of the forest. In the bottomland hardwood plots, regeneration was dominated by understory species such as pawpaw, although American hornbeam and red maple seedlings were also abundant (Table 5). Seedlings and small saplings of the canopy dominant species were present but much less abundant. There were relatively few oak seedlings and none of pine. Likewise, there were few seedlings of the dominant understory species, American holly and possumhaw. In contrast, in the slough plots seedling densities were lower, but regeneration was characterized by the canopy and understory dominant species (Table 6).

It appears that in the highly disturbed bottomland hardwood forest communities, the canopy gaps are becoming dominated by rapidly growing successional species, especially pawpaw. The appropriate conditions for pine regeneration have not been met in this forest for some years, either before or following the hurricane. In the sloughs where damage was much less, seedling populations are similar to the overstory and understory composition.

Table 5. Dominant overstory and understory seedling and small sapling species in bottomland hardwood plots.

	Density (stems/ha)* (0 - 140cm high, 140cm high - 2.5cm dbh)
Overstory	
Liquidambar styraciflua	1,020
Celtis laevigata	1,590
Ulmus spp.	1,625
Fraxinus spp.	280
Quercus spp.	170
Pinus taeda	0
Understory	
Ilex opaca	185
Ilex decidua	195
Carpinus caroliniana	3,120
Asimina triloba	10,720
Acer rubrum	2,540
Acer negundo	145
Lindera benzoin	325
Crataegus spp.	240
Ligustrum sinense	105
Other species	145
Total density	22,405

* based on 60 - 33.3m² plots

Table 6. Dominant overstory and understory seedling species in slough plots.

	Density (stems/ha)* (0 - 140cm high, 140cm high - 2.5cm dbh)
Overstory	
Nyssa spp.	770
Taxodium distichum	600
Liquidambar styraciflua	75
Quercus spp.	270
Ulmus spp.	1,415
Celtis spp.	225
Understory	
Acer rubrum	5,420
Fraxinus spp.	1,380
Planera aquatica	660
Ilex opaca	5
Carpinus caroliniana	80
Ilex decidua	45
Itea virginica	820
Other species	20
Total density	11,785

* based on 60 - 33.3m² plots

Discussion

The old-growth mixed bottomland hardwood forest communities of the Congaree Swamp National Monument were much more severely damaged by Hurricane Hugo than were the slough communities. At the time of the hurricane, leaf senescence prior to autumnal abscission was beginning for many of the deciduous species. It is possible that the defoliation of baldcypress and the defoliation and branch loss of the tupelo trees reduced their wind resistance. In addition, the buttressed boles of these species may have decreased the likelihood of uprooting. Similarly, sweetgum, elm and ash in the bottomland hardwood communities were defoliated and lost large branches but were less frequently uprooted than other canopy species that had not begun leaf senescence. The tardily deciduous oaks, such as laurel oak and water oak, and the pines were the most susceptible to windthrow. Differences in root architecture may also be important; although little is known about the rooting patterns of these floodplain species, the uprooted oaks were observed to have been very shallowly rooted.

Similar species responses were observed elsewhere in the southeastern U.S. in the path of Hurricane Hugo (Gresham et al. 1991, Hook et al. 1991, Duever and McCollom 1992, Sheffield and Thompson 1992). In the Hobcaw Forest of eastern South Carolina, baldcypress suffered light crown damage, whereas laurel and water oak were commonly uprooted or snapped off (Gresham et al. 1991). Duever and McCollom (1992) also reported greater damage to oaks and pines than to baldcypress in the Four Holes Swamp forest north of Charleston. Also, the greatest damage from high winds often occurs to the larger sized trees (Glitzenstein and Harcombe 1888, Gresham et al. 1991). In the old-growth bottomland hardwood forest communities of the Congaree Swamp, however, extensive secondary damage also occurred to small and medium-sized stems that were crushed beneath large overstory trees.

Mortality of the overstory trees is expected to be relatively low in the slough communities. Less than one percent of the baldcypress and tupelo trees were damaged so severely that they are likely to die. Mortality was higher for the sweetgum, oaks and elm that had become established in the sloughs. Many were growing on stumps, logs, or other elevated microsites that may not have served as stable rooting substrates. The hurricane actually reduced the diversity in the slough communities by having a disproportionally larger effect on invading bottomland or transitional species than on community dominants.

In the bottomland hardwood communities, projected mortality of canopy trees is much greater than in the sloughs. Half of the damaged oaks are expected to die (33.4% of all stems). It is also likely that none of the loblolly pines that were snapped off or uprooted (24.4%) will survive. The hurricane changed the stand composition in the bottomland hardwood communities by reducing the presence of oaks and pine in the overstory and also lowering the abundance of certain understory species, such as red maple and American hornbeam.

It is expected that tree mortality from the hurricane will continue as severely damaged individuals gradually die. Repeated sampling in the Four Holes Swamp forest has shown this to be the case (M. J. Duever, personal communication). Damaged trees also may be more susceptible to insect or fungal infestation or other disease. Furthermore, since hurricanes are a normal part of the climatic regime of the southeastern U.S., trees weakened in one storm may be pre-disposed to future damage. In the Congaree forest, Putz and Sharitz (1991) noted that many of the trees damaged by Hurricane Hugo showed evidence of prior mechanical damage or disease.

Forest recovery from such disturbance is by regrowth and sprouting of damaged individuals, release and rapid growth of established seedlings and saplings (advance regeneration), and germination and establishment of new seedlings. Following a hurricane, light intensity at the forest floor should increase not only in canopy gaps, but also beneath surviving trees (Canham et al. 1989). Thus, both light-demanding and shade-tolerant species can potentially regenerate. In the bottomland hardwood forests of the Congaree Swamp, the regeneration is dominated by rapidly growing successional species, especially pawpaw and red maple. Previously established saplings of several of the canopy dominants, especially sweetgum, sugarberry and elm, are also expected to grow rapidly in the increased light environment. Conversely, pine seedlings are not expected to become established. Although disturbances may increase the variety of microsites for seedling establishment (Schupp et al. 1989), the abundant coarse woody debris in many of the gaps may limit establishment of new seedlings by shading the forest floor and also providing structure for growth of light-demanding vines. Thus, in the bottomland hardwood communities, the removal of pines and large oaks and the invasion of canopy gaps by early-successional species have resulted in short-term changes in the forest composition. Recovery of the slough communities, where damage to the canopy trees was generally less severe, should be relatively rapid as a result of branch sprouting and canopy regrowth of damaged baldcypress and tupelo trees. Seedling populations were similar in composition to the canopy and subcanopy, and thus there is not expected to be a major change in forest structure in the sloughs.

Acknowledgments

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HURRICANE DAMAGE TO OLD-GROWTH FOREST IN CONGAREE SWAMP NATIONAL MONUMENT, SOUTH CAROLINA, U.S.A.[1]

Francis E. Putz and Rebecca R. Sharitz[2]

Abstract--Hurricane Hugo caused much damage to the old-growth forests of the Congaree Swamp National Monument, but most of the damage to trees >20 cm dbh consisted of crown breakage and defoliation. Serious damage (>25% of crown lost, snapped trunk, or uprooted) was more common in mixed bottomland forest (49% of trees seriously damaged) than in adjacent sloughs dominated by *Taxodium distichum* (L.) L.C. Rich. and *Nyssa aquatica* L. (19% of trees seriously damaged). Of the trees >20 cm dbh, about 12% were uprooted in the bottomland forest, whereas only 2% were uprooted in sloughs. The storm reduced diversity in sloughs because most trees of species characteristic of better drained sites, and especially those rooted on nurse logs and other unstable elevated microsites, were uprooted. Dynamics of the entire forest were greatly influenced by the capacity of most tree species to recover vegetatively after suffering even severe crown and stem damage. Trees with resprouted crowns, however, were particularly likely to be broken, presumably owing to the presence of stem rots and architecturally unsound branching patterns.

INTRODUCTION

Hurricanes and other large-scale disturbances strongly influence the structure, composition, and successional processes of many forests (Lugo and others 1983; Runkle 1985; Webb 1988; Boucher 1990). Such disturbances often set back succession by providing regeneration opportunities for early successional species (Clements 1916). Several recent studies have shown, however, that disturbance may also accelerate succession by damaging pioneer trees in the canopy and releasing the advanced regeneration of later successional species (Abrams and Scott 1989; Veblen and others 1989). In either case, disturbances, especially those that are spatially heterogeneous in intensity, often contribute to the maintenance of species diversity by providing a diversity of regeneration opportunities (Grubb 1977).

On September 21, 1989, winds in excess of 155 km/h from Hurricane Hugo struck the old-growth bottomland hardwood and the *Taxodium distichum* (L.) L.C. Rich. and *Nyssa aquatica* L. (cypress tupelo) dominated swamp forest in the Congaree Swamp National Monument. Several days after the storm we conducted a census to evaluate the effect of Hurricane Hugo on forest structure and species composition in one of the largest tracts of old-growth forest in eastern North America. In this paper, we contrast the storm's impacts on old-growth bottomland forest and adjacent forested sloughs and focus on the frequency and type of damage suffered by canopy trees of different species.

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[1] Putz, F. E., and Sharitz, R. R. 1991. Hurricane damage to old-growth forest in Congaree Swamp National Monument, South Carolina, U.S.A. Can. J. For. Res. 21:1765-1770.
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STUDY SITE AND METHODS

The Congaree Swamp National Monument encompasses 6125 ha of swamps and bottomland forests on the floodplain of the Congaree River in central South Carolina. Much of the Monument is old-growth forest with no signs of human disturbance for at least 100 years and numerous record-size trees (Gaddy 1977, Gaddy and Smathers 1980). The vegetation is extremely diverse and includes extensive areas of mixed bottomland hardwoods with the following common tree species (nomenclature follows Radford and others 1968): *Liquidambar styraciflua* L. (sweetgum), *Celtis laevigata* Nutt. (hackberry), *Ilex opaca* Ait. (American holly), *Carpinus caroliniana* Walt. (American hornbeam), and *Fraxinus pennsylvanica* Marsh. (red ash). *Pinus taeda* L. (loblolly pine) is locally dominant in a few bottomland areas in the Monument. Also common in slightly lower elevation areas are forested sloughs dominated by *N. aquatica* (water tupelo) and *T. distichum* (bald cypress), with scattered *Carya aquatica* (Michx. f) Nutt. (water hickory), *Acer rubrum* L. (red maple), and *Planera aquatica* J.F. Gmel. (water elm). The sloughs are inundated several months per year, whereas the bottomlands flood only occasionally.

To assess damage attributable to Hurricane Hugo, we censused trees >20 cm dbh (diameter at 1.4 m or above buttresses and butt swell) in 0.2-ha (20 x 100 m) plots in old-growth bottomland forest and forested sloughs throughout the Monument (Figure 1). Plots were located by selecting a place on a reserve map on the basis of accessibility, determining if the area was large enough to include an entire slough or bottomland forest plot, and selecting one plot corner in a haphazard fashion. Sampling was completed within 10 days after the storm. Twenty-one plots were censused (total area = 4.2 ha), 12 in bottomland forest and 9 in forested sloughs. To increase the accuracy of damage estimates for the less abundant slough species, we censused all trees other than *N. aquatica* and *T. distichum* in five additional sloughs. Additionally, we increased the sample size for *P. taeda* trees to 100 by censusing all trees >20 cm dbh of this species within 20 m of the boardwalk through the central portion of the Monument.

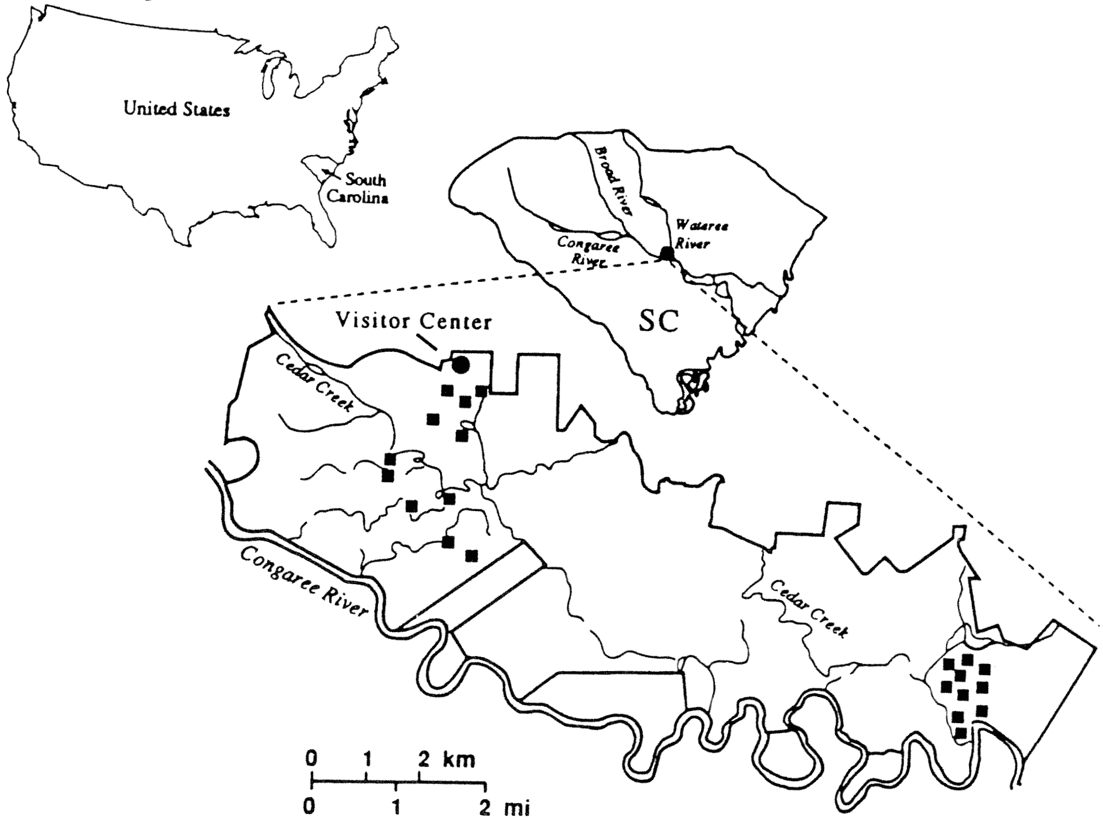

Figure 1--The Congaree Swamp National Monument indicating the locations of the sample plots with black boxes. The monument is approximately 145 km from the Atlantic Ocean.

Each tree was identified to species, measured for dbh, and classified as one of the following: having suffered no serious damage (e.g., only defoliated), uprooted, partially uprooted, trunk snapped below the lowermost live branch, or having lost major portions of its crown (25-50% and 50%). We also noted whether the trees showed obvious signs of having suffered previous damage, presence of heart rot, and height of stem breakage. Indications that a tree had suffered but recovered from serious mechanical damage prior to Hurricane Hugo included the presence of broken stem remains and abrupt irregularities in stem shape, criteria identical with those used by Putz and Brokaw (1989).

The relationships between different types of damage and tree size (dbh), tree species, prior damage, and habitat were determined by log likelihood ratio analyses of data from the 0.2-ha plots (G-tests with Williams' correction; Sokal and Rohlf 1981). Owing to the small numbers of damaged trees in some plots, analysis was based on combined data from all plots in a vegetation type.

RESULTS

Forested Sloughs

Although Hurricane Hugo caused substantial losses of leaves and small branches, only about 19% of the trees in forested sloughs suffered serious damage (>25% crown loss; Table 1). Uprooting was particularly uncommon in the sloughs. This was surprising since trees in swamps are generally thought to be prone to uprooting due to their shallow root systems and low soil shear strength (Schaetzl and others 1989). Although there were 25 uprooted trees in nine slough plots, none were of the dominant species *T. distichum* or *N. aquatica*. Furthermore, during the 8 days of field surveys we observed only one uprooted *T. distichum* anywhere in the Monument. There were no clear relationships between type of damage and tree size (Table 2), but trees with obvious signs of having suffered but recovered from previous stem breakage had a high probability of being damaged during Hurricane Hugo (Table 3).

Hurricane Hugo reduced canopy tree diversity in *Taxodium-Nyssa* sloughs by uprooting a disproportionately high number of trees of species other than the dominants (Table 4). None of the 104 *T. distichum* or 404 *N. aquatica* trees in the plots were uprooted. Of the few uprooted trees in sloughs, most were members of species characteristic of slough margins and other higher elevation and better drained sites. Most species that occurred in both sloughs and bottomland forest suffered higher incidences of uprooting in the sloughs (Table 4). About half of the uprooted trees in sloughs were clearly rooted on fallen logs, tip-up mounds from previously uprooted trees, or other elevated and mechanically unstable microsites. This was particularly true for *A. rubrum* trees, many of which were uprooted or leaning over due presumably to shifting of the nurse logs on which they often perched.

Bottomland Forest

Among-plot variation in tree density and in the proportion of damaged trees were very large in the bottomland hardwoods. Densities of trees >20 cm dbh

Table 1--Damage suffered by trees during Hurricane Hugo in 0.2-ha (20 X 100 m) plots in forested sloughs.

	Plot No.									
	1	2	3	4	5	6	7	8	9	Total[a]
Total no. of trees >20 cm dbh	21	83	83	81	89	63	51	67	120	658
Total no. of trees seriously damaged	6	11	26	22	11	19	8	11	11	125(19.0)
No. of uprooted trees	0	1	2	2	0	6	0	0	1	12(1.8)
No. of partially uprooted trees	0	1	7	3	1	1	0	0	0	13(2.0)
No. of snapped trees	6	1	9	7	6	5	0	6	3	43(6.5)
No. of trees with >50% crown loss	0	4	6	3	0	1	1	2	1	18(2.7)
No. of trees with 25-50% crown loss	0	4	2	7	4	6	7	3	6	39(5.9)

NOTE: Trees were considered seriously damaged if they lost more than 25% of their crown. Plots were in the southeastern (plots 1-6) and central (plots 7-9) portions of the Congaree Swamp National Monument.
[a] Percentages of total are noted in parentheses.

Table 2--Number of trees that snapped, uprooted (including trees partially uprooted), suffered substantial crown damage, or remained relatively undamaged (but may have suffered defoliation) during Hurricane Hugo.

dbh	Snapped	Uprooted	Crown loss >25%	Undamaged
		Forested sloughs		
20-40 cm	18(5.9)	14(4.6)	21(6.9)	251(82.6)
40-80 cm	23(7.5)	9(2.9)	30(9.7)	246(79.9)
>80 cm	2(4.3)	2(4.3)	5(10.9)	37(80.7)
P	ns	ns	ns	ns
		Bottomland forest		
20-40 cm	56(18.7)	41(13.7)	39(13.0)	164(54.7)
40-80 cm	31(17.0)	31(17.0)	39(21.4)	81(44.5)
>80 cm	3(8.3)	2(5.6)	11(30.6)	20(55.6)
P	ns	<0.001	<0.01	<0.01

NOTE: Data are from nine 0.2-ha plots in forested sloughs and twelve 0.2-ha plots in bottomland forest in the Congaree Swamp National Monument. Percentages of all trees in a size class are noted in parentheses. Probabilities that the incidence of damage varied with tree size class are based on log likelihood ratio tests.

Table 3--Incidence of serious damage in 0.2-ha plots to trees >20 cm dbh that either showed signs or showed no clear sign of having suffered serious damage prior to Hurricane Hugo in *Taxodium-Nyssa* sloughs and bottomland hardwoods.

	No. of trees seriously damaged	No. of trees not seriously damaged
Slough trees		
Previously damaged	52(28)	135(72)
Not previously damaged	73(16)	398(84)
P		<0.001
Bottomland hardwoods		
Previously damaged	88(71)	35(29)
Not previously damaged	129(41)	185(59)
P		<0.001

NOTE: Probabilities are based on log likelihood ratio tests. Percentages of all trees in a damage class are noted in parentheses.

Table 4--Uprooting frequencies for trees >20 cm dbh growing in forested sloughs and bottomland forests.

	Sloughs, frequency (uprooted/total)	P	Bottomland, frequency (uprooted/total)
Liquidambar styraciflua	6/13	<0.05	17/123
Acer rubrum	10/27	<0.05	2/23
Fraxinus pennsylvanica	4/29	ns	2/41
Carya aquatica	3/5	ns	2/11
Ulmus americana	3/8	ns	6/26
Populus heterophylla[a]	9/13		0/1
Platanus occidentalis[a]	6/8		0/1
Quercus falcata var. *pagodifolia*[a]	4/7		---

NOTE: Probabilities are based on tests. Slough data from the 0.2-ha plots were augmented by a census of five additional sloughs.
[a] Sample sizes too small for statistical analysis.

ranged from 34 to 64/0.2 ha, and the proportion of uprooted and snapped trees ranged from 4 to 50%. This extreme heterogeneity was undoubtably due in part to the specific (but unknown) paths of Hurricane Hugo and was presumably also influenced by stand structure and history of previous damage.

Approximately half of the trees in the bottomland plots suffered serious damage, but only about 30% were uprooted or snapped (Table 5). Trees in bottomland forests seem equally prone to being uprooted and to suffering stem breakage. Among large trees (>80 cm dbh), the incidences of snapping and uprooting were low but serious crown damage was common (Table 2); apparently a tree that loses a large portion of its crown is unlikely to suffer more serious damage. Alternatively, trees that resist windthrow may therefore be likely to receive heavy damage to their crowns. Many of the large trees appeared to have sustained, but recovered from, substantial damage prior to Hurricane Hugo. Trees that had recovered from serious damage prior to Hurricane Hugo suffered a very high probability of sustaining damage during the Hurricane (Table 3). The major short-term effect of Hurricane Hugo in bottomland hardwood forest, as in sloughs, was loss of much foliage and many small branches.

Pinus taeda in Bottomland Forest

Of the 100 *P. taeda* trees >20 cm dbh censused, only 46 escaped serious damage from Hurricane Hugo (Table 6). Uprooting and snapping were about equally common (21 and 28 trees, respectively). Most of the broken (snapped) trees had heart rot, but we suspect that many of the undamaged and uprooted trees were likewise infected. Damage to trees was severe in areas where *P. taeda* trees were common. This seemed mostly because when large *P. taeda* trees were either uprooted or snapped, they caused a great deal of damage to their neighbors.

DISCUSSION

Forests of the Congaree Swamp National Monument were severely disturbed by Hurricane Hugo, but the type and extent of tree damage varied with forest type. Throughout the area the canopy was opened by wind-induced defoliation; since this occurred only a few weeks prior to normal autumnal leaf abscission, the immediate deleterious effects on tree vigor were probably minor. Trees in bottomland forests, particularly where there were large individuals of *P. taeda*, often suffered much more serious damage. About half of the bottomland trees were uprooted, snapped, or had lost a substantial number of large branches. This contrasts markedly with the slightly more low-lying and poorly drained sloughs, where uprooting was particularly rare.

Table 5--Tree damage in bottomland hardwood forests of the Congaree Swamp National Monument attributable to Hurricane Hugo.

	Plot No.												
	1	2	3	4	5	6	7	8[a]	9	10	11	12	Total[b]
Total no. of trees >20 cm dbh	37	41	50	38	36	34	38	64	49	51	37	44	519
Total no. of trees seriously damaged	18	22	26	18	20	31	14	40	4	24	10	24	253(48.7)
No. of uprooted trees	3	2	5	2	5	11	0	17	1	4	3	11	64(12.3)
No. of partially uprooted trees	3	1	2	0	1	1	0	0	0	0	0	0	10(1.9)
No. of snapped trees	6	12	9	7	6	4	5	15	1	7	7	11	90(17.4)
No. of trees with >50% crown loss	2	2	2	4	4	5	3	5	0	6	0	0	33(6.4)
No. of trees with 25-50% crown loss	4	5	8	5	4	10	6	3	2	7	0	2	56(10.8)

NOTE: The plots were each 0.2 ha (20 x 100 m) and were located in the southeastern portion (plots 1-6) and central portions of the Monument (plots 7-12). Trees that lost more than 25% of their crowns were considered to be seriously damaged.
[a] Plot 8 contained seven snapped and three uprooted Pinus taeda.
[b] Percentages of total are noted in parentheses.

Table 6--Damage suffered by *Pinus taeda* >20 cm dbh in the Congaree Swamp National Monument during Hurricane Hugo.

dbh (cm)	Total no. of trees	No. of snapped trees	No. of uprooted trees	No. of trees with 25-50% crown loss	No. of trees with >50% crown loss	No. of trees with no serious damage
40-60	4	2	1	0	0	1
60-80	24	8	9	1	1	5
80-100	55	15	10	1	0	29
>100	17	3	1	1	1	11
Total	100	28	21	3	2	46

NOTE: No *Pinus taeda* trees 20-40 cm dbh were encountered.

To some extent the differences can be attributed to characteristics of the dominants of the latter, *T. distichum* and *N. aquatica*. Trees in sloughs might also have been sheltered from the wind by the surrounding forest, but the elevational range was generally <1 m. Furthermore, the tops of the crowns of many slough trees were often level with or higher than the canopy of the adjacent bottomland forest.

Observations of *T. distichum* rooting patterns in Florida revealed that the trees often develop several "sinker" roots that penetrate to greater depths than the rest of the root system (K. Ewel, personal communication). The root system ball of the one uprooted *T. distichum* tree we encountered exposed numerous downward growing roots at a depth of about 1 m. Such a root system may effectively anchor *T. distichum* trees in the frequently inundated soils of the sloughs and thus account for their persistence during strong winds. Uprooting and trunk snapping of *T. distichum* may be rare because the large trees have strong wood and because *T. distichum* trees normally display little leaf area relative to trunk diameter (Brown 1981) and thus have low wind resistance.

Defoliation and crown breakage by wind may in part account for the infrequency of uprooting and snapping of weak-wooded species such *N. aquatica*. After a tree loses leaves and branches, its wind resistance is substantially decreased and the probability of more serious damage is reduced. Although we did not conduct a quantitative survey, defoliation appeared to be particularly severe in *N. aquatica*.

In contrast with the dominant slough species, many of the rarer tree species in this community suffered disproportionately high probabilities of being uprooted during Hurricane Hugo. The reasons for this phenomenon undoubtedly vary from species to species, but overall it suggests that by growing in sloughs the trees had exceeded the bounds of their ecological tolerance range. For several decades prior to Hurricane Hugo, however, these colonizers from better drained habitats survived in the sloughs by rooting on elevated microsites, like nurse logs and tip-up mounds. When confronted with mechanical stresses of the magnitude imposed by the storm, their root systems or the substratum upon which they were perched proved unequal to the task of providing structural support. A consequence of the concentration of damage on species other than *T. distichum* and *N. aquatica* is that canopy diversity was reduced and dominance by these two species was increased by Hurricane Hugo. In *T. distichum* dominated swamps elsewhere in southeastern United States, dominance is maintained in part by occasional fires that disproportionately damage the rarer species (Ewel and Mitsch 1978).

A large proportion of trees in the Congaree Swamp National Monument had obviously suffered severe mechanical damage prior to Hurricane Hugo (Table 3). Damage and subsequent recovery was evident in the crown and bole structure of many trees, particularly in the larger *N. aquatica*. Previous mechanical damage is likely to have contributed to the incidence and severity of attack by heartrot fungi; trees with heart rot are very susceptible to further damage even if the crown resprouts. Susceptibility to damage is also increased if resprouted branches form v-shaped crotches with entrapped bark or other architecturally unsound crown morphologies.

To the extent that trees that cause canopy gaps resprout and close the openings they created, frequencies of canopy tree replacement are reduced. Heightened probabilities of repeated canopy-opening events near previously broken but recovered trees, however, may be reflected in the distribution and growth of understory species. Although breakage and resprouting seems to be a major process in the dynamics of other forests (Foster 1988, Webb 1988, Putz and Brokaw 1989, Boucher 1990), this is the first report of a positive feedback mechanism enhancing the likelihood of repeated damage and recovery. In complete contrast, however, resprouting does not occur in *Rhizophora apiculata* Blume dominated mangrove forests in southeast Asia, where even minor mechanical damage leads to tree death within 10-15 years (Putz and Chan 1986).

Among commercial tree species in North America, both *T. distichum* and *N. aquatica* are rated by foresters as relatively resistant to hurricane damage (Barry and others 1982). Along with *Sabal palmetto* Lodd. ex J.S. Shult. & J.H. Shult. (palm cabbage) and *Quercus virginiana* Mill. (live oak), *T. distichum* is ranked as highly resistant to uprooting and breakage. *Nyssa aquatica* is considered to be less resistant than *T. distichum* but is ranked as less prone to uprooting and breakage than are most *Quercus* spp., *Pinus* spp., and *Carya* spp. Observations in forested areas elsewhere on the South Carolina coastal plain (Francis Marion Forest and Santee Experimental Forest) have also revealed far more extensive damage to forest dominated by *Pinus* spp. and *Quercus* spp. than to stands of *Taxodium* and *Nyssa* (personal observation).

In the absence of fire, even the extensive damage of Hurricane Hugo to bottomland forests may not be followed by substantial *P. taeda* regeneration in the Congaree Swamp National Monument (Hough and Forbes 1943, Glitzenstein and others 1986, Foster 1988). In the area dominated by large *P. taeda* trees, there were few individuals <40 cm dbh. Trees that survived the storm will probably be subjected to severe attack by beetles that will breed in the downed timber and in damaged but standing trees. Annual ring counts of three fallen *P. taeda* trees (90, 101, and 113 cm dbh) were about 156, 157, and 180 years old, respectively, and grew extremely slowly (<1 mm/year) during the last 20 years. This suggests that conditions were suitable for *P. taeda* recruitment during the mid-1800s but have deteriorated subsequently. The understory of *Arundinaria gigantea* (Walter) Muhl. (switchcane), vines, shrubs, and small broad-leaved trees is likely to increase in density where the canopy was radically opened by Hurricane Hugo. Furthermore, thick mats of litter and organic matter still cover the ground, except where mineral soil was exposed by uprooted trees. Fire is a distinct possibility, however, especially now with heavy fuel loads in much of the bottomland forest.

It became evident in the course of our damage survey that the forests of the Congaree Swamp National Monument have suffered severe storms several times during the last few decades. We expect that in response to Hurricane Hugo and other storms, changes in tree species composition will be buffered by the capacity of hardwoods to resprout even after suffering severe damage. In sloughs, storms such as Hurricane Hugo reduce canopy tree species diversity and foster the dominance of *T. distichum* and *N. aquatica* by uprooting trees of other species. Because of the suscepti-bility of resprouted trees to wood-rotting organisms and further mechanical damage, the effects of Hurricane Hugo will be evident for many decades. These long-term effects will be concentrated in areas where trees have vegetatively recovered from severe mechanical damage.

ACKNOWLEDGEMENTS

It was a great pleasure to conduct fieldwork in the Congaree Swamp National Monument, particularly with the willing and able assistance of numerous people, but especially J. Titus, P. Megonigal, and K. Moorhead. The cooperation of the Monument staff was greatly appreciated. We also thank S. Porth for sharing with us his knowledge of this lovely forest. The manuscript benefitted from the comments of M. Davis, P. Anderson, D. Hibbs, and G. Schupp.

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HURRICANE DAMAGE TO THE CANOPY SPECIES OF A 24-YEAR-OLD SEED TREE REGENERATION EXPERIMENT IN A NON-ALLUVIAL SWAMP

David L. Gartner, Donal D. Hook, and Marilyn A. Buford[1]

Abstract--In the mid 1960's a 500-acre non-alluvial swamp on the Francis Marion National Forest in South Carolina was experimentally regenerated. The five treatments were: 1) clearcut, 2) leave 15 seed trees per acre, 3) leave 30 seed trees per acre, 4) leave 90 seed trees per acre, and 5) an uncut control. All seed trees were approximately 90-year-old swamp tupelo (*Nyssa sylvatica* var *biflora*) and averaged 14 inches in diameter at breast height.

On September 21, 1989, the area was hit by Hurricane Hugo, and was within the high impact zone (Hook and others, 1991). In the winter of 1992, data were collected from the study area to determine if the stands resulting from the various harvesting treatments were impacted differently by the hurricane.

Of the five main tree species, loblolly pine (*Pinus taeda* L.) received the most damage, followed by swamp tupelo, red maple (*Acer rubrum*), sweetbay (*Magnolia virginiana*), and bald cypress (*Taxodium distichum*) in decreasing order of damage. Most of the damage to swamp tupelo, red maple, sweetbay, and bald cypress was bent stems, with some broken stems. Loblolly pine stems were primarily broken or uprooted resulting in greater than 50 percent direct mortality for this species.

Hurricane damage differed significantly from that of the uncut control treatment for only a few treatment species combinations. The results followed two general patterns: 1) for bald cypress, red maple, swamp tupelo, and sweetbay, the harvested treatments had a higher percentage of stems in the Bent category than the uncut control, and 2) for loblolly pine, the harvested treatments had a higher percentage of stems in the Broken, Uprooted, and Dead categories than the uncut control.

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INTRODUCTION

A seed tree regeneration experiment was established in 1963 in a 500-acre non-alluvial swamp on the Francis Marion National Forest in South Carolina. The area is known as Bluebird Swamp. The study area was an approximately 90-year-old even-aged stand of swamp tupelo (*Nyssa sylvatica* var *biflora*) and bald cypress (*Taxodium distichum*). The stand contained 245 stems per acre that were 5 inches or greater in diameter, and averaged 168 square feet of basal area per acre in 1963. The Bayboro soil series (clayey, mixed, thermic Umbric Paleaquults) covers the entire site and is listed as hydric soil (USDA Soil Conservation Service, 1991).

The study was designed as a randomized complete block with three blocks and five treatments. The five treatments were: clearcut, leave 15 seed trees per acre, leave 30 seed trees per acre, leave 90 seed trees per acre, and an uncut control. All seed trees were swamp tupelo and were spaced as evenly as possible within the treatment area. Fifteen 4.9-acre plots were laid out in the swamp during the summer of 1963. Block 1 was located above a logging access road that was built across the swamp in the fall of 1965 and Blocks 2 and 3 were located below the road. Block 1 was harvested during the dormant season of 1965-66, Block 2 in 1966-67, and Block 3 in 1967-68. The harvest was done under a regular USDA Forest Service contract and rubber-tired skidders were used to log the area. During the growing season prior to each harvest, all plots of each block were mist-blown with 2,4,5-T to kill a heavy understory. Larger undesirable trees were poisoned by injecting them with 2,4,5-T. Following logging, swamp tupelo stumps were sprayed with a 1:30 solution of the 2,4,5-T esters and diesel oil to prevent sprouting (DeBell and Auld, 1971).

On September 21, 1989, the area was hit by Hurricane Hugo, and was within the high impact zone (Hook and others, 1991). The pre-Hugo average basal area across all plots, including remnant seed trees, was approximately 115 square feet per acre (range 106.1 - 126.7). The basal area, exclusive of remnant seed trees, ranged from 110 square feet per acre in the clearcut plots to 27.5 square feet in the control plots. Swamp tupelo and red maple (*Acer rubrum*) dominated the regeneration in terms of number of stems. In the harvested treatments, loblolly pine (*Pinus taeda* L.) contributed a major portion (at least 30 percent) of the basal area. See Hook and others (in press) for a more detailed description of the stand.

OBJECTIVES

We report on the treatment differences in the amount and type of hurricane damage received by the major tree species.

METHODS

In the summer of 1992, three 0.1-acre circular plots were randomly established within the central one-acre area of each original treatment plot for a total of 45 plots. For all stems 4.5 feet and taller, species and diameter at breast height (dbh) were recorded. Hurricane damage was documented for each stem as to whether it was bent, broken, uprooted, and/or dead. All blown down or broken loblolly pine stems were measured at breast height and recorded as dead in each plot. The damage classes are not mutually exclusive, so some stems were recorded in more than one damage class. The percent of stems in each damage class was calculated for each species from the sums of the data from the three subplots at the treatment plot level. These percentages were then analyzed by an ANOVA.

There was no apparent regeneration between Hurricane Hugo and when the measurements were taken except sprouts from bent and broken stems. These sprouts were removed from the data set for this analysis.

RESULTS

Effects of Species

Of the five main canopy tree species, swamp tupelo had the highest percentage of damaged stems with 73.5 percent. Loblolly pine had the second highest percentage with 63.5 percent. Red maple (*Acer rubrum*) had only 49.0 percent damaged stems. Sweetbay (*Magnolia virginiana*) had 32.6 percent damaged stems. Bald cypress received the least damage with 20.7 percent damaged stems. Bald cypress, red maple, swamp tupelo, and sweetbay reacted similarly in that the damage consisted primarily of bent stems with some broken stems (Table 1). The damage to loblolly pine consisted

Table 1--Percent of stems damaged.

Species	All Damage	Bent	Broken	Uprooted	Dead
Swamp Tupelo	73.5a	56.9a	22.5a	0.1b	0.1b
Red Maple	49.0ab	45.2a	4.3b	1.2b	0.2b
Sweetbay	37.6bc	36.7ab	1.3b	0.0b	0.0b
Bald Cypress	20.7c	18.2bc	2.5b	0.0b	0.0b
Loblolly Pine	63.5ab	14.6c	23.1a	29.2a	51.5a

Letters indicate species that are not significantly different from each other within a damage category using Tukey's procedure (Steel and Torrie, 1980).

primarily of uprooted and broken stems which caused a much higher direct mortality rate than observed for any other species. The ranking of species by the amount of damage received follows the ranking by Barry and others (1982) as shown in Table 2.

Table 2--Ranking of species from least to most susceptible to hurricane damage.

Bluebird Swamp	Barry and Others (1982)
Bald Cypress	Bald Cypress
Sweetbay	Sweetbay
Red Maple	Loblolly Pine
Swamp Tupelo	Red Maple
Loblolly Pine	

Because the hardwood stems resprout and cypress stems suffered little damage, the hurricane will probably not affect the hardwood and cypress composition of the stand. However, there probably will be a large reduction in the proportion of loblolly pine in the regenerating stand, as reported in Hook and others (in press).

Effects of Treatments

Table 3 shows how the combined canopy species in the regenerating stands in the different harvesting treatments were affected by Hurricane Hugo. When testing for differences in the percent of damaged trees, the main effect for treatments was not significant. Means for each treatment showed that the harvested treatments usually congregated around an average that was higher than the mean for the control treatment. These differences between individual harvested treatment means and the control treatment means were analyzed using Dunnett's test for treatment means being different from a control mean (Steel and Torrie, 1980). The 15 seed trees and 90 seed trees treatment means in the All Damaged category are significantly different from the control treatment mean (alpha = 0.05), along with the 90 seed tree treatment mean in the Bent category.

Table 3--The effect of regeneration treatments on the percent of stems damaged by Hurricane Hugo. All five major canopy species combined.

Damage Class	Treatment Means (percent) Clear -cut	15 Trees	30 Trees	90 Trees	Control
All	65.4	66.0*	59.4	70.4*	54.8
Bent	50.8	50.0	49.3	58.8*	43.3
Broke	16.3	21.3	12.2	15.8	15.4
Uproot	1.5	1.4	.8	1.0	.5
Dead	1.9	2.0	.9	1.1	.2

* Treatment mean significantly different from control mean via Dunnett's test at p = .05.

For the individual species, there is a general pattern of the harvest treatment means being larger than the uncut control treatment means for the All Damage category. For bald cypress (Table 4), red maple (Table 5), swamp tupelo (Table 6), and sweetbay (Table 7), the pattern of the harvest treatment means being larger than the uncut control treatment means also holds for the Bent category. The swamp tupelo 90 seed tree treatment All Damage category mean is significantly different from the control mean at the alpha = .05 using Dunnett's test. For loblolly pine (Table 8), the pattern holds for all of the damage categories except the Bent category. For loblolly pine clearcut treatment All Damage category was significantly different from the control treatment mean.

Table 4--The effect of regeneration treatments on the percent of stems damaged by Hurricane Hugo.

Bald Cypress

Damage Class	Treatment Means (percent) Clear -cut	15 Trees	30 Trees	90 Trees	Control
All	30.5	30.0	40.2	12.4	11.3
Bent	29.3	26.6	39.0	1.3	11.3
Broke	1.2	3.1	1.2	11.1	.00
Uproot	.00	.00	.00	.00	.00
Dead	.00	.00	.00	.00	.00

* Treatment mean significantly different from control mean via Dunnett's test at p = .05.

Table 5--The effect of regeneration treatments on the percent of stems damaged by Hurricane Hugo.

Red Maple

Damage Class	Treatment Means (percent) Clear -cut	15 Trees	30 Trees	90 Trees	Control
All	52.4	52.1	49.7	58.7	37.3
Bent	47.7	46.6	47.9	55.2	32.9
Broke	3.96	5.76	3.00	4.82	4.05
Uproot	1.73	2.11	.74	1.09	1.23
Dead	.54	.00	.00	.00	.00

* Treatment mean significantly different from control mean via Dunnett's test at p = .05.

Table 6--The effect of regeneration treatments on the percent of stems damaged by Hurricane Hugo.

Swamp Tupelo

Damage Class	Treatment Means (percent) Clear -cut	15 Trees	30 Trees	90 Trees	Control
All	71.3	75.8	63.8	81.7*	46.8
Bent	55.6	55.6	52.0	65.2	36.3
Broke	19.0	27.7	15.2	23.6	16.2
Uproot	.22	.33	.03	.17	.00
Dead	.33	.11	.00	.00	.00

* Treatment mean significantly different from control mean via Dunnett's test at p = .05.

Table 7--The effect of regeneration treatments on the percent of stems damaged by Hurricane Hugo.

Sweetbay

Damage Class	Treatment Means (percent) Clear -cut	15 Trees	30 Trees	90 Trees	Control
All	62.1	46.1	21.5	53.6	32.8
Bent	62.1	43.7	21.5	53.6	16.1
Broke	.00	4.3	.00	.00	16.7
Uproot	.00	.00	.00	.00	.00
Dead	.00	.00	.00	.00	.00

* Treatment mean significantly different from control mean via Dunnett's test at p = .05.

Table 8--The effect of regeneration treatments on the percent of stems damaged by Hurricane Hugo.

Loblolly Pine

Damage Class	Treatment Means (percent) Clear -cut	15 Trees	30 Trees	90 Trees	Control
All	81.6*	56.4	69.7	50.0	34.1
Bent	19.2	17.9	15.6	15.6	18.9
Broke	19.8	25.1	18.1	22.7	10.0
Uproot	54.5	15.4	39.3	14.7	12.7
Dead	68.3	42.8	63.6	30.5	16.3

* Treatment mean significantly different from control mean via Dunnett's test at p = .05.

SUMMARY

Loblolly pine received the most damage, followed by swamp tupelo, red maple, sweetbay, and bald cypress. Most of the damage to swamp tupelo, red maple, sweetbay, and bald cypress was in the form of bent stems with very little mortality. The damage to loblolly pine was primarily in the form of uprooted and broken stems leading to a high (over 50 percent) mortality rate. A higher percentage of stems were damaged on the treatment plots than on the control plots.

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Timber Supplies, Salvage, and Use

DAMAGE, HARVEST OPERATIONS, AND REGENERATION ACTIVITIES FOLLOWING HURRICANE HUGO IN SOUTH CAROLINA--PHOTOGRAPHIC DOCUMENTATION

Jeffrey L. Baumann, Robert G. Haight, Allan P. Marsinko, and Thomas J. Straka[1]

Abstract--Hurricane Hugo damaged 4.5 million acres of South Carolina forest land in 1989. Nearly 900 million board feet of sawtimber and nearly 2.6 million cords of pulpwood was salvaged from the damaged forest land. Approximately 1.2 million acres needed reforestation. Much of this acreage required site preparation. As a result many unique conditions were present in 1989 and the early 1990's in terms of damage, harvesting and regeneration.

This article includes representative photographs of much of the damage and many of the activities. Unusual activities are also included; for example, wet storage of salvaged logs, helicopter logging, horse logging, and planting of v-bladed strips.

Related activities are also included. Probably the most interesting example involves the Francis Marion National Forest red-cockaded woodpecker (RCW) population. Prior to the hurricane, the forest had 477 family groups of RCW's. Hurricane Hugo destroyed 87 percent of the RCW cavity trees and more than 50 percent of the pine sawtimber used as foraging habitat and for cavity trees. Nearly two-thirds of the birds were killed. Photographs document the damage and an interesting method of developing new tree cavities.

These photographs and related descriptions serve as basic documentation of the effect of Hurricane Hugo on South Carolina's forest resource, the early efforts to salvage damaged timber, and the reforestation activities that followed the hurricane. They provide an idea of the damage that can be expected after such a hurricane and the type of effort required to re-establish a storm-damaged forest.

Note that the article "Site Preparation and Tree Planting Costs on Hurricane-Damaged Lands in South Carolina" by Straka, Marsinko, Baumann, and Haight in this publication contains five photographs of site preparation activities following Hurricane Hugo.

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1. Typical Hurricane Hugo damage in a pine sawtimber stand. Tree snag in front has a "Gimme 12" campaign poster on it requesting the public to postpone any outdoor burning for a 12-month period.

2. Hurricane Hugo damage around one of the many homes.

3. Hurricane Hugo severely damaged the timber resource of the Francis Marion National Forest, once home of the second largest population of the endangered red-cockaded woodpecker.

4. Aerial shot of some of the many acres affected by Hurricane Hugo.

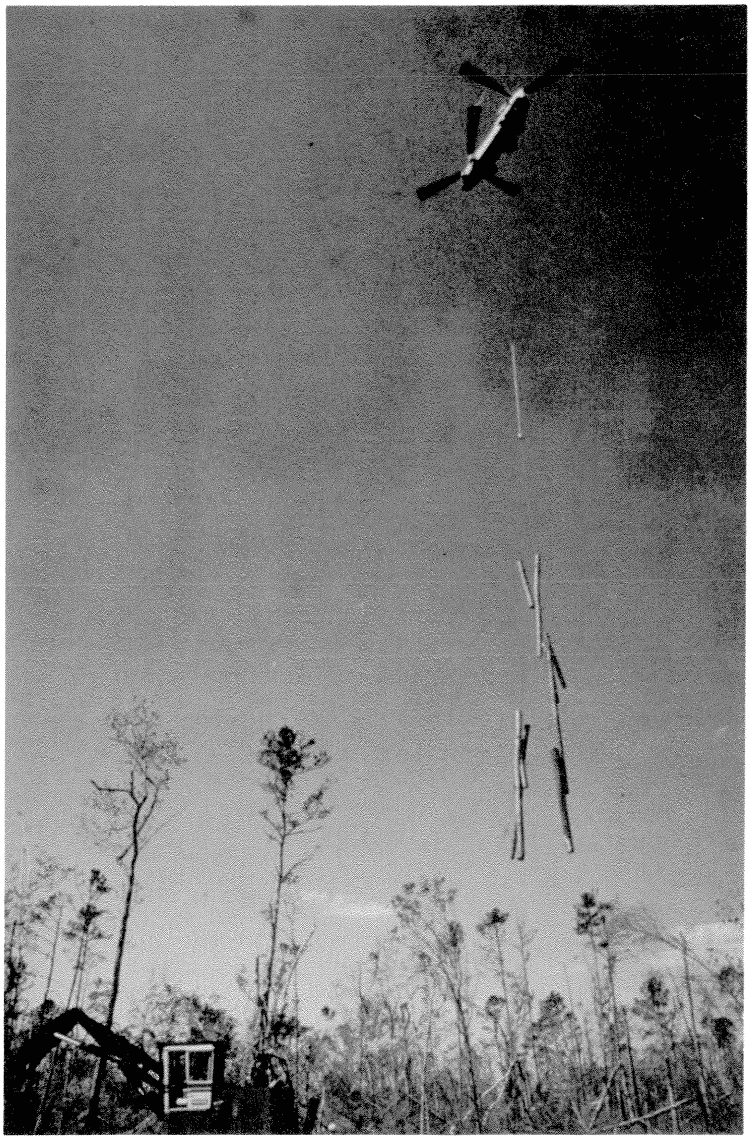
5. Even with salvage, much of the timber resource is not usable.

6. Young pine plantations were not spared the brunt of the hurricane force winds. Many plantations displayed the characteristic lean caused by the prolonged exposure to 75+ miles per hour winds. Fortunately, over time, these young trees straightened up.

7. A good example of the twisting effect the hurricane winds had on trees. Loggers were forced to extensively utilize chain saws in harvesting which slowed the salvage effort.

8. Most trees developed "ring shakes" which made them unusable for poles, veneer logs and sawtimber. Most ended up for pulpwood; landowners received on average only 10 cents on the dollar of pre-Hugo timber value.

9. All methods of logging were utilized to salvage as much timber as possible. Here mule logging is used on a sensitive site.



10. Higher tech methods like helicopter logging were also utilized.

11. **Road weight** limits were raised for logging trucks to help maximize salvage efforts.

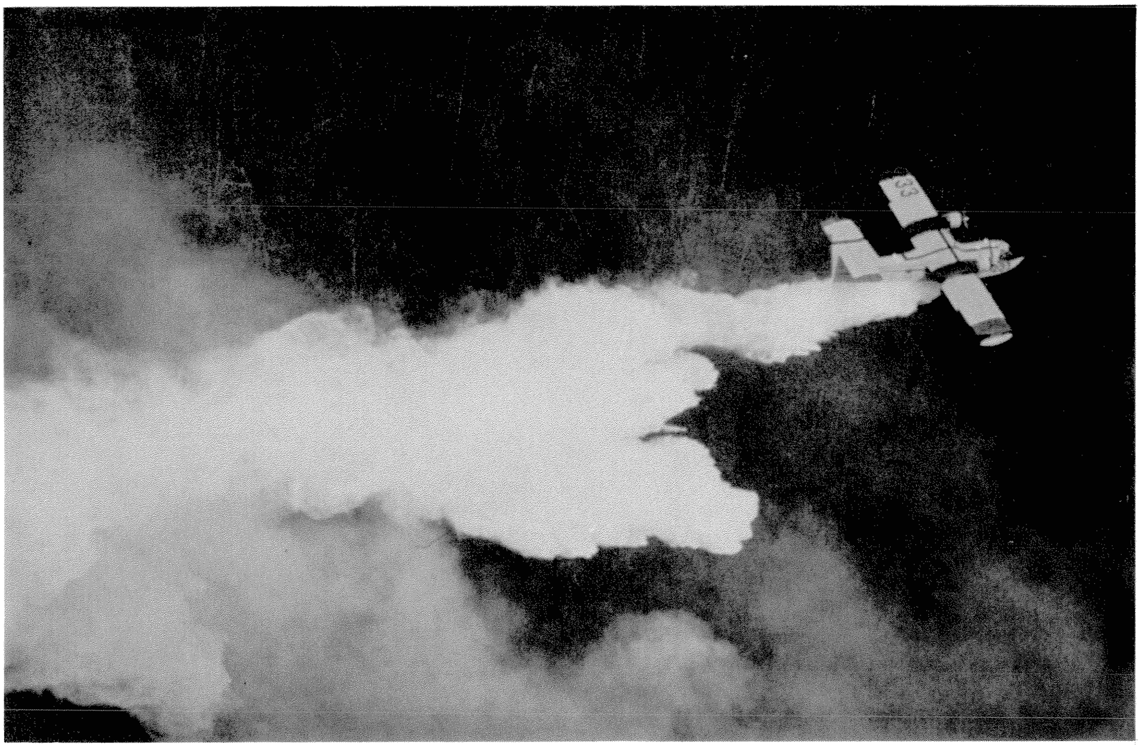
12. A large amount of wood needed to be salvaged over a short period of time. Mill capacity was exceeded. Wet storage was promoted and utilized to "preserve" wood quality until it could reach the saw.

13. Many acres would regenerate naturally over the next few years. There was a good seed crop of loblolly pine and many stands had advance regeneration of longleaf pine.

14. Other stands needed help through site preparation and artificial regeneration.

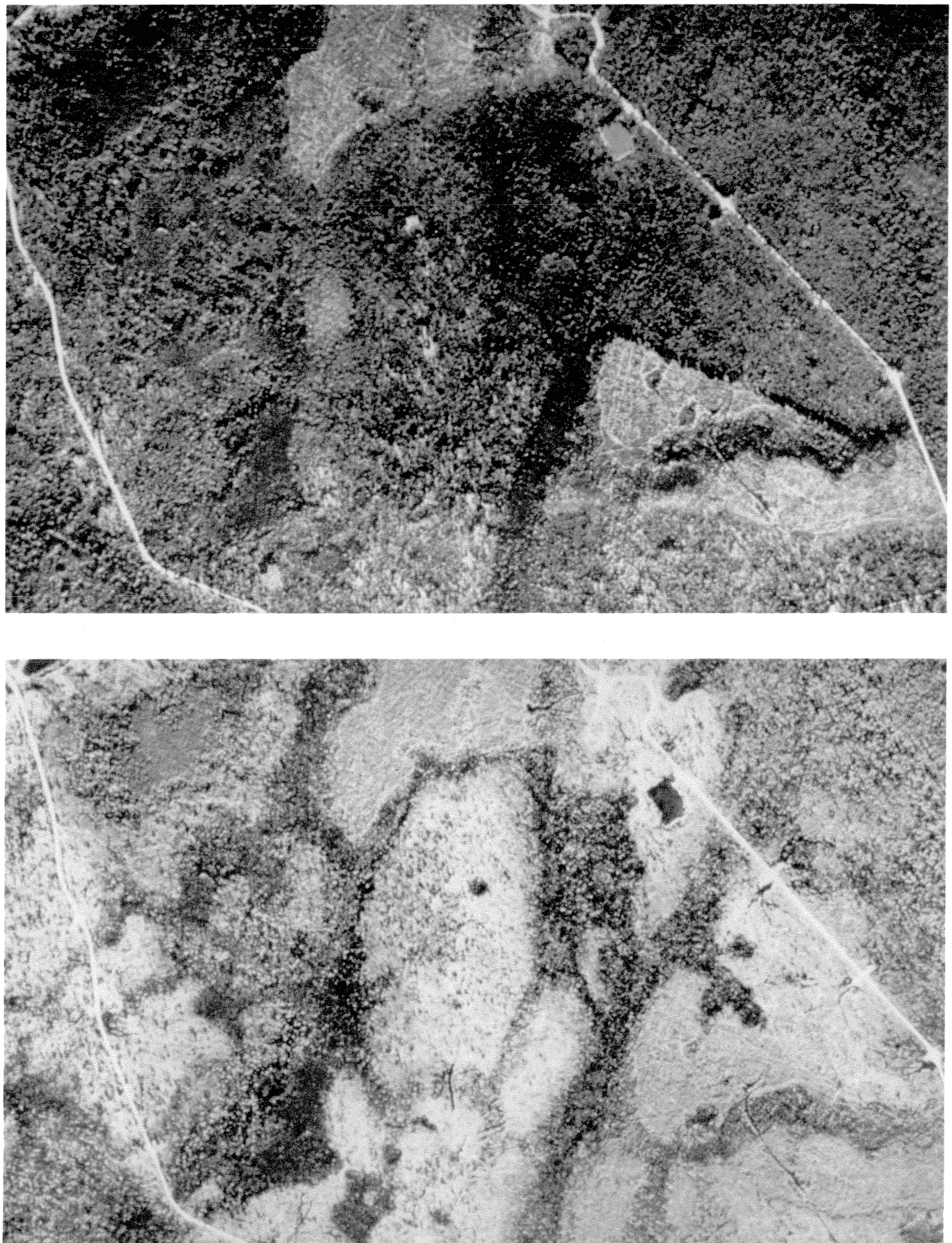
15. Through Federal Emergency Management Agency (FEMA) funds, John Deere 750 tractors were leased by the Forestry Commission and private contractors were hired to establish pre-suppression firebreaks around homes and communities.

16. Private contractors were also utilized in fire suppression work to construct firebreaks through the heavy debris left by Hurricane Hugo.

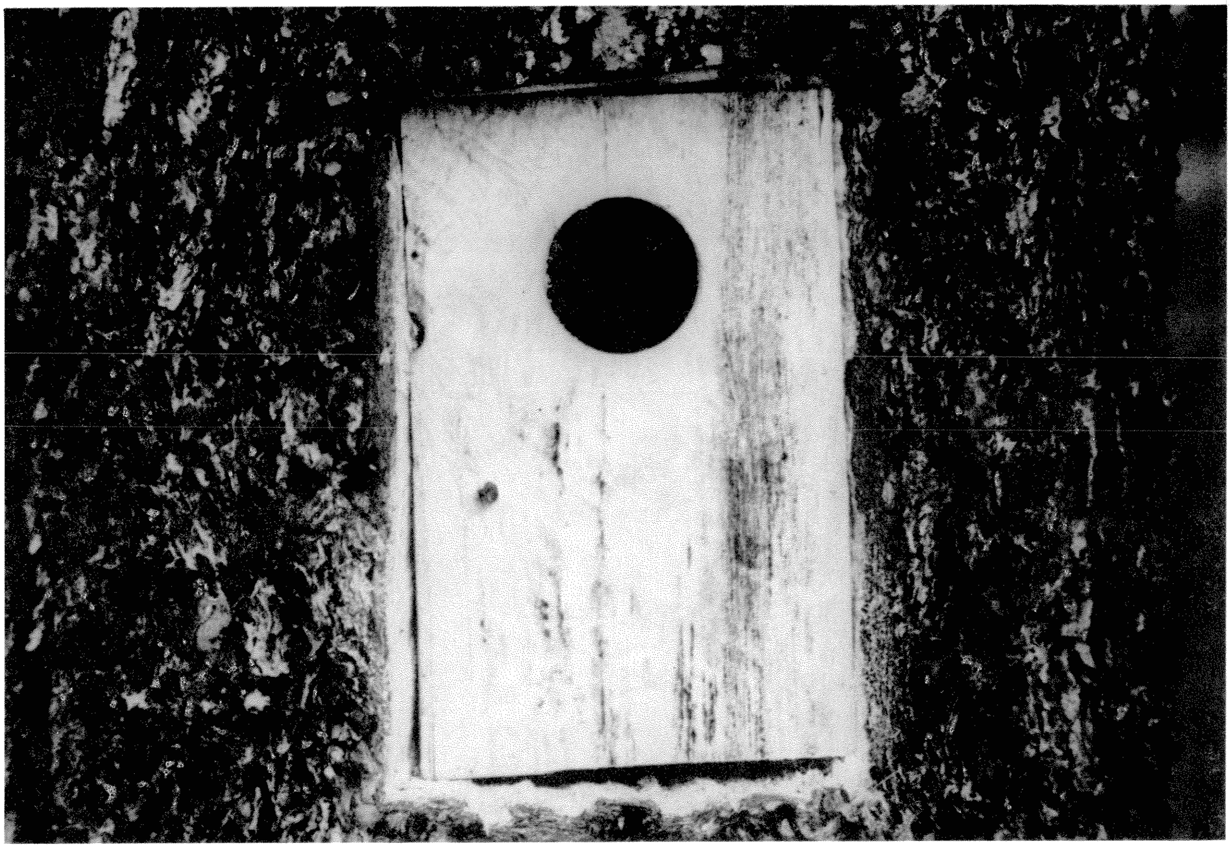


17. **FEMA** funded the use of CL-215 aerial tankers from Canadair to help suppress wildfires in the areas affected by Hurricane Hugo.

18. Hurricane-damaged timber.



19. Before-Hugo and after-Hugo photographs showing hurricane damage.



20. Following the hurricane, artificial cavities were used to provide nesting sites for red-cockaded woodpeckers. A chainsaw was used to cut a hole in a live pine and the insert was placed in the hole. Cracks around the insert were filled with wood filler and the artificial cavity painted to blend with the tree (USDA Forest Service).

21. Hurricane-damaged timber.

22. Hurricane-damaged timber.

23. Hurricane-damaged timber.

24. Hurricane-damaged timber.

HURRICANE HUGO: EFFECTS ON SOUTH CAROLINA'S FOREST RESOURCE

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INTRODUCTION

On September 21, 1989, Hurricane Hugo struck the coast of South Carolina near Charleston with sustained winds of 135 miles per hour. The storm moved northwest toward Rock Hill and exited the state with winds still at or near hurricane strength. Hugo has since been widely acknowledged as the greatest single forest disaster in the state's history.

Aerial and ground surveys conducted by the South Carolina Forestry Commission identified 23 counties with substantial forest damage. Damage estimates from this aerial survey guided the salvage of damaged timber, the establishment of fire control measures, and initial planning for reforestation. It was evident, however, that more comprehensive and objective data on the damage to the forest resource were needed to assess changes in wood supply, plan for necessary wood procurement shifts, and to guide long-term forest resource programs.

The Forestry Commission requested that the Forest Inventory and Analysis (FIA) Research Work Unit at the Southeastern Forest Experiment Station conduct a special inventory of the forest resource in the damaged area. The previous full-scale inventory of South Carolina was completed in 1986 (Tansey and Hutchins 1988). During the fall of 1989 and early 1990, objectives were established, field procedures developed, funds secured, and field crews assembled. The objectives of the inventory were to: (1) determine the volume of hurricane-related mortality and damage, (2) assess damage to merchantable and submerchantable pine plantations, and (3) quantify needed stand treatments resulting from the storm.

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This report presents results, our interpretations, and documents the procedures used in the collection and analysis of the data.

METHODS

Sampling Procedures

The sample plots used in the Hugo inventory included 2,530 permanent plots established in the 23 counties during the sixth survey of South Carolina in 1986 (Figure 1). FIA sample plots are based upon a 10-point cluster design. In most cases, five points are installed in a single forest condition using a basal area factor of 37.5 square feet per acre to sample trees 5.0 inches d.b.h. and larger. Trees less than 5.0 inches d.b.h. are tallied on 1/300-acre fixed plots at each of the point centers. More detailed information about standard FIA field sampling procedures is available (Tansey and Hutchins 1988; USDA Forest Service 1991). Between February 1990 and June 1990, each of the 2,530 ground samples was relocated and assessed for hurricane- and nonhurricane-related changes since 1986.

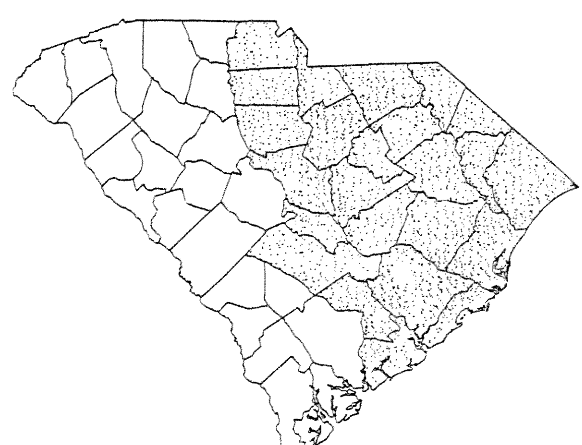

Figure 1--Distribution of 2,530 timberland sample locations that were remeasured and evaluated for hurricane damage.

In accordance with the objectives, sampling procedures differed for natural and planted stands. In natural stands, field crews accounted for each tree that was 3.0 inches d.b.h. and larger in 1986. This procedure provided assurance that any tree that had grown large enough to have merchantable volume (5.0 inches d.b.h. and larger) would be evaluated. Each tree was assigned to one of six categories: (1) live, without hurricane damage; (2) live, with hurricane damage; (3) dead, hurricane related; (4) dead, not hurricane related; (5) cut, not associated with the salvage of damaged stands; or (6) cut, associated with hurricane salvage or cleanup operation, regardless of whether the tree was utilized for a product. Live trees with hurricane damage were assessed for volume loss, percentage of crown missing, lean and bend, root damage, degree of damage to the tree bole, and salt burn. Data-collection procedures are documented in more detail in Appendix A.

In planted stands, data-collection procedures differed from those in natural stands in two respects: (1) field crews accounted for all trees that were 1.0-inch d.b.h. and larger in 1986; and (2) planted pine trees that had grown from less than 1.0 inch d.b.h. to greater than 1.0 inch and free-to-grow pine seedlings were tallied on 1/300-acre fixed plots around each of the point centers. These data were necessary to assess current stocking and damage levels in young plantations.

The collection of updated stand descriptive information was minimized. Items such as ownership, stand size, forest type, and stand age were not updated or reclassified. The use of these stand descriptors in this report reflects classifications made in the sixth inventory in 1986. Current stand origin (planted or natural) was noted. Field crews also recorded the treatments and/or disturbances, including hurricane damage, that had occurred in each stand since 1986. Finally, crews assessed treatment opportunities at each plot--salvage cuts, regeneration, thinning, etc.--along with the potential for natural pine regeneration.

Data Limitations

Since procedures were designed to provide data focused on hurricane damage, many estimates and classifications were carried forward from the 1986 inventory. Estimates of timberland area were not updated for this inventory; thus, no change in timberland area is factored into the volume change estimates. Forest type, ownership, stand size, and age were not re-estimated. The reader should be aware that tables displaying these stand and area descriptors may differ somewhat from true conditions in 1990. For example, major land transactions since 1986 that would affect the acreage by ownership are not reflected in tables or illustrations in this report. All displays of age class or stand type portray 1986 conditions prior to any cutting, treatment, or hurricane disturbance. An exception was made when planting was noted on a plot. Then, the broad stand type was changed to pine plantation and a zero (0) age class was assigned.

A complete assessment of current stocking and hurricane damage in very young natural stands was hampered because no trees less than 3.0 inches d.b.h. were measured or sampled there in 1990. Field crews did assess treatment opportunities in these stands, reflecting the degree of damage inflicted.

Finally, the Hurricane Hugo inventory is limited to providing updated volume statistics for the 23 counties identified as sustaining significant damage. Volume estimates for the entire state cannot be estimated directly from these data.

Classification of Live-Tree Damages

The inventory procedures were designed to estimate inventory change in the selected counties and to meaningfully describe damage to the existing inventory. The new inventory includes all merchantable trees that were alive at the time field crews visited each ground location. All types of significant damage to sample trees were recorded to best describe the condition of each tree. A logical classification system was needed to accurately assess and illustrate the true extent of damage, but no suitable one was known to exist. The challenge was to place each tree into a meaningful category that would provide a reasonable description of damage severity and risk of dying in the near future. Draft criteria were developed for different categories of tree size, species group, and stand type to place each tree in the appropriate class of damage. The criteria were submitted to 20 individuals or organizations for review. Review comments were received from 13 individuals or organizations, and final criteria were developed. These criteria and a description of evaluation methodology are in Appendix B.

The damage/risk classes were designed to reflect the likelihood of tree survival and present (or potential) value degrade. The categories are:

Class 1--High-risk tree with a high probability of dying in the near future. Damage and value loss are severe enough that this tree should not be retained in the stand.

Class 2--Moderate-risk tree with elevated risk of mortality; serious current or potential loss of value; retention in the stand is questionable.

Class 3--Low-risk tree that has a high probability of surviving, though not as high as an undamaged tree. Damage and value degrade are minimal--these trees should be retained in the stand in most management scenarios.

Healthy--No obvious hurricane damage. A tree with hidden or internal damage would be included here.

The damage/risk evaluation process placed trees into discrete categories. We recognize that, in reality, damaged trees belong on a continuum ranging from "not damaged" to "nearly dead." Our process was uncomfortably subjective. We found only a limited number of research studies for guidance (Barry and others 1982; Brewer and Linnartz 1973). We defend it primarily on the basis that it seems practical. We hope that our detailed description of methods will help in understanding Hugo damage and will lead to improvements in damage estimation techniques in the future.

Affected Area and Volume

This chapter summarizes our estimates of the amount and location of timberland that was significantly affected by Hurricane Hugo. It also provides estimates of the losses of softwood and hardwood timber volumes. Additional data on damage are in Appendix C.

More Than 4.5 Million Acres Damaged

The reinventory indicates that 4.5 million acres, or two-thirds of the 6.5 million acres of timberland in the 23 counties, were damaged by Hurricane Hugo (Appendix Table C.21). About 37 percent of South Carolina's timberland sustained some storm damage.

Timberland damage was most widespread near the coast and on the northeast side of the hurricane's eye as it moved in a northwesterly direction. Figure 2 shows the generalized distribution and extent of hurricane damage in South Carolina. One should not conclude, however, that all stands in the area shown as damaged sustained damage or that damage does not exist in the unshaded areas. Representations of damaged timberland were created by drawing Thiessen polygons (Newton and Bower 1990) around each ground location classed as having hurricane damage. Adjacent polygons depicting damage were merged into a single polygon by deleting interior polygon lines. Undamaged timberland and nonforest plot locations are portrayed as undamaged on the map. Therefore, the higher incidence of nonforest land in the central portion of the state lends an appearance of less damage there than in the lower coastal plain or in the more heavily forested areas to the north.

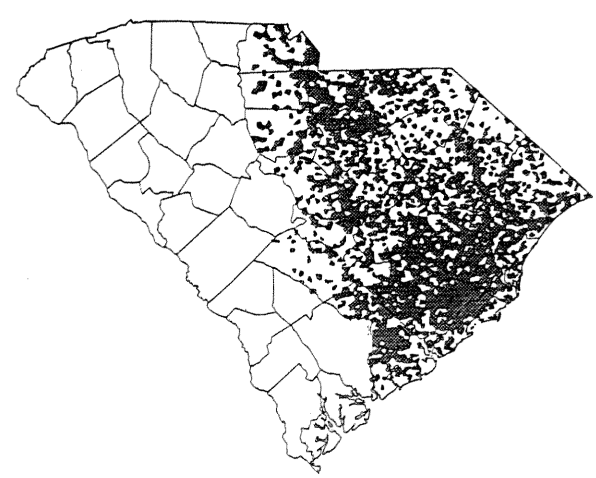

Figure 2--A generalized distribution of timberland in South Carolina damaged by Hurricane Hugo. Note: Not all stands in shaded areas sustained damage, and damage occurred in unshaded areas.

Hurricane Hugo damaged more than 90 percent of the timberland in six counties--Berkeley, Clarendon, Florence, Lee, Sumter, and Williamsburg. The distribution of damage suggests that there probably was damage in some counties not reinventoried, most notably Colleton and Lexington Counties. The damage in these counties was acknowledged prior to the field work; they were omitted because of the limited extent of damage and increased data-collection effort required.

Substantial hurricane damage was found in all stand types and broad management types (Appendix Table C.21). Sixty-two percent of the pine plantation acreage was affected, compared with 68 percent for natural pine and oak-pine stands, and 64 percent for upland hardwood stands. Lowland hardwood stands sustained the highest incidence of damage--77 percent. Lowland hardwood stands often contain large, shallow-rooted trees with large crowns, factors associated with increased susceptibility to wind damage (Barry and others 1982; Hook and others 1991). Across all stand types, the damage incidence rate averaged 76 percent for stands classified as sawtimber size, 67 percent for pole-timber, and 59 percent for sapling-seedling.

Timberland in public ownership was the most severely affected in terms of acres damaged--79 percent of the acreage controlled by public agencies sustained some hurricane damage (Appendix Table C.21). One factor contributing to the high incidence is the large concentration of National Forest in the most severely affected area near the coast in Berkeley and Charleston Counties. Another reason for the high rate of damage on public land is that the older stands and larger trees characteristic of public forests are more susceptible to wind damage. Tall, large-diameter trees sustained more damage than smaller trees. Forest industry land and nonindustrial private forest (NIPF) land were both equally affected by the hurricane; 68 percent of the acreage in these two classes was affected.

Softwood Inventory Reduced by 21 Percent

Hurricane Hugo reduced the inventory of softwood growing stock by 21 percent, from an estimated 4.8 billion cubic feet that existed prior to the storm to 3.8 billion cubic feet (Figure 3 and Appendix Table C.1). Some 376 million cubic feet of Hugo-damaged softwoods were salvaged, and 632 million cubic feet were killed but not salvaged. The extent and nature of damages to trees that were not killed will be discussed later. Softwood sawtimber volume declined from an estimated 19 billion board feet to 14 billion board feet, a drop of more than 25 percent (Appendix Table C.3).

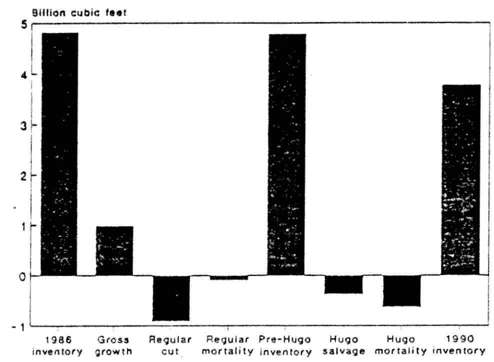

Figure 3--Change in volume of softwood growing stock, by component of change.

Not all the volume classed as salvage was utilized for wood products. Our total includes all damaged trees that were cut after the hurricane. Some of these trees were cut in cleanup operations in which the stems were not utilized, and some were cut but not utilized during salvage operations. The South Carolina Governor's Forest Disaster Salvage Council tracked actual salvage volumes removed for product use and can provide final statistics.

The pre-Hugo estimate of softwood inventory was developed by adding estimates of gross growth (1 billion cubic feet) to the 4.8 billion cubic feet present in 1986 and subtracting non-Hugo-related softwood removals (900 million cubic feet) and mortality (100 million cubic feet). We are fairly certain that softwood volume changed little from 1986 until Hugo struck, but we acknowledge that errors are associated with the computation. For instance, field crews encountered some difficulty in determining whether a tree was cut prior to the hurricane or whether it was removed during a storm-related salvage operation. Also, some growth occurred between the time Hugo struck and the date of plot measurement the next spring; this volume increment was assumed to be minimal.

In establishing the pre-Hugo inventory, all growth was assigned to the period before the storm's occurrence. To more accurately describe storm impacts in the text, all losses and changes are related to the pre-Hugo inventory rather than the 1986 inventory. This rule is not strictly adhered to in the appendix tables, but the values reported and their bases for change are well defined in the tables.

Declines in softwood inventory were recorded in all 23 counties, but declines were greatest in counties near the coast and along the path of the hurricane's eye (Figure 4). More moderate losses occurred in counties more distant from the path. Six counties--Berkeley (49 percent), Charleston (47 percent), Clarendon (45 percent), Sumter (44 percent), Lancaster (35 percent), and Lee (34 percent)--lost more than one-third of their pre-Hugo softwood inventory. Berkeley and Charleston Counties alone accounted for 43 percent of the Hugo-related drop in softwood inventory.

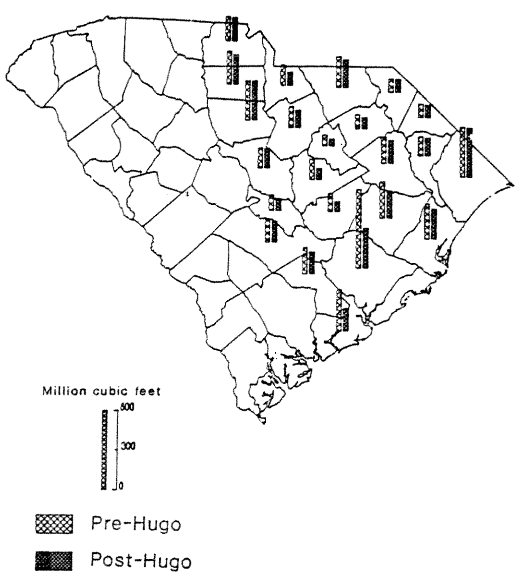

Figure 4--Pre- and post-Hugo softwood growing-stock inventories, by county.

Declines in softwood inventory varied considerably among the major ownership categories (Appendix Tables C.7 and C.9). The most severe loss occurred on land controlled by public agencies. Volume of softwood growing stock fell 34 percent to 451 million cubic feet on public land. Public land, which accounted for only 14 percent of the pre-Hugo softwood inventory, sustained 23 percent of the softwood volume loss. More than one-third of the total softwood mortality caused by the hurricane occurred on publicly owned timberland--about 204 million cubic feet. The location of National Forest land in the storm's path and the larger-than-average size of trees on this land explain the heavy losses sustained there. The volume of softwood growing stock dropped by only 12 percent to 907 million cubic feet on timberland controlled by forest industry. The percentage reduction was smallest for this owner category. In this region a high proportion of forest industry holdings are in young pine plantations. Of the 1.6 million acres of forest industry timberland, about a fourth was in planted pine stands under 20 years old in 1986. The small trees in the planted stands sustained considerably less damage and mortality than larger trees in older stands. Hugo-related salvage also was relatively small on industry land. Forest industry land supplied only 11 percent of all Hugo-related softwood growing-stock removals. Softwood inventory held by NIPF owners was reduced by 21 percent from 3.1 to 2.4 billion cubic feet.

No yellow pine species was especially resistant to the hurricane's winds (Figure 5 and Appendix Tables C.17 and C.19). Loblolly pine inventory fell by 22 percent in the wake of Hugo to 2.5 billion cubic feet. By far the most abundant species in the region, loblolly pine accounted for 72 percent of the decline in softwood inventory. Volume of longleaf pine fell by 25 percent to 303 million cubic feet. Slash and pond pine volumes declined by 27 and 29 percent to 146 and 180 million cubic feet, respectively. Shortleaf pine experienced a smaller decline of 13 percent to 205 million cubic feet. However, shortleaf occurrence is concentrated in the areas away from the coast.

Cypress survived the hurricane surprisingly well. The inventory of cypress fell by only 3 percent to 355 million cubic feet. Putz and Sharitz (1991) also found that cypress was able to withstand the hurricane's winds better than most species in the Congaree Swamp.

Softwood volume declined across the entire range of diameter classes (Figure 6 and Appendix Tables C.13 and C.15). Volume declined by 8 percent

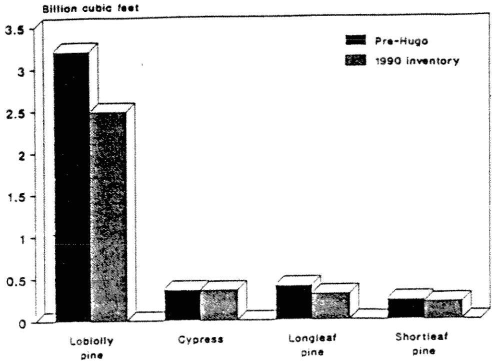

Figure 5--Pre- and post-Hugo softwood growing-stock inventories, by species.

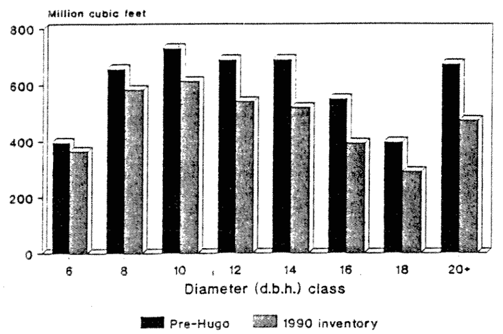

Figure 6--Pre- and post-Hugo softwood growing-stock inventories, by diameter class.

in the 6-inch class, by 11 percent in the 8-inch class, and by 16 percent in the 10-inch class. Reductions ranging from 22 to 32 percent were recorded in the larger diameter classes. The high losses in the larger size classes show that large pines were particularly susceptible to bole breakage, windthrow, and subsequent mortality.

Further Softwood Mortality Losses Likely

Observations of damaged trees not killed by the storm suggest that substantial additional softwood mortality is likely in the next few years. Of the 3.8 billion cubic feet of softwood growing stock classified as live timber (post-Hugo inventory), 29 percent, or nearly 1.1 billion cubic feet, was damaged to some extent (Appendix Table C.5). Almost half of this damaged volume was in the lowest risk category--class 3. However, nearly 0.6 billion cubic feet was in trees classed as moderate or high risk. No attempt will be made here to estimate the additional mortality that is likely to occur. The rate of loss will depend on factors such as weather, insects, disease, and further salvage efforts. However, the potential for additional mortality of several hundred thousand cubic feet is present.

As with mortality, damage to live trees was greatest on public forests (Appendix Tables C.11 and C.12). More than 36 percent of the 1990 softwood inventory on public land was damaged to some degree with severe and moderate damage (classes 1 and 2) present on 22 percent of the post-Hugo softwood inventory. About 36 percent of the post-Hugo softwood inventory on forest industry forests was damaged, but 19 percent was in the class 3 or low-risk group. Some 26 percent of the post-Hugo softwood volume on NIPF land was damaged; 6 percent was in the class 1 category, 8 percent in class 2, and 12 percent in class 3.

Softwood Damage Summary

Damage to softwood growing-stock (using the pre-Hugo inventory as a base) is summarized in Figure 7. About 8 percent of the pre-Hugo inventory was removed in salvage operations, and another 13 percent (0.6 billion cubic feet) was dead at the time of plot remeasurement. Hugo-related mortality will continue to accumulate for a number of years. Some 23 percent of the softwood inventory before Hugo is in damaged living trees. About 2.7 billion cubic feet, or only 56 percent of the pre-Hugo inventory, was classed as "healthy," or having no obvious storm-related damage. Thus, softwood inventory losses to Hurricane Hugo range somewhere between the 21 percent (1.0 billion cubic feet) killed directly or salvaged immediately after the storm and the 44 percent (2.1 billion cubic feet) killed, salvaged, or damaged. A reasonable estimate of softwood loss is around 30 percent of pre-Hugo inventory (1.4 billion cubic feet).

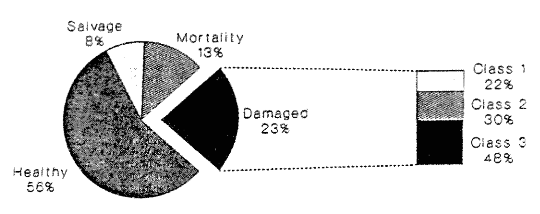

Figure 7--Summary of hurricane losses and damage to the pre-Hugo softwood inventory.

Hardwood Inventory Reduced by 6 Percent

Hurricane Hugo reduced the inventory of hardwood growing stock in the 23 counties by 6 percent to 4.8 billion cubic feet (Figure 8 and Appendix Table C.2). Sawtimber losses were similar in magnitude (Appendix Table C.4). An estimated 5.1 billion cubic feet of hardwood growing stock was present prior to Hugo, up from 5.0 billion cubic feet in 1986. Hardwood inventory reductions were attributed to 270 million cubic feet of Hugo-related mortality and to only 49 million cubic feet of salvage. These losses are small in comparison with softwood losses for two reasons. First, there was little hardwood salvage cutting--most of the efforts to salvage dead and damaged timber focused on pine species. Second, softwood species died more quickly after windthrow, bole breakage, or loss of limbs, whereas hardwood species were generally still alive. Even windthrown hardwoods and those that lost their entire crown were sprouting new growth the spring after the storm. Many of these severely damaged hardwoods will die, and the wood in those that do not will be degraded badly.

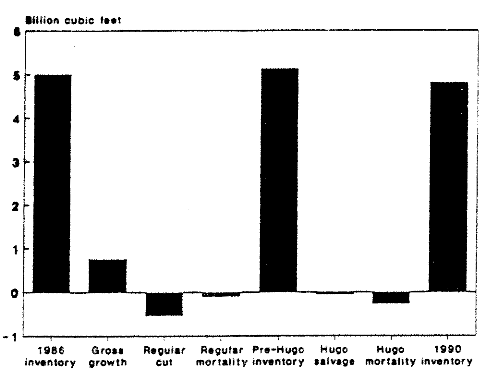

Figure 8--Change in volume of hardwood growing stock, by component of change.

Geographically, the distribution of hardwood volume loss followed essentially the same pattern as for softwoods (Figure 9). The counties with the most severe declines in hardwood volume are near the coast and along the path of the hurricane's eye. Lee County lost 34 percent of its hardwood inventory, whereas Charleston lost 16 percent, and Berkeley 14 percent. Among ownership classes, public land sustained the most severe reductions in hardwood volume (Appendix Tables C.8 and C.10). The hardwood inventory controlled by public owners declined by 16 percent to 237 million cubic feet. That controlled by forest industry decreased by 5 percent from less than 1.1 to about 1.0 billion cubic feet. Hardwood inventory on NIPF land dropped 6 percent from 3.8 to 3.6 billion cubic feet--near the average for all ownership categories.

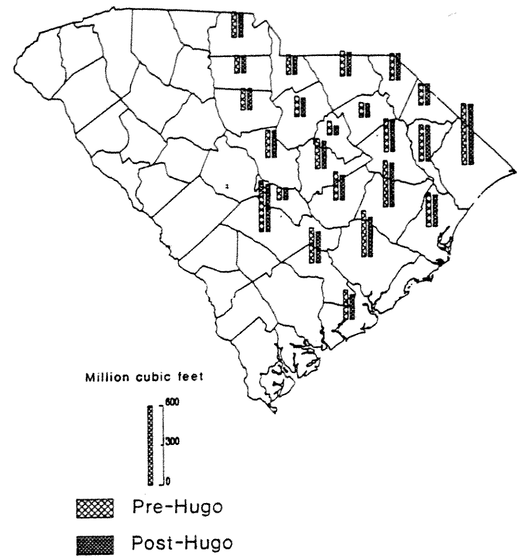

Figure 9--Pre- and post-Hugo hardwood growing-stock inventories, by county.

Large hardwoods were the most prone to hurricane-related mortality (Figure 10 and Appendix Tables C.14 and C.16). The inventory of hardwoods 20 inches d.b.h. and larger dropped by 9 percent, whereas reductions were more modest for smaller trees. Volumes of all major hardwood species in the region decreased (Figure 11 and Appendix Tables C.18 and C.20). Red oaks suffered the most severe drop of 10 percent to 1.0 billion cubic feet. The sweetgum inventory declined by 6 percent to 1.0 billion cubic feet. Volume of tupelo and blackgum--the predominant hardwood species group in the region--dropped 3 percent to 1.1 billion cubic feet. Volume of all white oaks dropped 7 percent to 420 million cubic feet. The small loss of blackgum and tupelo relative to other hardwoods is consistent with findings of a study in the Congaree Swamp (Putz and Sharitz 1991).

Very Heavy Hardwood Damage

Severely damaged hardwoods did not die as quickly after the storm as did softwoods. As a result, hardwood

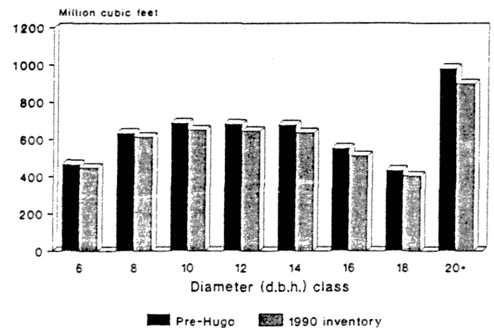

Figure 10--Pre- and post-Hugo hardwood growing-stock inventories, by diameter **class.**

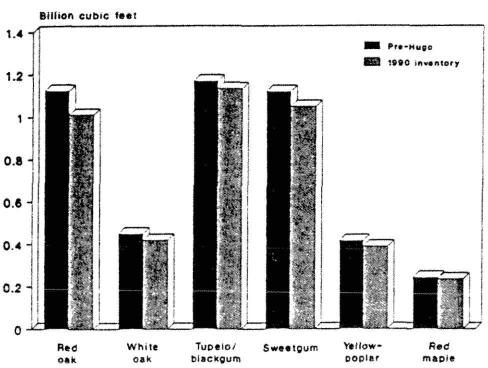

Figure 11--Pre- and post-Hugo hardwood growing-stock inventories, by species.

mortality understates the real terrible blow to the hardwood resource. That blow is expressed primarily in the figures for damaged, living trees. Thirty-two percent of the post-Hugo hardwood inventory is damaged to some degree (Appendix Table C.5). Damaged trees contain 5.3 billion board feet of hardwood saw-timber. About 12 percent of the 1990 hardwood growing stock is in high-risk trees. Only 6 percent of the softwood inventory is in this class. Eight percent of the hardwood volume is in class 2 trees and 12 percent is in class 3 trees.

Public lands contained the highest proportion of damaged hardwood volume --51 percent of the post-Hugo hardwood inventory on public forests was damaged to some degree (Appendix Tables C.11 and C.12). National Forests were most severely damaged; 60 percent of the 1990 hardwood inventory was damaged, and two-thirds of the damaged volume is in trees in classes 1 and 2. On both forest industry and NIPF land, about 31 percent of the 1990 hardwood inventory was damaged after the storm.

High-risk (class 1) trees are more prevalent with increasing diameter for hardwoods (Appendix Table C.14). Less than 10 percent of the volume in hard-wood trees 15.0 inches d.b.h. and smaller was classified as high risk. For hardwoods larger than 15.0 inches, the proportion in class 1 averaged 18 percent, and it exceeded 21 percent for the largest trees. The proportions of damaged hardwoods in classes 2 and 3 did not change substantially across the range of diameter classes.

Red oaks appear to have suffered the most (Appendix Table C.18). About 42 percent of the 1990 red oak inventory was damaged, and one-half of the affected trees was in class 1. Some 31 percent of white oak volume was affected, and 14 percent was in class 1 trees. In contrast, only about 22 percent of the tupelo and blackgum volume was damaged and most of this volume was in class 3 trees. About 304 million cubic feet, or 29 percent, of the sweetgum volume was damaged; 40 percent of yellow-poplar volume was damaged; and 42 percent of the soft maple volume was damaged.

Hardwood Damage Summary

The fate of the pre-Hugo hardwood inventory is outlined in Figure 12. The volume present before the storm was about 5.1 billion cubic feet. Only 5 percent of the pre-Hugo inventory, or 270 million cubic feet, was in trees that were killed outright by the storm. Only 1 percent was removed in salvage operations. Almost 577 million cubic feet, or 11 percent, of the pre-Hugo inventory is now in class 1 trees. Another 385 million cubic feet, or 8 percent, is in class 2 trees and some 577 million cubic feet is in class 3 trees. After subtracting out all Hugo-related damage, salvage, and mortality, about 3.3 billion cubic feet, or 64 percent, of the pre-Hugo hardwood inventory remains in an undamaged state.

Although the immediate loss of hard-woods to Hugo was relatively small (0.3 billion cubic feet of mortality and salvage volume), the potential for additional hardwood mortality and degrade is very high. A reasonable estimate of total hardwood damage is about 20 percent of the pre-Hugo hardwood volume, or 1.0 billion cubic feet. While hardwood mortality will

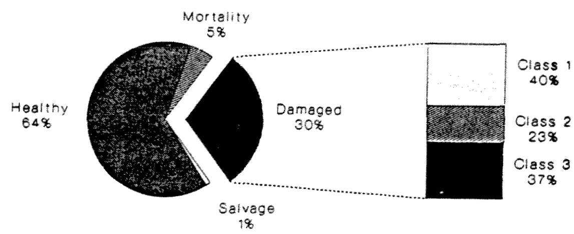

Figure 12--Summary of hurricane losses and damage to the pre-Hugo hardwood inventory.

not likely escalate to this level, loss estimates of this magnitude are justified because of the value loss associated with many of the wind-related damages.

Stand Condition Assessment

By any reasonable standard, the timber damage caused by Hurricane Hugo was catastrophic. But people are resilient, and they know that timber is a renewable resource. The people of South Carolina want to know what must be done to get their forests back to normal. And while their forests are recovering, they want to know what the effects on the timber industry will be. Answers to those questions depend on accurate descriptions of stand conditions before and after the storm.

We estimated the stocking of manageable stand (crop) trees just prior to Hurricane Hugo by the method described below. The term "stocking" as used here refers to the degree of occupancy of the land by trees as compared with a minimum standard required to fully utilize the growth potential of the land. Values used are expressed in percentage of full stocking.

(1) Stocking of all tally trees on each plot was summarized to establish the baseline stocking level of each plot at the time of the 1986 inventory. Only trees 3.0 inches d.b.h. and larger in natural stands and 1.0 inch in planted stands were tallied. Furthermore, only trees that were coded as being part of a manageable stand were considered; if a manageable stand did not exist in 1986, stocking of all growing-stock trees was summarized.

(2) Trees that were cut or died after the 1986 inventory but before Hugo were subtracted from the 1986 baseline stocking to establish the pre-Hugo condition or stocking for the stand.

Trees killed by the storm or salvaged soon after are no problem--they must be deducted to estimate current stocking. Assessment of current stocking, however, requires some conjecture about how many of the trees damaged by the storm will make satisfactory crop trees through the end of the timber rotation. Damage to live trees ranges from relatively minor to major and life threatening. Three different assumptions about damaged trees were made:

1. All damaged trees (risk classes 1, 2, and 3) are unsatisfactory for future stocking (maximum stocking reduction).

2. Only class 1 and class 2 trees are unsatisfactory (average reduction).

3. Only class 1 trees are unsatisfactory (minimum reduction).

Trees that were classed as acceptable in 1986 and were not damaged by the storm, plus those trees with light levels of damage, were all considered to be acceptable to retain in the stand until the end of a rotation. Different minimum levels of pre- and post-Hugo manageable stand stocking were used for assessments of regeneration needs and timber supply impacts.

Regeneration Needs Soar

Previous assessments of regeneration treatment opportunity have used 60-percent stocking as a minimum for determining whether a manageable stand exists (Tansey and Hutchins 1988). In 1986, the 23 counties reinventoried contained approximately 1.0 million acres of timberland judged to be in need of regeneration. In this analysis, we have used the same standard for our baseline estimate of added regeneration treatment opportunity. Stands that moved from greater than 60-percent stocking with manageable stand trees to less than 60 percent were included in the summary of additional acres needing regeneration. Pre- and post-Hugo stocking values different from these can also be used to estimate regeneration needs, and an example of this flexibility is demonstrated.

Depending on which live-tree damages were included as stocking reductions, the acreage reduced below minimum-stocking standards ranged from 0.8 to 1.5 million acres (Table I). Using the minimum-stocking-reduction scenario discussed above, 0.8 million acres shifted from more than 60 percent stocked with crop trees to less than 60 percent stocked. Under the average discount, 1.2 million acres were damaged severely enough to place them into a regeneration needs category. If all damaged trees are used as discounts (maximum discount), 1.5 million acres shift into a poorly stocked category. Considering this range, the acreage needing regeneration in these 23 counties has very likely more than doubled because of hurricane-related damages.

The average discount option probably yields the most realistic estimate of regeneration needs. Under the maximum discount, many acres are classed as poorly stocked based on fairly minor damages such as small portions of crown missing or minor degrees of lean and bend. On the other hand, the minimum discount probably understates the area of timberland where the need to start over exists. To a large extent, the decision to regenerate will depend upon the individual landowner's view of what constitutes an acceptable stand.

Under the average discount, stocking was reduced sufficiently on about one-fourth of the 4.5 million affected acres to warrant stand regeneration. Hugo added significant opportunities for regeneration in all types of stands. About 29 percent of damaged pine plantations were determined to be less than adequately stocked with acceptable trees based upon the defined standards. This proportion is as high as that for lowland hardwood and somewhat higher than that for natural pine stands (27 percent). The relatively high proportion of plantations classed as poorly stocked is partially attributable to the more complete evaluation of all potential crop trees in these stands as compared with natural stands. In general, however, the timber expectations of the owners of plantations probably exceed the expectations of the owners of natural stands.

Other minimum levels of stocking for pre-Hugo and post-Hugo conditions could be used to estimate the acreages of regeneration opportunities. Many stands that are moderately stocked with acceptable trees become more fully stocked as the trees grow and as natural regeneration becomes established (Baker 1989). We did not attempt to conduct a more complete

Table I--Area of timberland reduced below a manageable stand using different stocking discounts, by broad management class, for 23 counties in South Carolina, 1986-1990

Broad management class	All classes	Damaged area	Stocking reduced below manageable levels using:		
			Mimimal discount[a]	Average discount[b]	Maximum discount[c]
			Thousand acres		
Pine plantation	1,208.7	746.7	118.5	220.2	329.7
Natural pine	1,773.8	1,252.9	255.5	332.9	436.1
Oak-pine	832.4	545.4	67.8	105.5	135.1
Upland hardwood	989.2	634.7	102.0	119.0	147.9
Lowland hardwood	1,731.9	1,329.0	267.1	379.5	490.5
ALL classes	6,536.0	4,508.7	810.9	1,157.1	1,539.3

[a] Stocking reduction consists of Hugo mortality, Hugo salvage, and class 1 live-tree damage.
[b] Stocking reduction consists of Hugo mortality, Hugo salvage, and classes 1 and 2 live-tree damage.
[c] Stocking reduction consists of Hugo mortality, Hugo salvage, and classes 1, 2, and 3 live-tree damage.

evaluation of regeneration needs. Decisions about acceptable stocking are predicated upon many variables, among them site quality, forest type, management objectives, rotation age, and the mix of damages of various degrees and types. However, we do provide a detailed summary of acreage by stand type that displays the pre-Hugo and post-Hugo stocking categories (Appendix Table C.22). Hugo stocking reductions in this table are based upon the average discount option discussed above.

An example of how one might use different combinations of pre- and post-Hugo stocking values to assess damage is presented in Table II. Values in boldface type, corresponding to pre-Hugo stocking levels of 60 percent or greater and post-Hugo stocking of less than 60 percent, are those presented in Table I under average discount. An alternative assessment of added regeneration opportunity created by Hugo damage is indicated by a summary of acreage below and to the left of the stairstep line through the body of the table. Here, a sliding scale is used to define acceptable. The result depends, to a degree, on pre-Hugo stocking. For instance, stands with a pre-Hugo stocking of 50-59 percent are not included in a regeneration scenario unless stocking has been reduced below 40 percent. Stands 85-99 percent stocked would have to be reduced below 50 percent post-Hugo stocking. This assessment of added regeneration needs yields an estimate of 1.3 million acres, about the same as the estimate using the traditional 60-percent threshold. Appendix Table C.22 contains similar data by stand type so readers can conduct their own evaluations.

Regardless of the process and stocking guidelines used to estimate regeneration needs, it is obvious that Hugo added greatly to the already large backlog of acreage that lacked a manageable stand of trees. The additional area easily exceeds 1 million acres. In addition, the estimates presented here are low because small trees in natural stands (< 3.0 inches d.b.h.) were not reinventoried and losses of them were not discounted.

The extent to which natural regeneration will be able to rehabilitate damaged stands cannot be assessed using the Hugo inventory data. Plots were visited too soon after the storm for natural regeneration to have become established. These assessments will be made in a few years during the next full-scale inventory of South Carolina, scheduled for completion by 1993.

Table II--Area of timberland by pre- and post-Hugo stocking percentage for manageable stand trees, for 23 counties in South Carolina, 1986-1990a

Pre-Hugo stocking (percent)	All classes	Post-Hugo stocking (percent)								
		0-14	15-29	30-39	40-49	50-59	60-69	70-84	85-99	100+
		Thousand acres								
0-14	1,294.3	1,294.3								
15-29	429.7	84.6	345.1							
30-39	356.1	43.4	62.6	250.1						
40-49	418.1	64.2	57.0	52.7	244.2					
50-59	623.8	89.1	59.5	72.9	86.9	315.4				
60-69	629.5	**56.5**	**63.4**	**53.4**	**72.3**	**95.7**	288.2			
70-84	901.4	**91.1**	**53.6**	**82.9**	**81.8**	**65.7**	128.9	397.4		
85-99	716.8	**59.8**	**25.5**	**34.7**	**49.2**	**24.4**	68.2	131.9	323.1	
100+	1,166.3	**89.5**	**45.4**	**41.2**	**26.2**	**44.9**	44.4	104.1	126.7	643.9
All classes	6,536.0	1,872.5	712.1	587.9	560.6	546.1	529.7	633.4	449.8	643.9

[a] Based on trees 3.0 inches d.b.h. and larger in natural stands; all stems, including new planted stems, in plantations.

Future Timber Supplies Altered

We attempted to roughly assess the effects of the observed damage to stands on the region's future timber supplies. Our analysis did not include a sophisticated projection model. Rather, we assigned each sample stand to a damage class in a process similar to that used for the regeneration analysis. Three damage classes were assigned: no damage, light damage, and moderate/heavy damage. Stands that were harvested since 1986, but before the hurricane struck, were identified and portrayed as a separate category, Magnitude of stocking reduction was the primary consideration in placing each sample plot in one of the hurricane damage categories. The "no damage" category was assigned based upon field crew observation on the ground; this classification was cross-checked against tree tally to verify that no hurricane-damaged trees were present. The remaining stands were assigned to one of two damage groups based upon the severity of the stocking reduction attributed to hurricane damage.

<u>Light damage</u>:

1. Sample plots where pre-Hugo stocking was already below 30 percent of full stocking.

2. Sample plots where post-Hugo stocking remained above 75 percent of full stocking.

3. Sample plot with stocking standards between 1 and 2, where less than one-half of pre-Hugo stocking was lost and stocking reduction as a percentage of full stocking did not exceed 30 percentage points.

<u>Moderate to heavy damage</u>:
All damaged stands not assigned to "light" damage were classified as moderate/heavy damage.

The distribution of damaged acreage is depicted in age profiles (Figure 13). Classifications of stand age and type are based on 1986 conditions in most cases. Changes in these classifications that would be expected with timber cutting, natural disturbances, or stand development were not accounted for. Stands harvested between 1986 and 1990 are identified as a separate category in the profiles so that the timber supply impacts of recently harvested stands can be evaluated concurrently with the impacts of hurricane damage. When

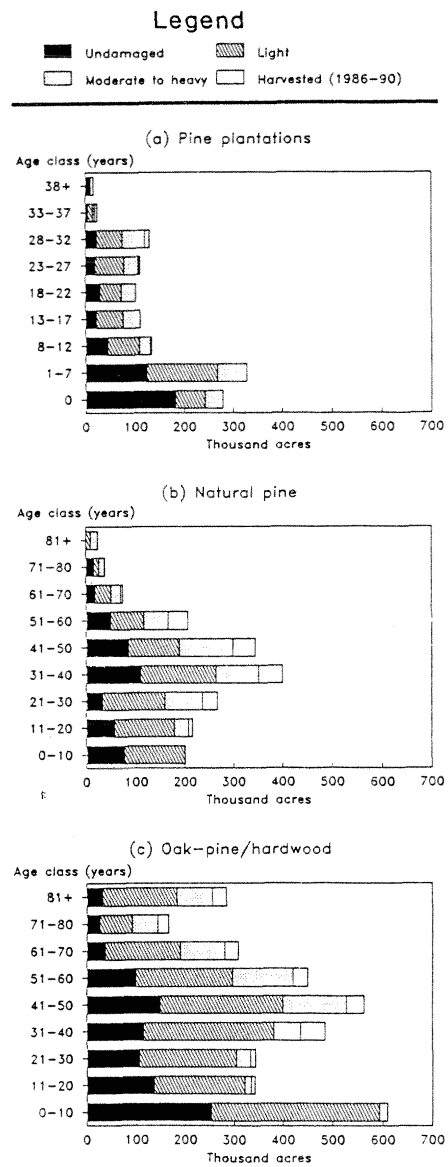

Figure 13--Stand-age profiles for pine plantations, natural pine stands, and oak-pine/hardwood stands, by degree of hurricane damage.

planting occurred on a sample plot between 1986 and 1990, the sample was assigned to pine plantation, age class 0. Pine plantations were assigned to a 5-year class, whereas natural stands were assigned to 10-year age classes.

More than 261,000 acres out of 1.2 million acres of pine plantations in the 23 counties were classed as moderately to heavily damaged (Figure 13a). On these areas, Hugo reduced manageable stand stocking by 70 percent based on the average stocking-reduction criteria discussed previously. These stands were left with an average stocking of healthy and class 3 damaged trees of only 28 percent of full stocking. Almost one-third of the nonharvested plantations age 15 and above were classed as moderately to heavily damaged.

Another 475,000 acres (39 percent of all plantations) were classed as lightly damaged. In these stands, Hugo reduced pre-Hugo stocking by an average of 16 percent. However, stocking of healthy and class 3 damaged trees in these stands averaged 81 percent of full stocking--an adequate amount for long-term development of acceptable trees. Pine plantations established since 1986 (age class 0) and those in age classes 5 and 10 account for almost four-fifths of the undamaged pine plantations.

About 400,000 acres of stands classed as natural pine in 1986, and not subsequently harvested, were moderately to heavily damaged (Figure 13b). This acreage represents 25 percent of all nonharvested natural pine stands. The hurricane reduced manageable stand stocking for this group by 77 percent, leaving an average of only one-fifth of full stocking. As with plantations, losses were concentrated in age classes that have the highest volumes. Almost one-third of all unharvested, natural pine stands greater than 20 years old were moderately to heavily damaged. In contrast, only 7 percent of natural pine stands less than 20 years old were so classified.

Light damage was inflicted on 743,000 acres of nonharvested natural pine stands. These stands are found across the range of age classes but make up more than one-half of each of the three youngest age classes for natural pine. Natural pine stands in this category lost 11 percent of their pre-Hugo stocking to the hurricane.

About 17 percent of the stands in oak-pine and hardwood forest types in 1986, and not subsequently harvested, were moderately to heavily damaged (Figure 13c). Altogether, some 582,000 acres of hardwood-dominated timberland were so classified. These severely damaged stands were concentrated in the 41-50 and older age classes. Almost 29 percent of hardwood and oak-pine stands past age 40 were moderately to heavily damaged. Only 7 percent of stands less than 40 years old were placed in that category. In moderately to heavily damaged hardwood and oak-pine stands, Hugo reduced stocking by an average 66 percent. The residual stands (comprised of healthy and class 3 damaged trees) averaged only 26 percent of full stocking.

More than one-half (1.8 million acres) of oak-pine and hardwood stands were lightly damaged. The hurricane reduced manageable stand stocking there by 15 percent. The remaining 1.0 million acres did not sustain any hurricane damage. Oak-pine and hardwood forests that were not damaged or were lightly damaged were distributed across all age classes, but they were more highly concentrated in the younger age classes.

Geographically, forest stands with moderate to heavy damage were distributed in a similar fashion to the volume-loss distributions shown earlier (Figure 14). Moderately to heavily damaged stands are concentrated near the coast and to the northeast side of the hurricane's path.

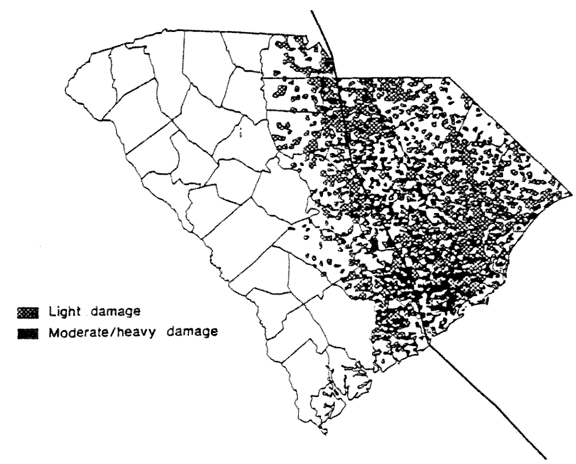

Figure 14--A generalized distribution of timberland in South Carolina damaged by Hurricane Hugo, by degree of damage.

From a timber supply standpoint, Hurricane Hugo had an immediate impact by damaging old, high-volume stands more severely than young, low-volume stands. The age structure of the forests was instantly skewed toward more young stands. The hurricane also reduced the stocking of residual trees on relatively large areas to a level that requires the establishment of a new, vigorous stand to restore long-term productivity. Regenerating new stands over large areas through planting and natural means will further tilt the age structure toward young stands. Concentrations of very young stands bode well for growth and inven-tory changes 15 to 20 years in the future. In the interim, however, timber supplies have been severely compromised in the 23 counties. The impact is, and will be, especially severe for both softwood and hardwood solid-wood-product industries. Much depends upon the degree to which (1) trees can respond to the varying degrees of damage without losing substantial value for their best use; and (2) damaged timber can be utilized and make a viable contribution to timber supplies in the short term.

Based on levels of damage depicted in the age profiles, potential timber supplies for the next 10 to 20 years have been reduced by 20-30 percent in the 23 counties. Manufacturers that depend on medium- to large-diameter trees will be impacted for a considerably longer period of time. Supply reductions could easily exceed 30 percent for manufacturers that cannot utilize damaged timber.

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APPENDIX A: DATA-COLLECTION PROCEDURES

In the 23 damaged counties, field crews relocated 2,530 permanent sample plots that were established in timberland in previous inventories. At each sample, crews recorded information about the condition of the stand, noting any treatments or disturbances that had occurred since the previous inventory in 1986. In addition, each stand was visually assessed for evidence of hurricane damage of any severity. Land use changes, windthrow orientation, and a description of the potential for natural pine regeneration were also recorded.

In natural stands, all trees 3.0 inches d.b.h. and larger at the time of the 1986 inventory were relocated. These trees were determined to be either alive, timber removals, or mortality. Live trees were evaluated for several storm-related damages. If a tree had died since the 1986 inventory, its death was attributed to the hurricane or to other natural causes. Likewise, trees removed from timberland by human activity were separated into regular removals and hurricane-related salvage operations.

In planted stands, all trees 1.0 inch d.b.h. and larger in 1986 were accounted for and evaluated in the same manner as above. In addition, pine trees that had grown from less than 1.0 inch d.b.h. to 1.0 inch or larger and all pine seedlings that were considered part of a manageable stand were tallied on 1/300-acre fixed plots at each of the five sample point centers. These "new" pine tally trees were also assessed for hurricane damage.

Stand Condition Variables

The following items were recorded for each sample:

Stand origin. This code identified stands that had evidence of planting or seeding.

Hurricane damage. This code specified whether or not hurricane damage was evident in the sample stand. It did not indicate the severity of the damage.

Past treatment. Up to three past treatments were coded by using standard FIA procedures. Only treatments that occurred between the 1986 survey and the hurricane survey were recorded.

Past disturbance. Any significant natural or human-caused disturbance such as disease, insects, or prescribed fire that occurred after the 1986 survey was identified (not including hurricane damage).

Treatment opportunity. At each sample location, field crews determined what treatments, if any, were needed to improve existing conditions in the stand. Possible recommendations included salvage, harvest, thinning, other stand improvement cuttings, stand conversion, regeneration, and no treatment.

Potential natural pine regeneration. This item was coded to describe the potential of hurricane-damaged stands to regenerate naturally with pine. The coding basically described three situations: stands that had adequate existing regeneration, stands with an adequate seed source (minimum basal area of 10 ft^2/acre), or stands that did not have an adequate seed source.

Nonforest plot (Optional Item 1). This item identified those samples that were cleared to a nonforest land use since 1986.

Throw orientation (Optional Item 2). Field crews, using standard FIA codes for aspect description, coded the predominant orientation of down or leaning trees on the sample acre.

Tree Variables

The following variables were recorded for individual trees on each plot:

Tree history. Each tree tallied was assigned to one of six categories: (1) pine ingrowth, tallied only in plantations; (2) live tree with damage; (3) mortality caused by the hurricane; (4) mortality not caused by the hurricane; (5) tree removed from timberland, not associated with a salvage cutting operation; and (6) tree removed as a result of a salvage cutting or cleanup operation. Live trees without damage were not entered on the field forms; information for these trees was extracted from computer files for the 1986 inventory.

Species. A three-digit standard FIA species code was assigned to each tree tallied.

Old d.b.h. The d.b.h. assigned in the 1986 survey was transferred to the tally sheet used in the Hugo inventory.

Tree class. A tree class code was assigned to each live tree tallied using FIA merchantability standards. Tree class was not changed from that coded in the 1986 survey unless it changed as a result of hurricane-inflicted damage.

Cubic-volume loss. An estimate of the percentage of the tree's merchantable volume missing because of hurricane damage.

Percentage of crown missing. An estimate of the percentage of live-tree crown lost because of hurricane-related damage. The crown ratio code noted in the 1986 survey was used as a base for making this determination.

Terminal leader missing. The absence of the tree's terminal leader was recorded if the breakage was caused by the storm.

Bole condition. Any damage to the bole of the tree was coded if the damage was caused by the hurricane. On a priority basis, injuries were coded as: (0) no damage, (1) split or twisted bole, (2) debris driven into tree, and (3) tree bole skinned through cambium.

Tree lean. The angle of lean was recorded for each live tree. Lean was defined as the degree from which the first 12-foot section of the tree varied from the vertical axis. A code of "00" was recorded for a tree with no deviation from vertical axis associated with hurricane winds. A code of "90" was used to describe a live tree lying on the ground.

Tree bend. Tree bend was coded in the same manner as tree lean except it was measured from the ground to the tip of the tree.

Distance to breakage. If the bole of a tree was broken due to wind damage, the distance in feet from the 1-foot stump to the point of breakage was recorded.

Root damage. The field crews looked for any evidence that the tree's root system had been damaged by the storm. Root injuries were recorded as: (1) no root damage, (2) roots exposed (root sprung), and (3) root damage below ground.

Cut-mortality period. For each tree tallied that had either died or was cut before the hurricane (tree history 6 or 8), a code was assigned to describe when the mortality or removal occurred. If the mortality or removal occurred within the past year, a 1 was recorded; 2 years ago, a 2 was recorded.

Salt burn. Field crews assigned a code to indicate the presence of crown damage from airborne saltwater spray. The brown or red foliage associated with this damage was treated as missing crown.

APPENDIX B: PROCEDURES AND CRITERIA FOR ASSIGNING TREES WITH HURRICANE DAMAGE INTO DAMAGE RISK CATEGORIES

The 1990 inventory includes all trees that were alive at the time field crews visited each sample location. Several kinds of damage were tallied during the Hugo inventory and they can occur singly or in multiples in any combination. This appendix documents the procedures and criteria used to assign trees to categories of damage that reflect the tree's risk of dying or its present or potential value loss.

Damage/Risk Class Definition

The damage/risk classes utilized are defined below. The terms "class 1," "class 2," and "class 3" are used instead of descriptive adjectives such as "severe," "moderate," or "light" so that users will review the definitions and criteria and attach descriptions that fit each person's assessment and use of the data.

Class	Description
1	High-risk trees with a high probability of mortality in the near future. Damage is so severe that retention in the stand until the end of a rotation is not feasible.
2	Moderate-risk trees with an elevated risk of dying soon. Death is not as "Imminent" as in class 1. Damage significantly degrades present or potential value, especially for high-value uses such as sawlogs and veneer logs. Tree growth is likely to be reduced for a number of years due to damages such as loss of crown or root damage. Retention in the stand is questionable and depends on tree and stand age, product objectives, etc.
3	Low-risk trees with a high probability of survival. Damage elevates the risk of mortality, but reduced growth and value degrade will probably be minimal.
4	Trees without obvious hurricane damage.

Criteria and Evaluation Procedure

Criteria for assigning trees to damage/risk classes are provided for the following combinations of species, stand type, and tree size or age class:

Softwood species in planted stands--
- Less than 5 years old
- 5-20 years old
- 21 years and older

Softwood species in natural stands--
- Saplings (1.0-4.9 inches)
- Poletimber (5.0-8.9 inches)
- Sawtimber (9.0 inches & larger)

Hardwood species in all stands--
- Saplings (1.0-4.9 inches)
- Poletimber (5.0-10.9 inches)
- Sawtimber (11.0 inches & larger)

The following procedure was used to make the damage/risk class assignment for each tree.

- Class 4 (healthy) was assigned if no obvious hurricane damage was present.

- Class 1 was assigned if one (or more) qualifying damage was present. When listed, associated damages were treated as a required combination with the primary condition.

- If the criteria for assignment to class 1 were not met, then criteria for class 2 were evaluated in the same manner as described above.

- If no damages listed for class 2 were present, then damage assignment defaulted to class 3.

The damage variables coded for each tree and used in the damage/risk classification process are described in Appendix A.

Table B.1--Damage/risk class criteria for softwood species in pine plantations less than 5 years old

Damage/risk class	Primary condition	Associated condition
4 (healthy)	No obvious damage	
1	Crown loss ≥ 75%	
	Root sprung	
	Split/twisted bole	
	Lean/bend ≥ 60 degrees	
	Salt burn present	Crown loss ≥ 30%
	Volume loss (residual trees) ≥ 30%	
2	Crown loss 40-74%	
	Lean/bend 15-59 degrees	
	Salt burn present	Crown loss < 30%
	Volume loss (residual trees) 10-29%	
	Terminal leader broken out	
3	Crown loss 1-39%	
	Root damage below ground	
	Skinned bole/other bole damage	
	Lean/bend 1-14 degrees	
	Volume loss (residual trees) 1-9%	

Table B.2--Damage/risk class criteria for softwood species in pine plantations 5-20 years old

Damage/risk class	Primary condition	Associated condition
4 (healthy)	No obvious damage	
1	Crown loss ≥ 75%	
	Root sprung	
	Split/twisted bole	Crown loss ≥ 50%
	Lean/bend ≥ 45 degrees	
	Salt burn present	Crown loss ≥ 30%
	Volume loss ≥ 30%	
2	Crown loss 40-74%	
	Lean/bend 15-44 degrees	
	Split/twisted bole	Crown loss < 50%
	Skinned bole/other bole damage	Crown loss ≥ 25%
	Salt burn present	Crown loss < 30%
	Terminal leader broken out	
	Volume loss 5-29%	
3	Crown loss 1-39%	
	Root damage below ground	
	Skinned bole/other bole damage	Crown loss < 25%
	Lean/bend 1-14 degrees	
	Volume loss 1-4%	

Table B.3--Damage/risk class criteria for softwood species in pine plantations greater than 20 years old

Damage/risk class	Primary condition	Associated condition
4 (healthy)	No obvious damage	
1	Crown loss ≥ 75%	
	Root sprung	
	Split/twisted bole	Crown loss ≥ 50%
	Lean/bend ≥ 35 degrees	
	Salt burn present	Crown loss ≥ 30%
	Volume loss ≥ 30%	
2	Crown loss 40-74%	
	Lean/bend 15-34 degrees	
	Split/twisted bole	Crown loss < 50%
	Skinned bole/other bole damage	Crown loss ≥ 25%
	Salt burn present	Crown loss < 30%
	Volume loss 5-29%	
3	Crown loss 1-39%	
	Root damage below ground	
	Skinned bole/other bole damage	Crown loss < 25%
	Lean/bend 1-14 degrees	
	Terminal leader broken out	
	Volume loss 1-4%	

Table B.4--Damage/risk class criteria for softwood saplings (1.0-4.9 inches d.b.h.) in natural stands

Damage/risk class	Primary condition	Associated condition
4 (healthy)	No obvious damage	
1	Crown loss ≥ 75%	Dominant/codominant trees
	Crown loss ≥ 50%	Intermediate/suppressed trees
	Root sprung	
	Split/twisted bole	Crown loss ≥ 50%
	Salt burn present	Crown loss ≥ 30%
	Lean/bend ≥ 45 degrees	
2	Crown loss 40-74%	Dominant/codominant trees
	Crown loss 25-49%	Intermediate/suppressed trees
	Split/twisted bole	Crown loss < 50%
	Skinned bole/other bole damage	Crown loss ≥ 25%
	Lean/bend 15-44 degrees	
	Salt burn present	Crown loss < 30%
	Terminal leader broken out	
3	Crown loss 1-39%	Dominant/codominant trees
	Crown loss 1-25%	Intermediate/suppressed trees
	Root damage below ground	
	Skinned bole/other bole damage	Crown loss < 25%
	Lean/bend 1-14 degrees	

Table B.5--Damage/risk class criteria for softwood poletimber (5.0-8.9 inches d.b.h.) in natural stands

Damage/risk class	Primary condition	Associated condition
4 (healthy)	No obvious damage	
1	Crown loss ≥ 75%	Dominant/codominant trees
	Crown loss ≥ 50%	Intermediate/suppressed trees
	Root sprung	
	Split/twisted bole	Crown loss ≥ 50%
	Lean/bend ≥ 45 degrees	
	Salt burn present	Crown loss ≥ 30%
	Volume loss ≥ 30%	
2	Crown loss 40-74%	Dominant/codominant trees
	Crown loss 25-49%	Intermediate/suppressed trees
	Split/twisted bole	Crown loss < 50%
	Skinned bole/other bole damage	Crown loss ≥ 25%
	Lean/bend 15-44 degrees	
	Salt burn present	Crown loss < 30%
	Volume loss 5-29%	
	Terminal leader broken out	
3	Crown loss 1-39%	Dominant/codominant trees
	Crown loss 1-25%	Intermediate/suppressed trees
	Root damage below ground	
	Skinned bole/other bole damage	Crown loss < 25%
	Lean/bend 1-14 degrees	
	Volume loss 1-4%	

Table B.6--Damage/risk class criteria for softwood sawtimber (9.0 inches d.b.h. and larger) in natural stands

Damage/risk class	Primary condition	Associated condition
4 (healthy)	No obvious damage	
1	Crown loss ≥ 75%	Dominant/codominant trees
	Crown loss ≥ 50%	Intermediate/suppressed trees
	Root sprung	
	Split/twisted bole	Crown loss ≥ 50%
	Lean/bend ≥ 35 degrees	
	Salt burn present	Crown loss ≥ 30%
	Volume loss ≥ 30%	
2	Crown loss 40-74%	Dominant/codominant trees
	Crown loss 25-49%	Intermediate/suppressed trees
	Split/twisted bole	Crown loss < 50%
	Skinned bole/other bole damage	Crown loss ≥ 25%
	Lean/bend 15-34 degrees	
	Salt burn present	Crown loss < 30%
	Volume loss 5-29%	
3	Crown loss 1-39%	Dominant/codominant trees
	Crown loss 1-25%	Intermediate/suppressed trees
	Root damage below ground	
	Skinned bole/other bole damage	Crown loss < 25%
	Lean/bend 1-14 degrees	
	Terminal leader broken out	
	Volume loss 1-4%	

Table B.7--Damage/risk class criteria for hardwood saplings (1.0-4.9 inches d.b.h.)

Damage/risk class	Primary condition	Associated condition
4 (healthy)	No obvious damage	
1	Crown loss ≥ 90%	
	Root sprung	Lean/bend ≥ 45 degrees
	Split/twisted bole	Crown loss ≥ 75%
	Lean/bend ≥ 75 degrees	
2	Crown loss 45-89%	
	Split/twisted bole	Crown loss < 75%
	Skinned bole/other bole damage	
	Lean/bend 15-74 degrees	
3	Crown loss 1-44%	
	Root damage below ground	
	Lean/bend 1-14 degrees	
	Terminal leader broken out	

Table B.8--Damage/risk class criteria for hardwood poletimber (5.0-10.9 inches d.b.h.)

Damage/risk class	Primary condition	Associated condition
4 (healthy)	No obvious damage	
1	Crown loss ≥ 90% Root sprung Split/twisted bole	Lean/bend ≥ 35 degrees Crown loss ≥ 75%, or Bole breakage in lower 20 ft
	Lean/bend ≥ 60 degrees Volume loss ≥ 30%	
2	Crown loss 45-89% Root sprung Split/twisted bole	Lean/bend < 35 degrees Crown loss < 75%, or Bole breakage above lower 20 ft
	Skinned bole/other bole damage Lean/bend 15-59 degrees Volume loss 5-29%	
3	Crown loss 1-44% Root damage below ground Lean/bend 1-14 degrees Terminal leader broken out Volume loss 1-4%	

Table B.9--Damage/risk class criteria for hardwood sawtimber (11.0 inches d.b.h. and larger)

Damage/risk class	Primary condition	Associated condition
4 (healthy)	No obvious damage	
1	Crown loss > 90% Root sprung Split/twisted bole	Lean/bend ≥ 25 degrees Crown loss ≥ 75%, or Bole breakage in lower 20 ft
	Lean/bend ≥ 45 degrees Volume loss ≥ 30%	
2	Crown loss 45-89% Root sprung Split/twisted bole	Lean/bend < 25 degrees Crown loss < 75%, or Bole breakage above Lower 20 ft
	Skinned bole/other bole damage Lean/bend 15-44 degrees Volume loss 5-29%	
3	Crown loss 1-44% Root damage below ground Lean/bend 1-14 degrees Terminal leader broken out Volume loss 1-4%	

Appendix C: Detailed Tables

Table C.1--Period change in volume of softwood growing stock on timberland, by county and component of change, for 23 counties in South Carolina, 1986-1990

County	1986 inventory (I_{86})	Gross growth (GG)	Regular mortality (M_r)	Hugo mortality (M_h)	Net growth (NG)	Regular removals (TR_r)	Hugo removals (TR_h)	Net change (NC)	1990 inventory (I_{90})
					Thousand cubic feet				
Berkeley	542,202	109,040	6,850	212,364	-110,174	49,770	79,184	-239,128	303,074
Calhoun	119,407	22,235	--	17,782	4,453	23,709	8,767	-28,023	91,384
Charleston	305,111	43,414	4,106	112,201	-72,893	34,329	34,258	-141,480	163,631
Chester	223,223	58,451	5,967	15,992	36,492	27,939	11,219	-2,666	220,557
Chesterfield	206,712	50,990	4,621	13,737	32,632	21,357	10,815	460	207,172
Clarendon	138,435	20,492	995	35,522	-16,025	17,752	27,956	-61,733	76,702
Darlington	102,759	15,903	388	6,563	8,952	11,404	15,607	-18,059	84,700
Dillon	96,508	19,530	2,781	2,051	14,698	11,044	5,505	-1,851	94,657
Dorchester	226,376	31,316	4,585	20,689	6,042	53,544	13,325	-60,827	165,549
Fairfield	286,611	90,995	11,613	867	78,515	68,972	--	9,543	296,154
Florence	242,192	42,479	5,208	18,659	18,612	78,253	6,884	-66,525	175,667
Georgetown	285,312	54,223	5,694	29,100	19,429	69,430	9,960	-59,961	225,351
Horry	388,917	67,958	5,349	4,883	57,726	71,594	3,672	-17,540	371,377
Kershaw	185,948	42,864	2,840	13,941	26,083	65,993	13,961	-53,871	132,077
Lancaster	158,758	46,947	4,785	19,332	22,830	46,096	35,403	-58,669	100,089
Lee	85,669	16,707	4,064	15,963	-3,320	14,788	12,603	-30,711	54,958
Marion	158,473	27,006	3,519	4,930	18,557	35,361	4,858	-21,662	136,811
Marlboro	92,880	24,812	5,308	2,845	16,659	9,648	--	7,011	99,891
Orangeburg	211,080	38,538	7,302	14,837	16,399	68,385	838	-52,824	158,256
Richland	161,380	35,327	3,239	4,288	27,800	38,963	1,340	-12,503	148,877
Sumter	146,349	26,157	632	31,405	-5,880	18,278	36,545	-60,703	85,646
Williamsburg	271,340	49,581	3,262	28,513	17,806	40,336	41,344	-63,874	207,466
York	179,464	46,536	3,894	5,625	37,017	37,760	1,669	-2,412	177,052
Total	4,815,106	981,501	97,002	632,089	252,410	914,705	375,713	-1,038,008	3,777,098

$NG = GG - M_r - M_h$

$NC = NG - TR_r - TR_h$

$I_{90} = I_{86} + NC$

Pre-Hugo inventory = $I_{86} + GG - M_r - TR_r$

Table C.2--Period change in volume of hardwood growing stock on timberland, by county and component of change, for 23 counties in South Carolina, 1986-1990

County	1986 inventory (I_{86})	Gross growth (GG)	Regular mortality (M_r)	Hugo mortality (M_h)	Net growth (NG)	Regular removals (TR_r)	Hugo removals (TR_h)	Net change (NC)	1990 inventory (I_{90})
					Thousand cubic feet				
Berkeley	327,876	40,760	2,154	43,800	-5,194	17,432	4,507	-27,133	300,743
Calhoun	92,800	12,516	2,762	1,352	8,402	7,478	--	924	93,724
Charleston	200,928	28,375	2,579	33,279	-7,483	3,996	1,848	-13,327	187,601
Chester	137,300	27,138	6,119	--	21,019	24,025	789	-3,795	133,505
Chesterfield	185,278	30,261	4,818	6,457	18,986	23,973	2,532	-7,519	177,759
Clarendon	230,430	28,114	3,141	23,217	1,756	36,608	6,304	-41,156	189,274
Darlington	109,084	20,115	5,578	5,223	9,314	11,560	1,107	-3,353	105,731
Dillon	154,598	25,581	5,186	829	19,566	14,038	--	5,528	160,126
Dorchester	279,752	39,117	2,121	26,983	10,013	49,858	3,168	-43,013	236,739
Fairfield	156,521	29,059	3,553	1,562	23,944	18,955	--	4,989	161,510
Florence	243,874	38,520	5,243	3,576	29,701	28,427	2,468	-1,194	242,680
Georgetown	241,573	33,970	2,575	15,794	15,601	16,146	--	-545	241,028
Horry	438,325	62,908	10,945	5,576	46,387	29,432	544	16,411	454,736
Kershaw	139,303	23,356	1,821	4,810	16,725	6,821	5,097	4,807	144,110
Lancaster	145,246	27,424	1,491	7,065	18,868	20,109	1,782	-3,023	142,223
Lee	93,000	14,129	2,172	24,936	-12,979	906	10,144	-24,029	68,971
Marion	278,067	41,113	8,349	3,585	29,179	35,278	--	-6,099	271,968
Marlboro	185,825	31,881	7,076	1,255	23,550	7,396	--	16,154	201,979
Orangeburg	399,404	60,739	7,684	25,613	27,442	67,927	--	-40,485	358,919
Richland	208,577	33,048	976	--	32,072	31,807	--	265	208,842
Sumter	240,320	25,611	3,660	18,536	3,415	32,794	1,108	-30,487	209,833
Williamsburg	341,219	44,945	6,473	11,165	27,307	32,323	7,604	-12,620	328,599
York	172,963	37,539	3,475	5,752	28,312	14,848	--	13,464	186,427
Total	5,002,263	756,219	99,951	270,365	385,903	532,137	49,002	-195,236	4,807,027

$NG = GG - M_r - M_h$

$NC = NG - TR_r - TR_h$

$I_{90} = I_{86} + NC$

Pre-Hugo inventory = $I_{86} + GG - M_r - TR_r$

Table C.3--Period change in volume of softwood sawtimber on timberland, by county and component of change, for 23 counties in South Carolina, 1986-1990

County	1986 inventory (I_{86})	Gross growth (GG)	Regular mortality (M_r)	Hugo mortality (M_h)	Net growth (NG)	Regular removals (TR_r)	Hugo removals (TR_h)	Net change (NC)	1990 inventory (I_{90})
	Thousand board feet								
Berkeley	2,187,329	457,920	24,755	1,056,557	-623,392	206,824	401,878	-1,232,094	955,235
Calhoun	467,356	103,953	--	91,698	12,255	117,130	30,941	-135,816	331,540
Charleston	1,441,830	240,403	23,332	618,091	-401,020	171,591	147,708	-720,319	721,511
Chester	732,457	238,739	10,087	64,428	164,224	97,552	48,082	18,590	751,047
Chesterfield	737,529	175,947	10,869	65,188	99,890	68,510	64,203	-32,823	704,706
Clarendon	645,232	106,844	5,225	189,637	-88,018	84,499	156,309	-328,826	316,406
Darlington	503,643	84,725	--	35,691	49,034	42,818	92,544	-86,328	417,315
Dillon	434,423	97,447	12,038	9,036	76,373	46,500	12,441	17,432	451,855
Dorchester	981,052	171,850	12,736	88,252	70,862	251,452	60,504	-241,094	739,958
Fairfield	944,591	333,560	38,302	5,796	289,462	257,110	--	32,352	976,943
Florence	1,081,686	219,601	12,189	83,966	123,446	406,868	41,575	-324,997	756,689
Georgetown	1,101,589	243,088	17,887	120,519	104,682	282,164	52,598	-230,080	871,509
Horry	1,684,945	357,104	19,691	21,580	315,833	313,535	22,726	-20,428	1,664,517
Kershaw	599,675	159,297	4,763	47,804	106,730	281,483	42,781	-217,534	382,141
Lancaster	460,865	163,457	15,177	78,051	70,229	179,249	114,594	-223,614	237,251
Lee	329,786	79,405	17,347	76,085	-14,027	39,728	58,605	-112,360	217,426
Marion	738,661	132,876	8,467	25,471	98,938	165,405	31,247	-97,714	640,947
Marlboro	284,079	109,509	14,701	12,024	82,784	13,459	--	69,325	353,404
Orangeburg	821,700	173,864	16,598	73,963	83,303	298,618	5,243	-220,558	601,142
Richland	614,031	138,011	11,046	13,919	113,046	169,727	5,610	-62,291	551,740
Sumter	589,302	114,150	4,499	161,826	-52,175	70,214	166,000	-288,389	300,913
Williamsburg	1,150,983	239,312	17,293	125,738	96,281	186,757	210,728	-301,204	849,779
York	476,528	185,890	10,200	15,646	160,044	144,672	7,419	7,953	484,481
Total	19,009,272	4,326,952	307,202	3,080,966	938,784	3,895,865	1,773,736	-4,730,817	14,278,455

$NG = GG - M_r - M_h$

$NC = NG - TR_r - TR_h$

$I_{90} = I_{86} + NC$

Pre-Hugo inventory = $I_{86} + GG - M_r - TR_r$

Table C.4--Period change in volume of hardwood sawtimber on timberland, by county and component of change, for 23 counties in South Carolina, 1986-1990

County	1986 inventory (I_{86})	Gross growth (GG)	Regular mortality (M_r)	Hugo mortality (M_h)	Net growth (NG)	Regular removals (TR_r)	Hugo removals (TR_h)	Net change (NC)	1990 inventory (I_{90})
				Thousand board feet					
Berkeley	1,018,776	136,093	1,778	148,919	-14,604	62,807	17,616	-95,027	923,749
Calhoun	272,262	47,983	8,944	6,717	32,322	10,276	--	22,046	294,308
Charleston	580,532	98,285	8,504	135,829	-46,048	6,563	2,359	-54,970	525,562
Chester	347,994	74,016	22,747	--	51,269	87,830	--	-36,561	311,433
Chesterfield	563,124	102,595	8,995	20,747	72,853	104,544	6,581	-38,272	524,852
Clarendon	731,638	111,183	5,805	80,820	24,558	124,594	24,318	-124,354	607,284
Darlington	330,963	45,281	20,080	24,282	919	34,284	4,398	-37,763	293,200
Dillon	452,454	87,923	10,011	4,606	73,306	25,212	--	48,094	500,548
Dorchester	856,940	120,240	5,823	102,641	11,776	171,302	17,054	-176,580	680,360
Fairfield	396,366	97,931	11,014	7,508	79,409	67,804	--	11,605	407,971
Florence	833,389	144,036	16,968	18,621	108,447	101,370	11,406	-4,329	829,060
Georgetown	766,458	122,049	3,606	52,253	66,190	41,442	--	24,748	791,206
Horry	1,388,656	230,958	37,015	17,706	176,237	105,446	2,234	68,557	1,457,213
Kershaw	386,776	74,687	1,845	9,650	63,192	15,353	10,288	37,551	424,327
Lancaster	316,751	60,101	2,613	11,512	45,976	59,701	5,808	-19,533	297,218
Lee	287,548	40,512	11,089	97,252	-67,829	2,305	35,931	-106,065	181,483
Marion	910,854	148,097	28,013	16,062	104,022	133,392	--	-29,370	881,484
Marlboro	520,285	108,559	26,789	4,693	77,077	35,886	--	41,191	561,476
Orangeburg	1,054,692	192,056	17,905	76,142	98,009	205,605	--	-107,596	947,096
Richland	667,731	121,999	3,913	--	118,086	120,226	--	-2,140	665,591
Sumter	832,963	106,070	6,869	73,646	25,555	129,359	1,275	-105,079	727,884
Williamsburg	1,064,967	156,556	20,462	44,165	91,929	96,356	24,755	-29,182	1,035,785
York	362,376	106,140	10,970	21,248	73,922	53,044	--	20,878	383,254
Total	14,944,495	2,533,350	291,758	975,019	1,266,573	1,794,701	164,023	-692,151	14,252,344

$NG = GG - M_r - M_h$

$NC = NG - TR_r - TR_h$

$I_{90} = I_{86} + NC$

Pre-Hugo inventory = $I_{86} + GG - M_r - TR_r$

Table C.5--Distribution of 1990 inventory of growing stock, by county, species group, and damage class, for 23 counties in South Carolina

County	Softwoods					Hardwoods				
	1990 Inventory	Percentage of inventory in--				1990 Inventory	Percentage of inventory in--			
		Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees		Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees
	Thousand cubic feet	Percent				Thousand cubic feet	Percent			
Berkeley	303,074	30	28	24	18	300,743	33	18	21	28
Calhoun	91,384	97	1	--	2	93,724	96	--	1	3
Charleston	163,631	64	9	13	14	187,601	53	17	17	13
Chester	220,557	98	--	--	2	133,505	98	1	1	--
Chesterfield	207,172	69	28	2	1	177,759	43	39	7	11
Clarendon	76,702	40	24	15	21	189,274	38	9	9	44
Darlington	84,700	97	--	2	1	105,731	76	1	10	13
Dillon	94,657	100	--	--	--	160,126	92	--	1	7
Dorchester	165,549	69	10	11	10	236,739	69	8	12	11
Fairfield	296,154	99	--	1	--	161,510	100	--	--	--
Florence	175,667	54	30	9	7	242,680	51	24	6	19
Georgetown	225,351	61	10	20	9	241,028	61	15	11	13
Horry	371,377	60	23	16	1	454,736	68	21	6	5
Kershaw	132,077	73	12	11	4	144,110	64	12	6	18
Lancaster	100,089	81	5	2	12	142,223	79	2	5	14
Lee	54,958	72	7	16	5	68,971	54	10	17	19
Marion	136,811	92	3	3	2	271,968	87	3	4	6
Marlboro	99,891	95	2	3	--	201,979	95	2	1	2
Orangeburg	158,256	85	7	6	2	358,919	91	3	4	2
Richland	148,877	93	5	1	1	208,842	85	10	1	4
Sumter	85,646	43	21	16	20	209,833	51	8	15	26
Williamsburg	207,466	38	41	11	10	328,599	38	27	14	21
York	177,052	87	7	3	3	186,427	90	1	2	7
Total	3,777,098	71	14	9	6	4,807,027	68	12	8	12

Table C.6--Distribution of 1990 inventory of sawtimber, by county, species group, and damage class, for 23 counties in South Carolina

County	Softwoods					Hardwoods				
	1990 Inventory	Percentage of inventory in--				1990 Inventory	Percentage of inventory in--			
		Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees		Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees
	Thousand board feet	Percent				Thousand board feet	Percent			
Berkeley	955,235	32	29	20	19	923,749	31	16	22	31
Calhoun	331,540	98	1	--	1	294,308	94	--	1	5
Charleston	721,511	63	9	12	16	525,562	46	21	18	15
Chester	751,047	98	--	--	2	311,433	97	2	1	--
Chesterfield	704,706	69	27	2	2	524,852	43	39	4	14
Clarendon	316,406	35	25	14	26	607,284	25	8	11	56
Darlington	417,315	97	--	2	1	293,200	72	2	12	14
Dillon	451,855	100	--	--	--	500,548	90	--	1	9
Dorchester	739,958	72	9	11	8	680,360	58	10	15	17
Fairfield	976,943	100	--	--	--	407,971	100	--	--	--
Florence	756,689	53	30	9	8	829,060	43	29	5	23
Georgetown	871,509	60	9	21	10	791,206	59	14	10	17
Horry	1,664,517	60	25	14	1	1,457,213	64	23	7	6
Kershaw	382,141	79	11	5	5	424,327	51	13	6	30
Lancaster	237,251	78	1	1	20	297,218	76	1	5	18
Lee	217,426	77	6	10	7	181,483	54	11	15	20
Marion	640,947	94	2	2	2	881,484	87	2	3	8
Marlboro	353,404	94	3	2	1	561,476	94	4	--	2
Orangeburg	601,142	88	9	2	1	947,096	91	3	4	2
Richland	551,740	90	8	1	1	665,591	80	14	1	5
Sumter	300,913	47	19	15	19	727,884	49	8	15	28
Williamsburg	849,779	39	42	9	10	1,035,785	34	27	12	27
York	484,481	86	10	1	3	383,254	88	--	4	8
Total	14,278,455	72	14	8	6	14,252,344	63	13	8	16

Table C.7--Period change in volume of softwood growing stock on timberland, by component of change and ownership class, for 23 counties in South Carolina, 1986-1990

Inventory item	All ownerships	National forest	Other public	Forest industry	Farmer	Miscellaneous private
			Thousand cubic feet			
1986 Inventory (I_{86})	4,815,106	354,368	281,936	1,080,693	1,220,060	1,878,049
Gross growth (GG)	981,501	57,922	59,914	265,970	226,911	370,784
Regular mortality (M_r)	97,002	6,509	6,118	19,662	28,590	36,123
Hugo mortality (M_h)	632,089	167,707	36,395	87,696	131,121	209,170
Net growth (NG)	252,410	-116,294	17,401	158,612	67,200	125,491
Regular removals (TR_r)	914,705	30,360	28,844	291,625	222,433	341,443
Hugo removals (TR_h)	375,713	11,107	15,881	40,317	107,038	201,370
Net change (NC)	-1,038,008	-157,761	-27,324	-173,330	-262,271	-417,322
1990 Inventory (I_{90})	3,777,098	196,607	254,612	907,363	957,789	1,460,727

$NG = GG - M_r - M_h$

$NC = NG - TR_r - TR_h$

$I_{90} = I_{86} + NC$

Pre-Hugo inventory = $I_{86} + GG - M_r - TR_r$

Table C.8--Period change in volume of hardwood growing stock on timberland, by component of change and ownership class, for 23 counties in South Carolina, 1986-1990

Inventory item	All ownerships	National forest	Other public	Forest industry	Farmer	Miscellaneous private
			Thousand cubic feet			
1986 Inventory (I_{86})	5,002,263	184,892	86,205	1,090,291	1,514,479	2,126,396
Gross growth (GG)	756,219	24,689	15,901	151,846	238,050	325,733
Regular mortality (M_r)	99,951	2,988	1,718	21,171	38,820	35,254
Hugo mortality (M_h)	270,365	37,249	6,313	47,490	75,647	103,666
Net growth (NG)	385,903	-15,548	7,870	83,185	123,583	186,813
Regular removals (TR_r)	532,137	19,925	6,598	158,503	135,597	211,514
Hugo removals (TR_h)	49,002	207	--	4,953	23,623	20,219
Net change (NC)	-195,236	-35,680	1,272	-80,271	-35,637	-44,920
1990 Inventory (I_{90})	4,807,027	149,212	87,477	1,010,020	1,478,842	2,081,476

$NG = GG - M_r - M_h$

$NC = NG - TR_r - TR_h$

$I_{90} = I_{86} + NC$

Pre-Hugo inventory = $I_{86} + GG - M_r - TR_r$

Table C.9--Period change in volume of softwood sawtimber on timberland, by component of change and ownership class, for 23 counties in South Carolina, 1986-1990

Inventory item	All ownerships	National forest	Other public	Forest industry	Farmer	Miscellaneous private
			Thousand board feet			
1986 Inventory (I_{86})	19,009,272	1,623,832	1,069,257	3,492,092	5,185,255	7,638,836
Gross growth (GG)	4,326,952	266,259	226,353	1,013,555	1,106,316	1,714,469
Regular mortality (M_r)	307,202	23,437	15,112	44,469	96,839	127,345
Hugo mortality (M_h)	3,080,966	918,303	161,893	333,279	640,227	1,027,264
Net growth (NG)	938,784	-675,481	49,348	635,807	369,250	559,860
Regular removals (TR_r)	3,895,865	132,220	136,555	1,150,044	1,019,350	1,457,696
Hugo removals (TR_h)	1,773,736	60,708	86,005	127,903	517,632	981,488
Net change (NC)	-4,730,817	-868,409	-173,212	-642,140	-1,167,732	-1,879,324
1990 Inventory (I_{90})	14,278,455	755,423	896,045	2,849,952	4,017,523	5,759,512

$NG = GG - M_r - M_h$

$NC = NG - TR_r - TR_h$

$I_{90} = I_{86} + NC$

Pre-Hugo inventory = $I_{86} + GG - M_r - TR_r$

Table C.10--Period change in volume of hardwood sawtimber on timberland, by component of change and ownership class, for 23 counties in South Carolina, 1986-1990

Inventory item	All ownerships	National forest	Other public	Forest industry	Farmer	Miscellaneous private
			Thousand board feet			
1986 Inventory (I_{86})	14,944,495	570,272	179,228	3,541,280	4,258,998	6,394,717
Gross growth (GG)	2,533,350	81,662	28,403	572,192	785,093	1,066,000
Regular mortality (M_r)	291,758	9,873	--	70,386	98,878	112,621
Hugo mortality (M_h)	975,019	144,847	18,178	168,079	262,298	381,617
Net growth (NG)	1,266,573	-73,058	10,225	333,727	423,917	571,762
Regular removals (TR_r)	1,794,701	78,537	12,030	553,137	399,157	751,840
Hugo removals (TR_h)	164,023	--	--	4,850	81,951	77,222
Net change (NC)	-692,151	-151,595	-1,805	-224,260	-57,191	-257,300
1990 Inventory (I_{90})	14,252,344	418,677	177,423	3,317,020	4,201,807	6,137,417

$NG = GG - M_r - M_h$

$NC = NG - TR_r - TR_h$

$I_{90} = I_{86} + NC$

Pre-Hugo inventory = $I_{86} + GG - M_r - TR_r$

Table C.11--Distribution of 1990 inventory of growing stock, by ownership class, species group, and damage class, for 23 counties in South Carolina

Ownership class	Softwoods					Hardwoods				
	1990 Inventory	Percentage of inventory in--				1990 Inventory	Percentage of inventory in--			
		Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees		Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees
	Thousand cubic feet	Percent				Thousand cubic feet	Percent			
National forest	196,607	55	12	22	11	149,212	40	21	20	19
Other public	254,612	70	16	8	6	87,477	64	11	11	14
Forest industry	907,363	64	19	11	6	1,010,020	70	12	7	11
Farmer	957,789	75	13	7	5	1,478,842	68	12	7	13
Miscellaneous private	1,460,727	74	11	8	7	2,081,476	70	11	7	12
All ownerships	3,777,098	71	14	9	6	4,807,027	68	12	8	12

Table C.12--Distribution of 1990 inventory of sawtimber, by ownership class, species group, and damage class, for 23 counties in South Carolina

Ownership class	Softwoods					Hardwoods				
	1990 Inventory	Percentage of inventory in--				1990 Inventory	Percentage of inventory in--			
		Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees		Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees
	Thousand board feet	Percent				Thousand board feet	Percent			
National forest	755,423	58	12	20	10	418,677	36	20	18	26
Other public	896,045	70	17	7	6	177,423	43	20	16	21
Forest industry	2,849,952	66	19	8	7	3,317,020	64	15	8	13
Farmer	4,017,523	75	13	7	5	4,201,807	64	12	8	16
Miscellaneous private	5,759,512	73	13	7	7	6,137,417	63	12	8	17
All ownerships	14,278,455	72	14	8	6	14,252,344	63	13	8	16

Table C.13--Change in volume of softwood growing stock on timberland, by diameter class, for 23 counties in South Carolina, 1986-1990

Diameter class (inches at breast height)	1986 Inventory	Net change	1990 Inventory	1990 inventory in--			
				Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees
	Thousand cubic feet			Percent			
5.0-6.9	429,755	-65,092	364,663	68	13	13	6
7.0-8.9	636,017	-53,320	582,697	71	12	12	5
9.0-10.9	750,921	-138,543	612,378	73	14	8	5
11.0-12.9	768,374	-227,552	540,822	72	14	6	8
13.0-14.9	670,699	-151,324	519,375	72	14	7	7
15.0-16.9	546,665	-154,674	391,991	72	15	7	6
17.0-18.9	390,308	-99,269	291,039	69	15	9	7
19.0-20.9	255,152	-63,967	191,185	74	13	7	6
21.0 and larger	367,215	-84,267	282,948	66	17	11	6
All classes	4,815,106	-1,038,008	3,777,098	71	14	9	6

Table C.14--Change in volume of hardwood growing stock on timberland, by diameter class, for 23 counties in South Carolina, 1986-1990

Diameter class (inches at breast height)	1986 Inventory	Net change	1990 Inventory	1990 inventory in--			
				Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees
	Thousand cubic feet			Percent			
5.0-6.9	473,665	-26,509	447,156	78	8	7	7
7.0-8.9	604,044	8,979	613,023	75	11	8	6
9.0-10.9	659,619	-9,128	650,491	72	11	8	9
11.0-12.9	711,364	-66,034	645,330	71	10	7	12
13.0-14.9	642,148	-6,502	635,646	73	11	6	10
15.0-16.9	544,058	-32,429	511,629	64	14	7	15
17.0-18.9	432,505	-27,642	404,863	62	14	7	17
19.0-20.9	292,547	-10,185	282,362	60	13	9	18
21.0 and larger	642,313	-25,786	616,527	54	14	11	21
All classes	5,002,263	-195,236	4,807,027	68	12	8	12

Table C.15--Change in volume of softwood sawtimber on timberland, by diameter class, for 23 counties in South Carolina, 1986-1990

Diameter class (inches at breast height)	1986 Inventory	Net change	1990 Inventory	1990 inventory in--			
				Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees
	Thousand board feet			Percent			
9.0-10.9	2,733,479	-497,748	2,235,731	74	13	8	5
11.0-12.9	3,480,059	-1,024,486	2,455,573	72	14	6	8
13.0-14.9	3,446,844	-781,009	2,665,835	72	14	7	7
15.0-16.9	3,052,743	-861,508	2,191,235	72	15	7	6
17.0-18.9	2,318,662	-597,629	1,721,033	69	15	9	7
19.0-20.9	1,576,250	-401,458	1,174,792	74	13	7	6
21.0 and larger	2,401,235	-566,979	1,834,256	66	17	11	6
All classes	19,009,272	-4,730,817	14,278,455	72	14	8	6

Table C.16--Change in volume of hardwood sawtimber on timberland, by diameter class, for 23 counties in South Carolina, 1986-1990

Diameter class (inches at breast height)	1986 Inventory	Net change	1990 Inventory	1990 inventory in--			
				Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees
	Thousand board feet			Percent			
11.0-12.9	2,453,516	-214,030	2,239,486	70	10	7	13
13.0-14.9	2,603,726	-11,132	2,592,594	72	12	6	10
15.0-16.9	2,478,661	-138,623	2,340,038	64	14	7	15
17.0-18.9	2,124,710	-131,826	1,992,884	62	14	7	17
19.0-20.9	1,536,842	-56,647	1,480,195	59	13	9	19
21.0 and larger	3,747,040	-139,893	3,607,147	53	14	11	22
All classes	14,944,495	-692,151	14,252,344	63	13	8	16

Table C.17--Change in volume of softwood growing stock on timberland, by species, for 23 counties in South Carolina, 1986-1990

Species	1986 Inventory	Net change	1990 Inventory	1990 inventory in--			
				Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees
	Thousand cubic feet			Percent			
Longleaf pine	451,329	-148,690	302,639	80	8	6	6
Slash pine	195,053	-49,239	145,814	68	19	7	6
Shortleaf pine	244,145	-39,025	205,120	85	7	3	5
Loblolly pine	3,173,218	-684,412	2,488,806	69	15	10	6
Pond pine	277,260	-97,505	179,755	59	15	16	10
Virginia pine	54,852	-2,940	51,912	79	4	2	15
Pitch pine	--	--	--	--	--	--	--
Table Mountain pine	--	--	--	--	--	--	--
Spruce pine	15,678	-2,298	13,380	67	17	3	13
Sand pine	--	--	--	--	--	--	--
Eastern white pine	--	--	--	--	--	--	--
Eastern hemlock	--	--	--	--	--	--	--
Spruce and fir	--	--	--	--	--	--	--
Baldcypress	295,328	-11,304	284,024	77	13	5	5
Pondcypress	74,169	-2,458	71,711	76	13	8	3
Cedars	34,074	-137	33,937	90	2	1	7
All species	4,815,106	-1,038,008	3,777,098	71	14	9	6

Table C.18--Change in volume of hardwood growing stock on timberland, by species, for 23 counties in South Carolina, 1986-1990

Species	1986 Inventory	Net change	1990 Inventory	1990 inventory in--			
				Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees
	Thousand cubic feet			Percent			
Select white oaks	272,297	-4,575	267,722	71	11	4	14
Select red oaks	92,266	-9,072	83,194	63	10	5	22
Chestnut oak	--	--	--	--	--	--	--
Other white oaks	159,951	-8,096	151,855	65	10	11	14
Other red oaks	997,617	-68,770	928,847	58	12	9	21
Hickory	162,474	-12,027	150,447	69	6	8	17
Yellow birch	--	--	--	--	--	--	--
Hard maple	1,524	253	1,777	100	--	--	--
Soft maple	379,354	8,598	387,952	58	12	13	17
Beech	7,159	-81	7,078	66	--	19	15
Sweetgum	1,094,447	-44,362	1,050,085	71	14	7	8
Tupelo and blackgum	1,152,982	-19,399	1,133,583	78	11	6	5
Ash	168,598	-11,422	157,176	64	13	10	13
Cottonwood	34,812	-2,114	32,698	70	15	11	4
Basswood	275	58	333	--	--	100	--
Yellow-poplar	246,737	-11,649	235,088	60	13	8	19
Bay and magnolia	16,306	1,091	17,397	85	--	5	10
Black cherry	9,649	194	9,843	76	4	9	11
Black walnut	3,179	290	3,469	70	19	11	--
Sycamore	26,500	-6,049	20,451	74	6	4	16
Black locust	--	--	--	--	--	--	--
Elm	90,972	-3,530	87,442	77	11	4	8
Other eastern hardwoods	85,164	-4,574	80,590	75	6	7	12
All species	5,002,263	-195,236	4,807,027	68	12	8	12

Table C.19--Change in volume of softwood sawtimber on timberland, by species, for 23 counties in South Carolina, 1986-1990

Species	1986 Inventory	Net change	1990 Inventory	1990 inventory in-- Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees
	Thousand board feet			Percent			
Longleaf pine	1,971,710	-683,707	1,288,003	80	9	4	7
Slash pine	476,183	-133,231	342,952	74	15	3	8
Shortleaf pine	644,400	-135,583	508,817	84	7	1	8
Loblolly pine	12,939,294	-3,327,718	9,611,576	69	16	9	6
Pond pine	1,095,182	-399,830	695,352	59	13	15	13
Virginia pine	142,686	2,082	144,768	80	2	2	16
Pitch pine	--	--	--	--	--	--	--
Table Mountain pine	--	--	--	--	--	--	--
Spruce pine	85,748	-15,586	70,162	69	18	--	13
Sand pine	--	--	--	--	--	--	--
Eastern white pine	--	--	--	--	--	--	--
Eastern hemlock	--	--	--	--	--	--	--
Spruce and fir	--	--	--	--	--	--	--
Baldcypress	1,342,624	-33,448	1,309,176	76	14	5	5
Pondcypress	256,991	1,363	258,354	76	14	7	3
Cedars	54,454	-5,159	49,295	84	6	--	10
All species	19,009,272	-4,730,817	14,278,455	72	14	8	6

Table C.20--Change in volume of hardwood sawtimber on timberland, by species, for 23 counties in South Carolina, 1986-1990

Species	1986 Inventory	Net change	1990 Inventory	1990 inventory in--			
				Healthy trees	Class 3 trees	Class 2 trees	Class 1 trees
	Thousand board feet			Percent			
Select white oaks	829,475	-32,877	796,598	64	12	5	19
Select red oaks	349,767	-31,137	318,630	54	12	5	29
Chestnut oak	--	--	--	--	--	--	--
Other white oaks	505,941	-23,157	482,784	56	12	13	19
Other red oaks	3,142,149	-306,073	2,836,076	49	13	10	28
Hickory	504,622	-91,285	413,337	58	8	8	26
Yellow birch	--	--	--	--	--	--	--
Hard maple	1,981	497	2,478	100	--	--	--
Soft maple	824,432	-18,253	806,179	45	14	16	25
Beech	16,393	333	16,726	50	--	24	26
Sweetgum	3,067,063	-97,404	2,969,659	66	16	8	10
Tupelo and blackgum	3,586,932	6,144	3,593,076	77	12	6	5
Ash	471,183	-14,355	456,828	62	13	10	15
Cottonwood	136,056	305	136,361	69	18	10	3
Basswood	--	--	--	--	--	--	--
Yellow-poplar	914,192	-35,830	878,362	57	14	8	21
Bay and magnolia	15,565	584	16,149	71	--	10	19
Black cherry	6,437	-1,445	4,992	100	--	--	--
Black walnut	5,699	1,707	7,406	64	36	--	--
Sycamore	114,364	-28,433	85,931	75	--	4	21
Black locust	--	--	--	--	--	--	--
Elm	202,674	-10,621	192,053	69	13	6	12
Other eastern hardwoods	249,570	-10,851	238,719	73	6	5	16
All species	14,944,495	-692,151	14,252,344	63	13	8	16

Table C.21--Area of timberland, by ownership class, hurricane damage status, and previous stand type, for 23 counties in South Carolina

Ownership class and damage status	All stand types	Previous stand type				
		Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
		Acres				
Public						
No damage	112,503	26,721	51,762	12,895	10,667	10,458
Damaged	420,358	59,767	198,063	51,472	21,627	89,429
Total	532,861	86,488	249,825	64,367	32,294	99,887
Forest industry						
No damage	516,688	266,733	76,771	50,316	38,532	84,336
Damaged	1,092,775	449,281	166,864	79,131	68,046	329,453
Total	1,609,463	716,014	243,635	129,447	106,578	413,789
Nonindustrial private						
No damage	1,398,047	168,493	392,336	223,836	305,259	308,123
Damaged	2,995,604	237,671	887,980	414,759	545,058	910,136
Total	4,393,651	406,164	1,280,316	638,595	850,317	1,218,259
All ownerships						
No damage	2,027,238	461,947	520,869	287,047	354,458	402,917
Damaged	4,508,737	746,719	1,252,907	545,362	634,731	1,329,018
Total	6,535,975	1,208,666	1,773,776	832,409	989,189	1,731,935

Table C.22--Area of timberland, by broad management class and pre- and post-Hugo stocking percentage for manageable stand trees, for 23 counties in South Carolina

Broad management class and pre-Hugo stocking (percent)	All classes	Post-Hugo stocking (percent)								
		0-14	15-29	30-39	40-49	50-59	60-69	70-84	85-99	100+
	Acres									
Pine plantations										
0-14	50,543	50,543								
15-29	25,410	7,156	18,254							
30-39	15,305	--	--	15,305						
40-49	51,701	14,180	--	2,460	35,061					
50-59	54,082	9,807	12,947	7,607	2,336	21,385				
60-69	65,571	7,107	--	--	5,042	12,995	40,427			
70-84	177,808	14,534	7,955	18,665	22,167	10,352	14,423	89,712		
85-99	170,663	10,536	9,751	--	4,640	7,798	7,377	30,046	100,515	
100+	597,583	30,045	10,321	18,711	14,375	15,191	22,341	48,520	45,899	392,180
All classes	1,208,666	143,908	59,228	62,748	83,621	67,721	84,568	168,278	146,414	392,180
Natural pine										
0-14	395,308	395,308								
15-29	114,515	23,044	91,471							
30-39	104,214	14,936	9,803	79,475						
40-49	106,979	16,695	27,854	2,418	60,012					
50-59	159,892	30,020	16,804	21,605	21,631	69,832				
60-69	191,813	18,759	12,836	9,044	15,221	16,763	119,190			
70-84	254,364	44,771	12,012	16,622	20,774	7,494	39,407	113,284		
85-99	238,761	37,569	3,503	13,128	15,037	2,418	24,431	37,748	104,927	
100+	207,930	38,169	23,536	9,987	2,459	12,836	4,792	12,820	16,369	86,962
All classes	1,773,776	619,271	197,819	152,279	135,134	109,343	187,820	163,852	121,296	86,962
Oak-pine										
0-14	229,089	229,089								
15-29	99,555	14,036	85,519							
30-39	68,267	9,517	7,127	51,623						
40-49	76,258	9,378	2,460	24,072	40,348					
50-59	90,742	14,427	--	14,777	11,818	49,720				
60-69	64,006	4,465	16,716	6,989	7,493	4,635	23,708			
70-84	107,087	7,343	4,582	6,909	7,395	7,228	23,262	50,368		
85-99	53,347	--	--	2,396	8,280	2,259	11,106	5,903	23,403	
100+	44,058	4,696	4,506	2,679	2,396	4,582	--	6,978	7,513	10,708
All classes	832,409	292,951	120,910	109,445	77,730	68,424	58,076	63,249	30,916	10,708
Upland hardwood										
0-14	304,551	304,551								
15-29	86,758	9,461	77,297							
30-39	72,748	7,132	8,680	56,936						
40-49	84,101	8,921	9,925	2,336	62,919					
50-59	115,008	10,201	12,850	9,298	10,384	72,275				
60-69	109,474	14,278	9,686	7,282	16,904	11,248	50,076			
70-84	105,937	7,408	9,390	8,847	9,832	8,596	17,936	43,928		
85-99	65,449	2,186	--	4,847	3,639	2,478	5,469	21,000	25,830	
100+	45,163	2,336	--	--	--	--	5,076	--	2,489	35,262
All classes	989,189	366,474	127,828	89,546	103,678	94,597	78,557	64,928	28,319	35,262
Bottomland hardwood										
0-14	314,765	314,765								
15-29	103,439	30,867	72,572							
30-39	95,620	11,787	37,037	46,796						
40-49	99,121	15,036	16,799	21,388	45,898					
50-59	204,055	24,619	16,874	19,642	40,738	102,182				
60-69	198,596	11,850	24,145	30,135	27,598	50,028	54,840			
70-84	256,189	17,034	19,623	31,823	21,693	32,085	33,857	100,074		
85-99	188,591	9,517	12,268	14,327	17,595	9,415	19,813	37,191	68,465	
100+	271,559	14,237	6,996	9,774	6,996	12,329	12,231	35,754	54,436	118,806
All classes	1,731,935	449,712	206,314	173,885	160,518	206,039	120,741	173,019	122,901	118,806
All classes										
0-14	1,294,256	1,294,256								
15-29	429,677	84,564	345,113							
30-39	356,154	43,372	62,647	250,135						
40-49	418,160	64,210	57,038	52,674	244,238					
50-59	623,779	89,074	59,475	72,929	86,907	315,394				
60-69	629,460	56,459	63,383	53,450	72,258	95,669	288,241			
70-84	901,385	91,090	53,562	82,866	81,861	65,755	128,885	397,366		
85-99	716,811	59,808	25,522	34,698	49,191	24,368	68,196	131,888	323,140	
100+	1,166,293	89,483	45,359	41,151	26,226	44,938	44,440	104,072	126,706	643,918
All classes	6,535,975	1,872,316	712,099	587,903	560,681	546,124	529,762	633,326	449,846	643,918

HURRICANE HUGO: A SOUTH CAROLINA UPDATE

Allan P.C. Marsinko, Thomas J. Straka, and Jeffrey L. Baumann[1]

In September of 1989, Hurricane Hugo cut a wide swath of destruction from just north of Charleston, South Carolina, through Charlotte, North Carolina. This class 4 hurricane devastated more than one-third of South Carolina (Figure 1) as it took human lives, destroyed buildings, downed power lines, and damaged roads. The economic costs exceeded $5 billion.

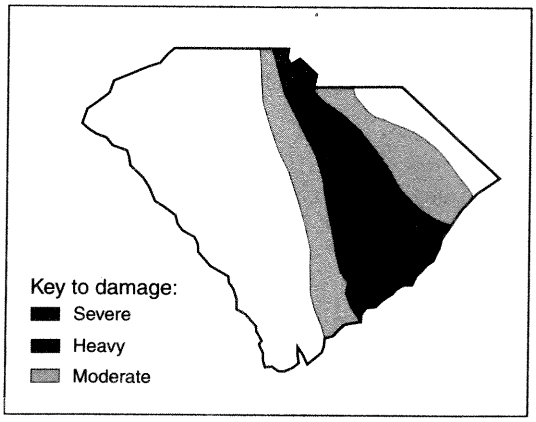

Figure 1--Path of Hurricane Hugo through South Carolina.

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Although many of the events of September 21 and 22 were widely publicized, the effect on forestland was less well known. The hurricane damaged more than $1 billion of timber and destroyed valuable wildlife habitat. The Francis Marion National Forest, which contained abundant mature timber and a thriving red-cockaded woodpecker population, was hit particularly hard. Across 23 counties, 32% of the pine and 22% of the hardwood were damaged--equivalent to four years of timber output. (Unless otherwise noted, information is based on current estimates by the South Carolina Forestry Commission.)

After immediate transportation and housing needs had been attended to, resources and concerns shifted to salvage and public safety due to fire danger. The next major concerns included fire prevention, reforestation, and rebuilding the economies of affected areas. More than three years later, we can begin to evaluate the effectiveness of these efforts.

FIRST STEPS

The forestry community reacted quickly. The South Carolina Forestry Commission began an aerial survey of the damage the day after the hurricane. Consultants immediately began conducting appraisals and sales. Forest industry undertook salvage efforts and attempted to identify methods of and locations for storing salvaged logs until they could be processed. State and federal agencies worked with salvage operations and information-gathering. State agencies provided salvage, price, and tax information.

On September 23, South Carolina State Forester Jack Gould declared a forest disaster and requested an emergency meeting of the Foresters Council, an organization of state forestry leaders. As a result a salvage plan was drawn up and the governor's office was contacted for assistance. Governor Campbell issued an executive order on October 5 creating the Governor's Forest Disaster Salvage Council to coordinate efforts to harvest and salvage damaged timber, with an emphasis on recovering as much as possible.

Four subgroups were established. The Utilization Committee had responsibility to "move the wood." It contacted in-state and out-of-state timber companies in order to increase utilization of damaged wood. Sprinkler systems and water storage systems for timber were encouraged. The committee coordinated logging crews, chip exports, and rail and highway transportation.

The Information Committee developed a network to inform residents, landowners, and the general public about salvage efforts. The Government Affairs Committee supported state and federal legislation to enhance salvage operations and forest regeneration. For example, it worked to temporarily increase gross weight limits for log trucks; promoted congressional action to give financial assistance to landowners; and obtained regulatory exemption for temporary sprinkler and water storage permits. The Statistics and Monitoring Committee established a data collection system to monitor salvage operations.

SALVAGE OPERATIONS

More than $1 billion worth of timber was damaged (Table 1), though figures vary according to differing assumptions about what constitutes a loss. The hurricane caused considerable loss of sawtimber value, as much had to be processed as pulpwood or composition products. In addition, growing stock decreased significantly in average volume per acre (Figure 2) and net annual growth (Figure 3), with the Francis Marion National Forest most severely affected.

In response to a critical shortage of loggers and processing facilities, a top priority for the Salvage Council was recruiting out-of-state loggers and finding out-of-state markets. But difficult and dangerous working conditions, along with unusually wet weather, made recruiting and retaining loggers a problem.

Hugo left many areas covered with large timber debris, which prevented traditional mechanized harvesting. Helicopter logging was minimal. The relatively slow rate of chainsaw harvesting, the vast amount of damaged timber, limited availability of harvesting crews, and restrictions imposed by wet sites combined to decrease the amount of wood salvaged. Slightly more than 25% of the damaged wood was salvaged following Hurricane Camille on Mississippi's Gulf Coast in 1969. Because Hurricane Hugo caused more damage than Camille and wood-handling

Table 1--Damage to timber in South Carolina from Hurricane Hugo.

	Volume		Dollar value	
	Sawtimber (mbf)	Pulpwood (cords)	Sawtimber	Pulpwood
Pine	6318,892	6,130,620	890,964,000	91,959,000
Hardwood	3,984,003	7,038,029	163,341,000	35,190,000
Total	10,302,895	13,168,649	1,054,308,000	127,149,000

Source: South Carolina Forestry Commission data.

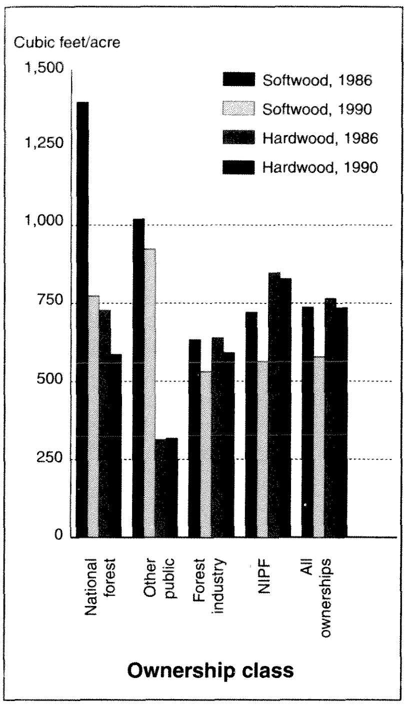

Figure 2--Average volume per acre of growing stock by owner and species in areas affected by Hurricane Hugo (Egbert and others 1992).

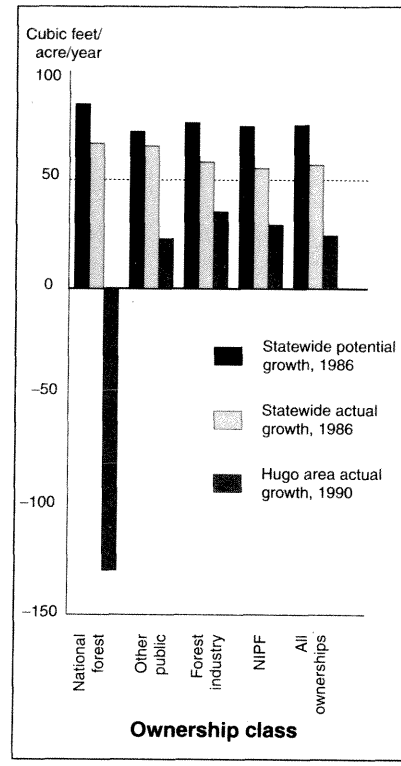

Figure 3--Effect of Hurricane Hugo on South Carolina timberland productivity in 23 counties (Egbert and others 1992). Potential growth based on Forest Survey definition of net annual growth.

facilities were not proportionally greater, the salvage goal was set at 25% (625 million cubic feet) of the original rough damage estimates. Overall, 62% of this goal was met (Table 2)--or 15% of the total damage.

The increased logging activity amid hazardous conditions resulted in eight deaths by March 1990 (South Carolina Forestry 1990). This is about four times as many deaths as would normally occur during the same period. However, it should be noted that considerably more wood than usual was removed during this period. Also, at least two of the eight deaths appear to have occurred in residential areas, and one occurred when a log rolled off a truck (pers. commun., J. Knight, Occupational Safety and Health Administration, Columbia, South Carolina, 1993). Two additional deaths were associated with helicopter logging, a technique not often used in this area.

Of the wood salvaged, 49% came from the forests of nonindustrial private owners; 18% came from public land; and 13% was salvaged from industry acres. The source of the remaining 20% is not known. About 90% of the salvaged timber was used in-state.

Table 2--Volume of salvaged timber (387,450,045 cubic feet) relative to salvage goal (625,000,000 cubic feet).

	Volume	Percent of goal
Softwood		
Sawtimber (mbf)	797,130	99.64
Pulpwood (cords)	2,090,376	106.65
Hardwood		
Sawtimber (mbf)	64,365	10.38
Pulpwood (cords)	507,726	15.16

Source: South Carolina Forestry Commission data.

Activity in the timber market affected nonindustrial private forest (NIPF) landowners' ability to salvage wood. Those who had not sold timber within the last few years were at a disadvantage in securing contracts (Nodine 1992).

Landowners who tried to salvage timber were often dissatisfied with logger performance and damage to residual trees. Market conditions were poor, and owners suffered financially. Higher logging costs, the extent of the damage, and the nature of the damage (which changed much sawtimber into a lower quality product) resulted in stumpage prices dropping to 20%-50% of prehurricane levels. Immediately after the storm, a few landowners gave their timber to loggers just to get the land cleared.

WET STORAGE OF SALVAGED LOGS

One of the first concerns of the Governor's Forest Disaster Salvage Council was securing facilities for wet storage of salvaged logs, since the large volume of harvested logs was expected to exceed the short-term capacity of converting plants. Industry was asked to identify potential storage areas (rock quarries, lakes, ponds, dry-land sprinklered sites) that could be reached by truck or rail. By December 1989, 30 potential sites had been identified with a total storage capacity of 160 million board feet, or 20% of the anticipated pine salvage volume of 800 million board feet. The South Carolina Department of Health and Environmental Control temporarily allowed mills to bypass the permit procedure for specified sprinkler systems.

By the end of 1989, however, few logs had been placed in water storage. Wet weather hampered logging, so mills were able to process almost all of the logs harvested. Response increased in 1990, and an estimated 140 million board feet of salvaged pine logs and 6 million board feet of hardwood logs were stored under sprinklers. Logs were typically stored in rows or piles 10-25 feet high. Standard irrigation sprinklers applied a continuous spray. Logs were normally stored for several months, and in some cases more than one year, before being processed.

Sprinkler storage proved to be an effective and low-cost retention method. As long as enough water was applied to maintain the required moisture levels, it prevented insect and fungal attack on freshly harvested logs and stopped further activity on logs infested prior to storage. No serious problems were encountered in processing these logs into lumber, veneer, and plywood, and no product degrade could be attributed to sprinkler storage (Syme and others 1992).

REFORESTATION

About one-quarter of the damaged area required reforestation (Table 3). This required a major commitment of resources. Most of the damage--and most of the area in need of reforestation--belonged to NIPF landowners. By mid-1990, 81% of NIPF landowners had not made plans for reforestation. Most of those who attempted to salvage timber felt reforestation was necessary and were interested in doing so, but felt they should not have to bear the full cost (Nodine 1992).

Table 3--Effects of Hurricane Hugo on South Carolina forestland.

Ownership class	Acres affected	Acres needing reforestation
Nonindustrial private landowners	2,995,604	720,100
Forest industry	1,092,775	263,600
Public	420,358	173,400
Total	4,508,737	1,157,100

Source: Sheffield and Thompson 1992.

NIPF owners were offered a free reforestation examination via the Hurricane Hugo Technical Assistance Program ("Gimme Green"). The federal government provided $5 million to promote reforestation and give technical assistance. More than 1,000 landowners requested the free exams for 310,000 acres. By the summer of 1992, state service foresters and 24 contracted consulting firms had serviced all requests. Of 223,000 acres inspected, 82% were in pine; of these, 54% were adequately stocked; 2% were understocked but could be rehabilitated; 21% had or could be managed for natural regeneration; and 23% needed artificial reforestation. The second phase of Gimme Green, begun in January 1993, offered a free reforestation exam to every landowner with more than 10 acres in an eight-county area. By the end of February 1993, 1,000 additional requests had been received.

The Hugo Incentive Program (HIP), designed and administered by the Forestry Commission, provided $3 million in federal funds as direct cost-share assistance for NIPF landowners affected by Hurricane Hugo. It paid approximately 75% of the total reforestation cost. During a two-week period in March 1991, 1,017 individuals applied for assistance under HIP, requesting more than $16 million. As of February 1993, 534 requests had been funded for $3 million, and almost $2 million had been paid to landowners who completed the work. Congress has appropriated an additional $3 million for this program, thus finding an additional 382 requests. By June 1993 there were 1,180 requests.

Reforestation costs are higher than normal due to the large amounts of residual vegetation. Mechanical site preparation costs were higher than on undamaged lands, and they rose with increased residual vegetation (Marsinko and others 1993). Chemical site preparation costs tended to be about average, although they also rose with increasing levels of residual vegetation.

Hurricane Hugo changed NIPF landowners' attitudes (Nodine 1992). About one-third had relied on their forestland as a primary or secondary source of income. After Hugo, income expectations shifted farther into the future or disappeared altogether. Land use priorities shifted from timber production to holding the land as an investment. Private owners had problems arranging timber salvage operations and were not expected to make large capital expenditures to reforest their lands.

SUBSEQUENT HAZARDS

As mentioned earlier, much of the damaged wood was not or could not be salvaged. This increased the danger of fire and insect infestations. The fire danger was and still is significant, with the potential to damage dwellings and commercial structures as well as timber. After the salvage operation more than 2 billion cubic feet of damaged timber remained available as fuel. Fires in this debris could jeopardize remaining merchantable and unmerchantable timber. The South Carolina Forestry Commission acted to reduce the risk by restricting or banning outdoor burning and by plowing massive firebreaks. The commission received approximately $15 million from the Federal Emergency Management Agency (FEMA) to lease additional fire suppression equipment and heavy equipment to plow firebreaks through downed timber. Almost 5,000 miles of firebreaks involving 6,000 landowners were established to protect 94 communities.

The state also instituted programs to heighten public awareness of fire danger and reduce the incidence of fires. One of these, Gimme 12 ("Give me 12 months of minimal wood or debris burning"), was an extensive fire prevention campaign financed by $1 million from FEMA. With paid media advertising, direct mail to affected residents, student packets, and a complete range of promotional products and events, it has been described as one of the most intensive fire prevention campaigns in the history of the United States.

During the four years prior to the hurricane, the counties most extensively damaged by Hugo had the highest arson rates. In the two years following the hurricane, the percentage of incendiary fires was lower overall. The percentage of fires caused by debris burning increased (mostly in the extensively damaged area), probably due to the fuel buildup. However, the number of fires per year was lower throughout the state (Table 4).

The risk-reducing actions were aided by two relatively wet seasons following Hugo. In addition, destruction of trees caused the water table to rise and the soil to become more moist than usual, which may have further reduced the risk.

ECONOMIC EFFECTS

The long-term impact of Hurricane Hugo is expected to be significant. The

Table 4--Mean annual number of fires before and after Hurricane Hugo.

	Fires per year, 1986-89	Fires per year, 1990-91	% change
Extensive damage	1,463	1,110	-24
Moderate damage	480	387	-19
Light damage	1,447	1,034	-29
Total (affected area)	3,390	2,531	-25
State total	5,480	3,852	-30

Source: South Carolina Forestry Commission annual reports for 1986-91.

buying radius of most of the 43 sawmills in the affected area is 75 miles or less. The entire buying area of some sawmills was within the damaged zone. Although not all the timber was destroyed, three mills had closed by mid-1992 and others are expected to follow (Syme and Saucier 1992). Pulp mills in the affected area reacted quickly to ensure their supply by establishing or increasing procurement activities in the undamaged areas of South Carolina, as well as in Georgia and North Carolina.

Figure 4 and Figure 5 illustrate the price relationships for pine sawtimber and pulpwood before and after Hugo. One plausible explanation for the numbers is offered here. Although damage was confined to the midlands and the coastal plain, prices were affected statewide. Immediately after the hurricane, prices in the most affected areas dropped by half. Hugo flooded the market with timber, likely forcing prices downward. But prices rose the following year. Unusually large quantities of timber entered the market when Hugo hit; many mills may have expected a decreased future supply--a timber glut in one year resulting in a shortage (or perceived shortage) the following year--so prices rose. Prices later approached pre-Hugo levels as the market began to stabilize and other sources of timber became apparent.

Even though the upland area of the state was spared by Hugo, prices appear to have been affected in similar ways. Sawtimber from the coastal plain usually does not find its way into the upland area, but some upland sawmills did process salvaged timber. This could have lowered upland sawtimber prices, although upland prices fluctuated considerably just prior to Hugo. The confusion and uncertainty could have contributed to

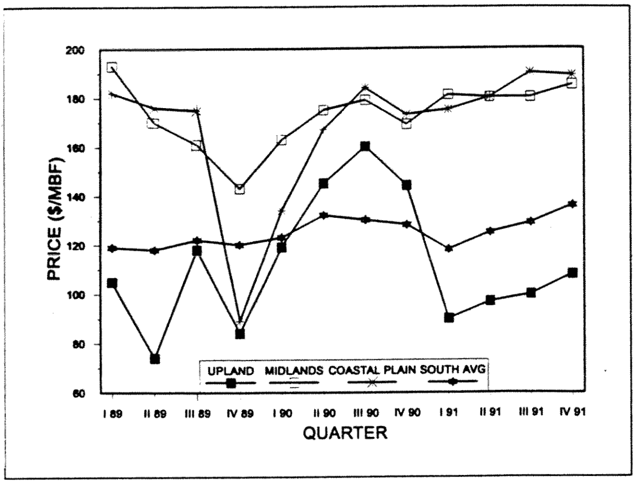

Figure 4--Pine sawtimber prices before and after Hurricane Hugo (Timber Mart South 1990, 1991, 1992).

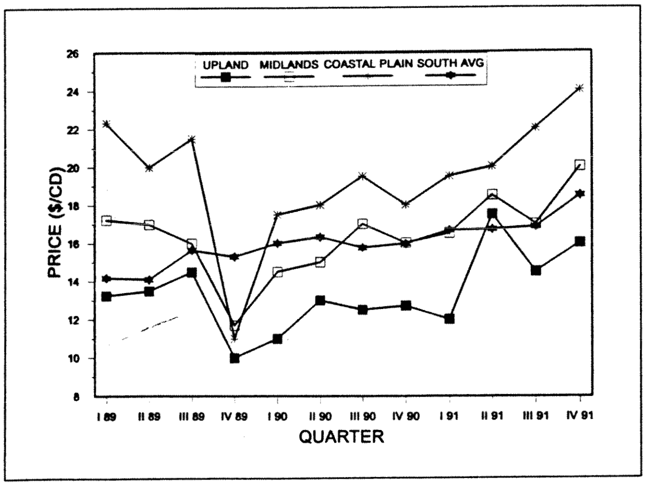

Figure 5--Pine pulpwood prices before and after Hurricane Hugo (Timber Mart South 1990, 1991, 1992).

the disproportionate rise in upland prices the year after Hugo, which disappeared as quickly as it appeared.

Pulpwood in the upland area is routinely shipped to mills in the area affected by Hugo. The glut caused by Hugo temporarily decreased the need for this pulpwood, and upland prices dropped. The longer term shortage caused pulpwood prices to increase in the affected areas and more pulpwood was purchased from the upland area, driving prices higher.

Post-Hugo harvesting costs were higher than normal, which would reduce stumpage prices for sawtimber and pulpwood. Anticipation of splits and breaks in lumber would be expected to result in lower delivered prices for logs (Lupold 1993) and would, in turn, reduce stumpage prices for sawtimber.

Nearby processors whose timberlands were not affected benefitted from the hurricane. They were able to buy salvaged timber at depressed prices while holding their own timber for future use--when prices were higher due to the expected shortage. These purchases enabled more timber to be salvaged than would otherwise have occurred and might have provided some price support for damaged timber.

The net effect in South Carolina, however, is expected to be negative. It will take years before timber production in the affected region approaches prehurricane levels. Some small and medium-sized mills will close, removing their economic benefits from rural communities. Larger, diversified mills and pulp mills should survive, even though their costs might be higher and community benefits lower.

WILDLIFE AND RESEARCH

Hurricane Hugo had a devastating impact on the Francis Marion National Forest red-cockaded woodpecker (RCW) population. Prior to the hurricane, the forest had 477 family groups of RCWs and was considered to have the healthiest population in the world (Hooper and others 1991). Hugo destroyed 87% of the RCW cavity trees and more than 50% of the pine sawtimber used as foraging habitat and for cavity trees. Sixty-three percent of the birds were killed (Hooper and others 1990).

As the result of a coordinated restoration effort, the RCW population has made considerable progress in the last three years (Watson and others, in press). Timber salvage operations were designed to aid the RCW by retaining all pines greater than 10 inches in diameter that were leaning less than 45 degrees and still had a crown. Salvage also reduced the heavy fuel loads. Prescribed burning, a critical part of RCW management, was almost back to pre-Hugo levels by 1992.

To replace lost cavities, three methods were used: drilling new cavities, drilling startholes (Copeyon 1990, Taylor and Hooper 1991), and placing wooden inserts directly into living trees (Allen 1991). About 300 of each type were created, and 80% are currently used (Carlson 1991). The RCW population has now increased from about 100 family groups immediately after the storm to 320 family groups. The effect of Hugo on foraging habitat is still being analyzed.

Gray squirrel populations were also severely affected. In general, however, heavy wildlife mortality was not documented. Cely (1991) concluded that Hugo's primary effects on wildlife will result from alterations to coastal and forested habitats. The openings created by Hugo will help some species and harm others; and some will benefit at the direct expense of others.

Some species, including the principal game animals, received a mixed blessing. Deer, for example, will find more browse created by increased openings, but will suffer during the winter from the loss of mast-producing trees. Turkeys have lost hard mast-production and roosting sites, but their poults should benefit from increased insect production in blowdown areas. Thus Hugo could present future challenges to game managers.

Hugo and other catastrophic occurrences reveal the risks associated with current methods of protecting rare and endangered species. When these are confined to a few protected areas, the destruction of one such area can severely damage an entire population.

As it moved through South Carolina, the hurricane's path also crossed experimental forest areas containing ongoing research projects. On the Santee Experimental Forest, nine long-term studies accounting for 221 research years were prematurely terminated (Hook and others 1991). As a result of the hurricane, however, a number of new studies were initiated, ranging from meteorological and biological aspects to economic effects to building design.

LESSONS LEARNED

Much of the response to forest damage was based on documentation from Hurricane Camille 20 years earlier. There will be other hurricanes, and they will damage forests. Information about Hugo will likely be used when these occur.

Based on experience to date, it is apparent that more funds would have benefitted the reforestation effort.

It is also becoming clear that reforestation following a disaster should be a long-term effort. Hurricane Hugo devastated homes and other property as well as forests. Initially, repairs to houses and other facilities along with timber salvage took priority. As a result, some NIPF landowners are just beginning to consider regeneration.

One of the principal lessons taught by Hugo was that planning prior to a disaster is extremely important. A salvage plan would have helped. Salvage Council member Lupold (1993) noted that a computerized database containing information about forestry and wood products organizations and landowners would have saved the council four to five weeks by facilitating the gathering of information. Syme and others (1992) indicated that the lack of planned water storage sites was a significant problem and recommended that wet log storage facilities be part of a disaster plan.

Plans that include a disaster response manual, up-to-date databases, and a compilation of disaster-related research would be of immense value. To maintain their value, plans should be updated periodically. Land use and regulations change. Technological changes can affect the use of computerized databases as well as logging methods. For example, much of the wood salvaged from Hurricane Camille was cut by shortwood loggers. Wood damaged by Hurricane Hugo was often well suited to this type of logging, but few shortwood loggers were available by 1989.

Immediate and extensive action on the part of many people resulted in the salvage of much timber. Quick and effective action saved many red-cockaded woodpeckers. Continuing efforts have reduced the risk of fire and enhanced reforestation efforts. The wildlife population is recovering and adapting to its altered environment. Reforestation has begun and forest industry is adapting to changes in the forest and the timber market.

More than three years later, salvage operations have concluded but reforestation efforts continue. The most obvious lesson is that a disaster response plan, continually updated, could have helped responses to Hurricane Hugo and would be valuable if--or when--the next disaster strikes.

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EFFECTS OF HURRICANE HUGO ON THE FORESTS OF NORTH AND SOUTH CAROLINA[1]

Michael T. Thompson[2]

Abstract--The reinventory indicates that 4.5 million acres of timberland in a 23-county area in South Carolina, and 1.6 million acres in a 27-county area in North Carolina were damaged by Hurricane Hugo (Sheffield and Thompson 1992). Significant damage occurred in 55 percent of the pine plantations, 60 percent of the natural pine stands, 55 percent of the oak-pine stands, 43 percent of the upland hardwood stands, and 74 percent of the lowland hardwood stands. Lowland hardwood stands typically contain large shallow-rooted trees with large crowns, which are highly susceptible to wind damage. Public timberland in South Carolina suffered a very high rate of damage (79 percent). Much of the National Forest land in the study area was in the direct path of the hurricane. The pre-Hugo inventory of softwood growing stock was reduced by 16 percent to 6.2 billion cubic feet; and the pre-Hugo inventory of hardwood growing stock by 4 percent to 9.9 billion cubic feet in the 50-county area. The reductions in inventories of both softwoods and hardwoods were most severe on public land. Large-diameter trees suffered a higher rate of mortality and damage than smaller trees. Of the 6.2 billion cubic feet of softwood growing stock that survived the storm, 20 percent, or 1.2 billion cubic feet, was damaged to some extent. Almost 0.7 billion cubic feet were in trees classed as moderately to severely damaged. Nearly 1.8 billion cubic feet, or 18 percent, of the hardwood inventory after Hugo was damaged. About 12 percent of the hardwood volume was in trees with moderate to severe damage. As a result of the hurricane, an additional 1 million acres of timberland in South Carolina and 0.4 million acres in North Carolina were identified as needing regeneration.

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[1] A paper presented at the 72nd Annual Meeting of the Appalachian Society of American Foresters held in Greenville, SC, on January 20-22, 1993.
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ASSESSMENT OF HURRICANE HUGO DAMAGE ON STATE AND PRIVATE LANDS IN SOUTH CAROLINA

Michael C. Remion[1]

INTRODUCTION

Hurricane Hugo has been labeled the most economically devastating natural disaster ever to strike the continent of North America. The damage to timberlands alone in South Carolina exceeds the combined losses of timber caused by Hurricane Camille and Frederick, the Yellowstone fires of 1988, and the volcanic eruption of Mount St. Helens. The magnitude of devastation caused by Hugo is incomprehensible! In South Carolina, the storm left in its wake; 41 deaths, 5,343 homes destroyed with another 18,600 sustaining major damage, 18,000 miles of roads and highways blocked by downed timber, and the destruction of enough timber to construct 660,000 new homes. total damage in South Carolina is estimated at $5 billion. The use of aerial, infrared photography provided by the United States Forest Service (USFS) will be an invaluable resource in assessing damage caused by the storm and planning rehabilitation efforts related to the storm.

DAMAGE ASSESSMENT

Timber

Hurricane Hugo struck South Carolina's coast on Friday, September 22, 1989 at 12:01 A.M., Eastern Standard Time. The eye of the storm hit the Isle of Palms located approximately seven miles due east of Charleston, South Carolina. The intensity of the storm was rated as a category 4 with sustained winds of 139 miles per hour (mph). After entering the mainland, the storm followed a northward track passing through Sumter, SC, located 90 miles inland, and travelled onward to Charlotte, NC, located approxi-mately 190 miles north-northwest of the Isle of Palms. Windspeed was measured at 109 mph in Sumter, SC

On the afternoon of September 22, 1989, the South Carolina Forestry Commission (SCFC) began initial timber damage appraisals using two light aircraft employing the aerial sketch-mapping technique. Flight line intervals were 5 strips on both sides of the aircraft. The damage categories recorded were no damage, light, moderate and heavy timber damage. The aerial surveys were completed on September 24, 1990. Tables 1 and 2 reflect the findings of these surveys relative to the estimated impact of the storm on the timber resource and subsequent timber landmass in South Carolina.

Approximately 36% of South Carolina's total 12.2 million acres of forested land was damaged by the hurricane. A total of 23 counties received varying degrees of timber damage encompassing 60 percent of the total land base in the state. The damage to sawtimber represents 2.5 and 16 years worth of annual pine and hardwood timber harvest, respectively. Of the total merchantable hardwood and pine inventory in South Carolina, Hugo destroyed:

- 10% of the pine sawtimber
- 13% of the hardwood sawtimber
- 5% of the pine pulpwood
- 18% of the hardwood pulpwood

Reforestation

Reforestation needs relative to the storm's damage are displayed in Table 3.

Of the 4.4 million acres of forested land impacted by Hugo, 1.3 million acres were totally destroyed and will require reforestation. The rehabilitation of damaged timberlands through reforestation will be a monumental task. Several Hugo bills addressing reforestation assistance are presently pending in the United States Congress. They are:

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[1] South Carolina Forestry Commission, P. O. Box 21707, Columbia, SC 29221.

Table 1--Timberland damaged by Hugo.*

Degree of Damage	Number of Counties	Acres	Percent of Total
Heavy	7	1,130,000	25
Moderate	3	1,260,150	29
Light	13	2,045,113	46
TOTAL	23	4,435,363	100

* (Ownership pattern: 64% private, 10% government, 26% industry)

Table 2--Hugo timber damage assessment.

Product	Units	Value
Pine Sawtimber	3,305,000,000 bd.ft.	$ 581,603,692
Hardwood Sawtimber	3,457,000,000 bd.ft.	231,591,882
Pine Pulpwood	4,249,000 cords	63,736,517
Hardwood Pulpwood	16,001,000 cords	80,003,672
Young Growth Estimate	unmerchantable	83,954,672
TOTAL	----------	$1,040,890,335

Table 3--Reforestation needs related to Hugo.

Ownership	Acres Damaged	Acres Requiring Reforestation
Private Landowners	2,409,845	679,195
Forest Industry	1,143,595	336,874
Other Corporate	436,082	132,098
State Ownership	131,868	42,883
Federal Ownership	313,973	140,736
TOTAL	4,435,363	1,331,786

- The Hugo Reforestation Act which provides authorization for $100 million in cost-share assistance to landowners wishing to re-establish timber stands damaged by the hurricane.

- The Emergency Reforestation Act (5.2043) which provides for a long-term $300 million program to help reforest timberlands damaged by Hugo, a cost-sharing program to pay 75 percent of reforestation costs to owners of timber stands that suffer damage due to a natural disaster, and the establishment of an Emergency Reforestation Committee to develop subsequent program regulations.

- The Hurricane Hugo Tax Assistance Act (5.1748) which provides for a deduction for timberland owners based on the fair market value of the timber, the amortization of reforestation expenses up to $30,000 and the proceeds from the sale of damaged timber be treated as an "involuntary conversion" so the proceeds can be reinvested in reforestation.

Insects and Disease

The area of immediate concern to forest managers following the hurricane was the invasion of damaged timber by various insect- and disease-causing organisms. Of particular concern was the rate of infestation of damaged pine timber by engraver beetles and blue stain fungi. Historically, these two organisms, through their mode of action, have been responsible for hastening the loss of product utility of pine sawtimber following hurricane damage.

To monitor the activity of these pests, the SCFC and the USFS, Forest Pest Management, established 12 plots in the damaged area. Figure 1 illustrates the rate of infestation over a 5-month period.

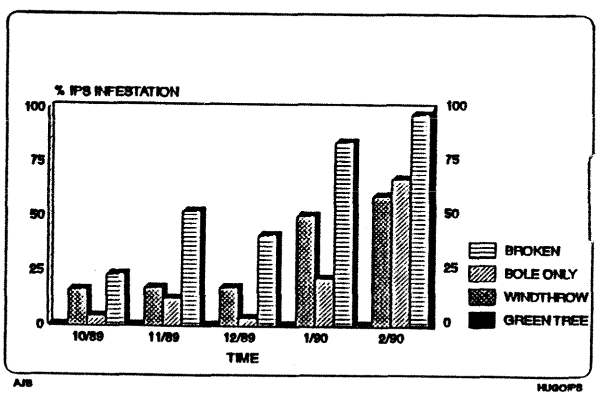

Figure 1. Pine infestation by Ips and blue stain after Hugo.

Due to unseasonably warm weather during January and February, the rate of infestation dramatically increased. It is estimated that this increase will result in the loss of 2 months' salvage longevity of the pine timber. Other pests being monitored in the Hugo area include black turpentine beetle, southern pine beetle, reproduction weevils, and annosus root rot.

Salvage

On September 23, 1989, a forest disaster was officially declared in South Carolina. Subsequently, the Governor of South Carolina created the Governor's Forest Disaster Salvage Council on October 6, 1989. The primary objective of the council is to promote effective use of the destroyed timber through public awareness and open communications between affected landowners, cooperating agencies, and the forest industry.

The results of salvage efforts through mid-March, 1990 are displayed in Table 4.

Due to the rapid invasion of insect and disease organisms, it is estimated that major salvage efforts will subside by late June, 1990. It is presently estimated that only 15 percent of the total damaged timber will be salvaged at the culmination of the project.

Table 4--Hugo timber salvage as of March 14, 1990.*

Product	Damaged Units	Salvaged Units	% Salvaged
Pine Sawtimber	3,305,000,000 (bd. ft.)	408,442,710 (bd. ft.)	12.4%
Hardwood Sawtimber	3,457,000,000 (bd. ft.)	26,762,820 (bd. ft.)	.8%
Pine Pulpwood	4,249,000 (cords)	1,035,865 (cords)	24.4%
Hardwood Pulpwood	16,001,000 (cords)	214,838 (cords)	1.3%
TOTAL	-------	-------	9.2%

* (Sources: 71% private, 14% industry, 15% government)

Fire

Through the assistance of Federal Emergency Management Act (FEMA) funds, the SCFC has launched a major forest fire prevention and suppression campaign. This is a combined effort of many state, federal, and local agencies to prevent the loss of life and property within the Hugo area. This federally funded project is scheduled to end on September 30, 1990.

APPLICATIONS OF AERIAL PHOTOGRAPHY

On October 4, 1989, the USFS Aerial Survey Team (Region 8, Atlanta, Georgia) began photographing counties impacted by Hugo. The survey team has completed photography in 15 of the 23 affected counties. The photography is color, infra-red taken at a scale of 1:12,000. The primary purpose of the aerial photographic mission is to provide photography for current and future assessment of insect and disease impact on the timber resource within the Hugo area. However, this photography has proven to be a valuable resource for a diversity of other uses by private landowners, forest managers, and agencies dealing with various facets of Hugo's destruction.

Some additional applications of the Hugo aerial photography are:

- Stream bed rehabilitation (SCS - USDA)
- Forest Inventory Analysis (USFS - USDA)
- Casualty loss determination
- Insurance claims documentation
- Reforestation efforts - federal and state subsidy programs
- Fuels management (fire prevention)
- Fire suppression
- Tax re-assessment
- Road maintenance and rehabilitation
- Sand dune renourishment
- Historical reference
- Timber Salvage - debris removal

ACKNOWLEDGMENTS

On behalf of the citizens of South Carolina, I want to thank the many people from across this country and abroad for assisting the Hugo victims in our state. These people gave freely of their time, talents and financial resources to help us recover from this devastating storm. The assistance of the many USFS employees who detailed to South Carolina to assist in the rehabilitation efforts is also greatly appreciated. Special appreciation is extended to the USFS Aerial Survey Team, Forest Pest Management, Region 8, Atlanta, Georgia. This team has made many personal sacrifices and worked under strenuous conditions to provide the forest landowners in South Carolina with resource photography. Their cooperative spirit is to be commended!

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HURRICANE HUGO—DAMAGE ASSESSMENT USING PERMANENT PLOT REMEASUREMENT[1]

Raymond M. Sheffield[2]

Abstract--A network of 3,500 permanent ground plots was utilized to assess damage from a major hurricane that struck the Southeastern United States in 1989. Hurricane Hugo inflicted varying degrees of forest damage across an area of 4.4 million hectares. This paper summarizes data collection and analytical procedures used to assess forest damage across this area. Results that are easily provided from remeasurement of permanent plots are highlighted. Advantages and disadvantages of ground-based permanent plot assessment systems are highlighted.

INTRODUCTION

Hurricane Hugo struck the Southeastern United States in September 1989 with winds of 217 kilometers per hour, or 60 meters per second (Powell, Dodge, and Black 1991). Hugo extensively damaged forest stands in North Carolina and South Carolina. It significantly altered forest conditions and inventory volumes and rendered many short- and long-term forestry resource programs obsolete. Forestry agencies in the two states conducted aerial and ground reconnaissance surveys to determine the extent of the damage. Their observations and subjective estimates were adequate for planning initial responses, but they needed more quantitative measures for long-term planning.

The South Carolina Forestry Commission asked the Forest Inventory and Analysis (FIA) Research Work Unit at the Southeastern Forest Experiment Station to conduct a special inventory of forests in that state's affected area. This damage assessment was later expanded to include a large portion of North Carolina (Figure 1). The area of timberland in the study region totaled 4.4 million hectares. Utilizing a previously established network of permanent ground plots throughout this region, FIA designed damage inventory procedures to: (1) quantify the extent of damage and describe associated stand conditions, (2) determine the volume of hurricane-related mortality and damage to live trees, and (3) provide an estimate of current inventory volume.

METHODS

FIA is a research activity of the USDA Forest Service. Its mission is to comprehensively inventory the status and trends of the country's diverse forest ecosystems, their use, and their health (U. S. Department of Agriculture, Forest Service 1992). Six regional FIA units maintain a network of permanent samples on forest land across the United States. More than 3,500 of these permanent plots were in North and South Carolina counties damaged by Hurricane Hugo. Prior to the hurricane, these ground plots had been visited and measured last in 1984 in North Carolina and 1986 in South Carolina.

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[1] A paper presented at the IUFRO Conference on Inventory and Management in the Context of Catastrophic Events, University Park, PA, on June 21-24, 1993.

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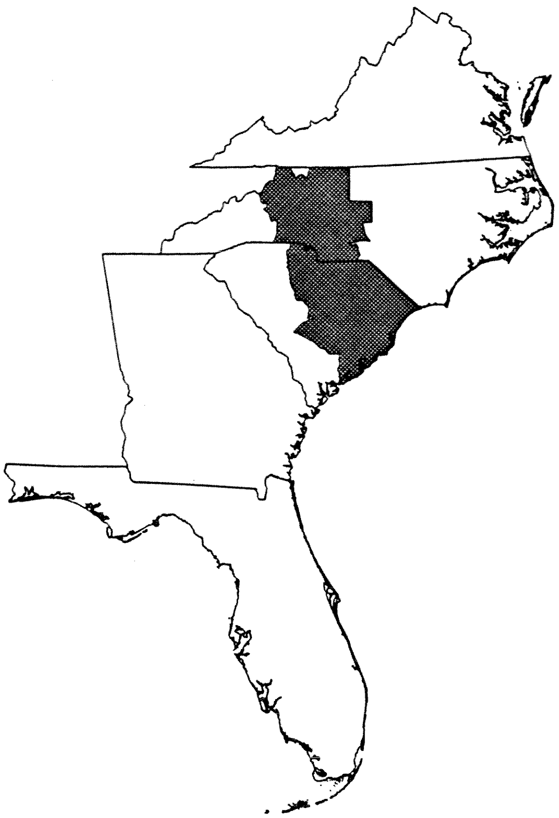

Figure 1--Area in North Carolina and South Carolina reinventoried for hurricane damage to timberland.

Field Procedures

Data collection procedures are briefly summarized in this paper; details are available in a report by Sheffield and Thompson (1992). Two-person crews visited each sampling location in 1990, 5 to 9 months after Hurricane Hugo struck. Each tree above a minimum diameter at 1.4 meters above the ground was relocated. The minimum diameter used was 7.6 centimeters for trees in natural stands and 2.5 centimeters for trees in planted stands. Each tree was assigned one of the following six tree histories:

- tree alive without hurricane damage
- tree alive with hurricane damage
- tree dead (hurricane related)
- tree dead (other causes)
- tree cut, associated with hurricane salvage efforts
- tree cut, associated with normal harvest operations

For all live trees with hurricane damage, specific classes of damage were noted. Damage classes were:

- leaning or bending (degrees from vertical)
- root system damage
- damage to tree bole
- loss of tree crown

Any combination of these could be assigned to a tree; multiple damages, such as severe lean and exposed root systems, were common.

Analytical Procedures

Standard protocols for the analysis of data from a damage inventory are not available. One must adjust methods to account for the magnitude of loss and the specific goals that have been specified. After Hugo, we wanted to quantitatively estimate damage to individual trees and to stands of trees. Little published data were available in the literature to assist in this process, so various approaches to solving these problems were used.

In a ground-based damage inventory, the types of damage to individual trees must be categorized. Damage may be so minor that the tree's value, growth, and probability of survival are not affected. Conversely, damage may be so severe that the tree's value has been destroyed, its growth potential reduced to a fraction of normal, or its survival chances severely reduced. Guidelines for assigning meaningful categories of damage were not found in the literature, so we developed our own classification framework. Our design permits decisions about individual trees to be made on the basis of value, likely contribution, and development in the future. Detailed criteria for assignment of softwood and hardwood trees into four damage categories were developed and modified based on review by more than a dozen individuals. Sheffield and Thompson (1992) describe the process and the criteria. Here I present the damage/risk classes used and a brief description of levels of tree damage in each class.

Class 1. High-risk tree with a high probability of dying in the near future. Damage and value loss are severe enough that this tree should not be retained in the stand.

Class 2. Moderate-risk tree with elevated risk of mortality. Damage and value loss are substantial enough to make the retention of this tree in the stand questionable. Retention depends upon management objectives, stand and rotation age, and product objectives.

Class 3. Low-risk tree with a high probability of survival. Damage elevates the risk of mortality slightly, but reduced growth and value degrade are minimal. This tree should be retained in the stand under most management scenarios.

Healthy. No obvious hurricane damage. A tree with hidden or internal damage would be classed as healthy.

The assessment of stand conditions depends on the condition of individual trees remaining in the stand. Thus, the decision to regenerate or salvage requires sound judgments about individual trees and about the level of residual stocking needed for an acceptable stand. One must also determine which categories of damage are acceptable for inclusion in minimum residual stocking. In the analysis of damage from Hurricane Hugo, I used the three broad categories of damage to trees in different ways to estimate lower- and upper-bound values for timberland area by condition class and treatment opportunity. For example, in South Carolina the estimate of timberland area needing regeneration because of Hurricane Hugo ranged from 328,000 to 623,000 hectares depending on which live tree damages were used to discount existing stocking in the stand (Sheffield and Thompson 1992).

RESULTS AVAILABLE FROM PERMANENT PLOTS

Damage inventories utilizing permanent plot remeasurement can provide a wealth of information to the resource manager or analyst. The classifications and resource items that can be displayed depend in part on the classifications that have been made prior to the damage event. Forest type and age, for example, are sometimes difficult to assess after severe damage or salvage has occurred. The following is a brief summary of the kinds of results that were available in the Hurricane Hugo damage assessment.

(1) Areal extent of damage. Timberland area damaged can be estimated and displayed for political or administrative units, ownership categories, forest types, or any other stand classification available from the existing inventory. Information about the impact on the age structure of the forest is often needed to evaluate timber supply impacts. Figure 2 shows how the age structure of natural pine stands in South Carolina were affected by Hugo. Maps showing the geographic extent and distribution of forest damage are also easily produced (Figure 3). If the coordinates of each permanent sampling point are known, a geographic information system can overlay information about stand damage severity with other layers. In Figure 3, state and county boundaries and the path of the hurricane's eye are shown along with damage. Inventory results such as this map are similar to products developed from satellite imagery. Ground-based inventories, however, can provide more quantitative estimates of timber volumes associated with conditions on the ground.

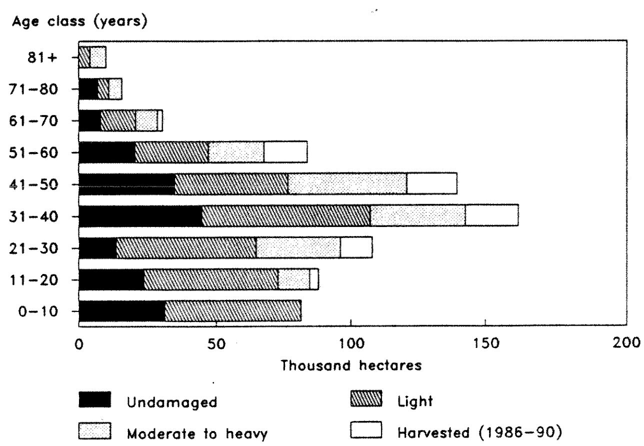

Figure 2--Stand-age profile for natural pine stands in South Carolina, by degree of hurricane damage.

(2) Inventory updates. The remeasurement of all merchantable-size trees facilitates accurate estimates of current inventory volume, change since the previous sample measurement, and volume loss due to the damaging event. Figure 4 summarizes volume change for softwood species in South Carolina. In this example, softwood volume totaled 136 million cubic meters in 1986 and had dropped to 107 million cubic meters in 1990. Mortality and timber salvage due to hurricane damage accounted for 29 million cubic meters. Inventory updates such as this can be summarized by ownership class, stand condition, political or geographic unit, species, or tree size.

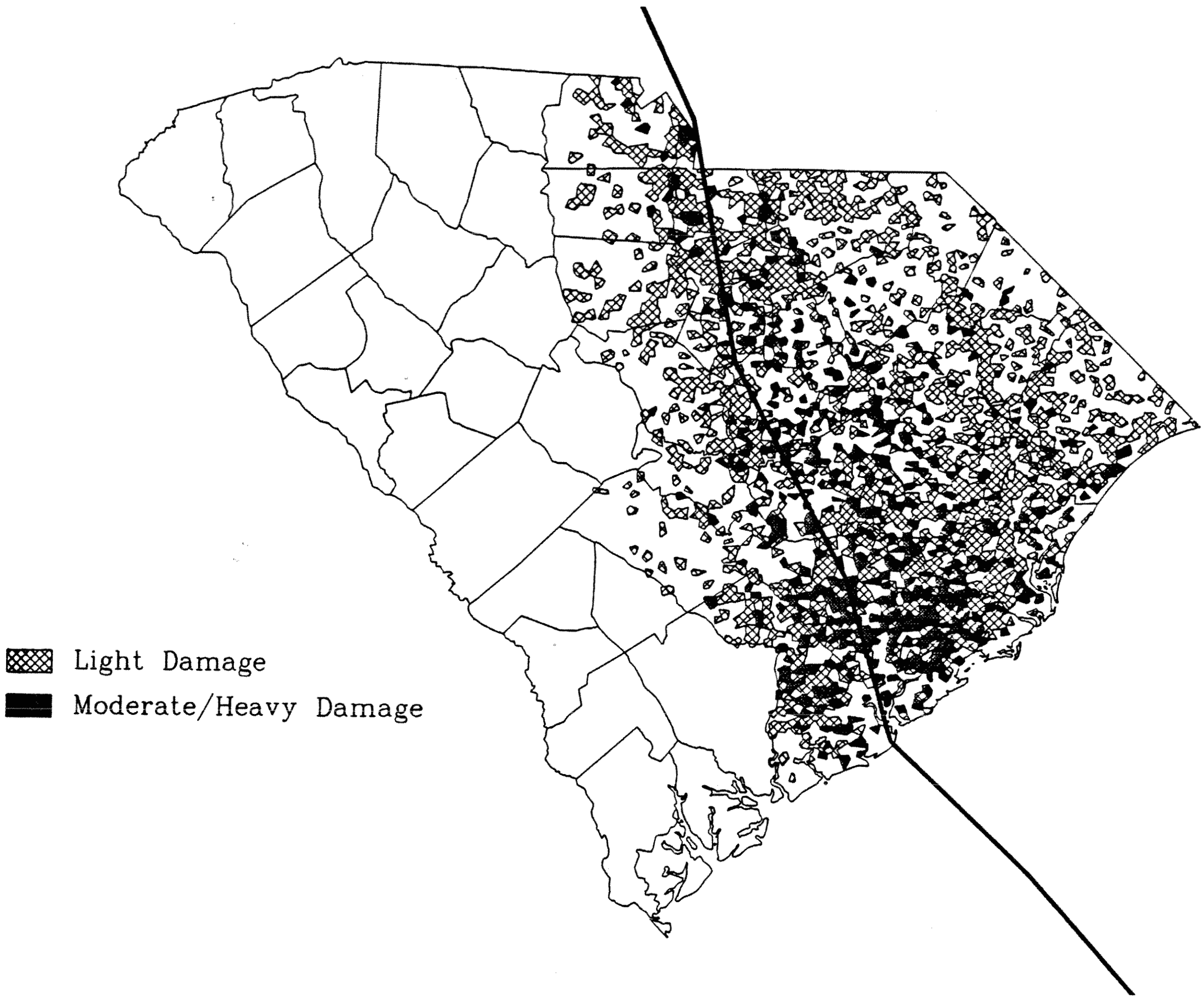

Figure 3--A generalized distribution of timberland in South Carolina damaged by Hurricane Hugo, by degree of damage.

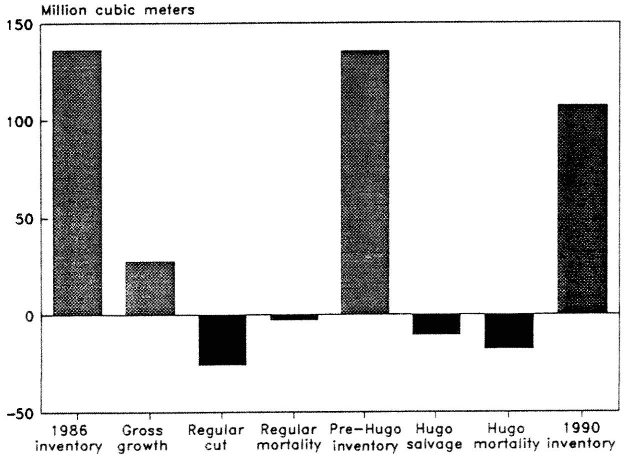

Figure 4--Change in volume of softwood growing stock in South Carolina, by component of change.

(3) Damage severity in live trees. Estimates of the prevalence and severity of damages to the current inventory of live trees are needed to predict future mortality. If substantial numbers of live trees are classed as severely damaged (class 1), mortality is likely to remain high for a long time (Figure 5). In this example, 68 percent of the hardwood volume in South Carolina was classed as healthy and 32 percent damaged. About 37 percent of the damaged trees were classed as severely damaged (class 1). If these trees die, an additional reduction in inventory volume of around 12 percent can be anticipated.

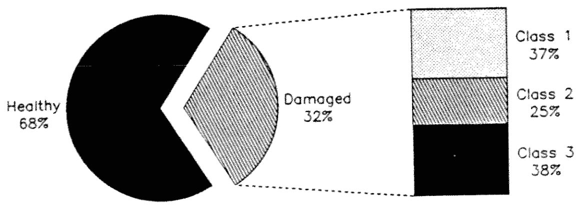

Figure 5--Incidence of damage in post-Hugo hardwood growing stock in South Carolina, by damage/risk class.

(4) Estimates of treatment opportunities. For long- and short-term planning, estimates of stand treatment needs for regional areas are essential after catastrophic events such as hurricanes. The classifications described earlier help in estimation of the forest areas needing regeneration, salvage, and other treatments.

PERMANENT PLOT DAMAGE ASSESSMENT--ADVANTAGES AND DISADVANTAGES

Advantages

A network of permanent ground samples offers five obvious advantages over other methods such as remote sensing for forest damage assessment:

(1) Forest conditions that existed before the catastrophic event are known.

(2) Quantitative estimates of volume loss and damage are direct outputs from the system, and can be provided for critical subsets of the overall resource.

(3) Up-to-date estimates of inventory volumes are provided.

(4) Ground-based inventories set the stage for subsequent remeasurements to estimate recovery.

(5) Ground-based inventories provide precise values needed to validate the rough estimates that can be made with remote sensing data.

Disadvantages

(1) Depending on the inventory objectives, ground-based activity can be more costly than other inventory methods.

(2) Results may take longer to produce because field visits are so time consuming.

(3) A satisfactory network of permanent plots for producing reliable results may not exist.

(4) Large numbers of samples may be needed.

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ASSESSING INTERNAL HURRICANE DAMAGE TO STANDING PINE POLETIMBER

Timothy D. Faust, Mark Fuller, Robert H. McAlister, and Stanley J. Zarnoch[1]

Abstract--Two test methods were used to assess type, location, and degree of internal stem damage to standing pine poletimber (5.0-8.9 inches diameter at breast height, DBH) caused by Hurricane Hugo. A total of sixty trees (15 from each of the four Forest Inventory Analysis [FIA] damage classes) were taken from three sites in the Francis Marion National Forest. Internal damage was expected in the form of ring shake and compression failure. Five stem sections (A through E) were taken from each tree at different heights. From each section, specimens were cut from four quadrants (Tension, Compression, Left, and Right) relative to the wind direction during the storm, for toughness and tension (perpendicular to the grain) testing. A total of 2,147 toughness specimens were tested. A total of 273 specimens were tested in tension perpendicular to the grain. The dependent variables analyzed were toughness, tension strength and specific gravity with FIA damage class as the whole plot factor.

Although there was an increasing trend in toughness from damage class 1 through 4, analysis of variance showed damage class not to be a significant effect on toughness. Stem section and quadrant were found to be significant on toughness. Much of the variation in toughness due to stem section may be attributed to the effects of juvenile wood differences with tree height. Also a high occurrence of reaction wood in quadrant C (side of the tree away from the wind) would contribute to lower toughness strength. Similarly, specific gravity (SG) values showed an overall increase from damage class 1 through 4. Specific gravity of damage classes 1 and 4 was found to be significantly different. Statistical analysis showed no apparent relationship between damage class and tension strength perpendicular to the grain.

The lack of evidence for internal damage is relatively unimportant compared to the evidence of change in the wood properties from the formation of reaction wood. In leaning stems (FIA damage classes 2,3,4), reaction wood should continue to form. In straight trees, reaction wood formed in the two growth seasons following the storm but it is unclear whether it will continue to form. The results lead to the conclusion that stands with leaning stems should be harvested and replanted.

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INTRODUCTION

On September 22, 1989, Hurricane Hugo struck the South Carolina coast with sustained winds of 135 mph and gusts up to 175 mph. In the fall of 1989 the Forest Inventory and Analysis (FIA) Research Work Unit at the Southeastern Forest Experiment Station began a special inventory of the areas damaged by Hugo. A classification system was needed which would assign hurricane damaged trees to discrete categories based on the amount of inflicted damage. The objective was to "provide a reasonable description of damage severity" and estimate the probability of mortality in the near future (Sheffield and Thompson, 1992). The criteria for damage class were empirically derived and a system of four damage classes emerged (Table 1).

Hugo caused extensive immediate damage to the Francis Marion National Forest with an estimated 75% of all marketable trees (DBH > 5.0) on the ground (Ehinger, 1990). The FIA damage class system was devised and implemented in an effort to quantify the damage inflicted on the forest resource and to help foresters decide on the proper management strategies for the remaining stands. However, there were questions still unanswered. What possible long range effects did Hugo have on the remaining 25%? In the case of poletimber (5.0-8.9 DBH) a question which naturally arose was "Should storm damaged poletimber be allowed to mature into sawtimber?" Internal damage to the stem in the form of ring shake and compression failures could reduce the utility of these trees for high value products such as structural lumber. Such damage may not be evident until processing of the lumber is completed, adding further to the costs of utilizing these trees. Also, if stems with internal damage do enter the market, a significant liability risk due to increased failure rates will occur. Thus, sawtimber from internally damaged stems should be sold for pulp chips, a lower value product.

Traditionally storm damage has been classified in terms of visual damage such as snapping of the trunk, uprooting, and bending (Webb, 1988). Similarly, Mayer (1988) defined four types of storm damage as: Stem breakage, stock (base of stem) breakage, root breakage, and tree throw. There have been other studies which differentiate only between tree throw and stem breakage. Although it is apparent that high winds could cause internal damage to tree stems, little information is available on the subject. The FIA damage class system which provides tree classification in terms of apparent storm damage and potential mortality allows only for conjecture as to the degree of internal stem damage. Although the FIA damage class system is only approximate, it is a very practical classification system which brings us a step closer to understanding the nature of storm-damaged timber. What is needed is correlation between this visual damage classification system and actual internal damage as measured by mechanical testing and visual observation.

OBJECTIVE

The objective of this study was to assess type, location and degree of internal stem damage to standing pine poletimber and to relate this damage to the FIA damage classes. Internal damage in the form of compression failures, ring shake and reaction wood were examined by toughness tests, tension perpendicular to the grain tests and visual observation of reaction wood formation, respectively. Wood specific gravity was measured at each location and analyzed with the mechanical properties. A summary of the study variables is presented in Table 1.

METHODS AND MATERIALS

A total of sixty poletimber-sized trees consisting of longleaf pine (*Pinus palustris* Dim.) and loblolly pine (*Pinus taeda* L.) was taken from natural stands in the Francis Marion National Forest near McClellanville, South Carolina, in August of 1991. To avoid the possibility of site bias, the trees were taken from three different sites. A member of the FIA research work unit helped select the trees for the study which consisted of 15 trees in each FIA damage class. Five stem sections were cut from each selected tree, as described below, and brought to the laboratory for further processing. In an attempt to obtain the best group of samples from each stem it was first necessary to determine the point along the stem most likely to sustain wind damage; the critical stress point (CSP). Observations in the field were used to determine the critical stress point as the average height of broken poletimber-sized stems in close proximity to the sample tree. Using this value of critical stress point,

Table 1--Summary of study variables

Variable	Levels
Wind Damage Class (FIA)	1 - High risk of mortality in the near future. Tree lean is greater than 45°, 2 - Moderate risk of mortality, damage may degrade value for use as sawlogs or plylogs. Tree lean 15° to 44°, 3 - High probability of survival, risk of reduced growth and value degrade is minimal. Tree lean is less than 15°. 4 - No obvious wind damage. Tree is essentially straight.
Quadrant	T - Side of tree facing the wind during the storm (under tension stress). C - Side of tree opposite the wind direction (under compression stress). L - Left side of tree facing opposite the wind (under shear stress). R - Right side of tree facing opposite the wind (under shear stress).
Section (tree height)	A - Breast height B - 3 feet below critical stress point C - Critical stress point (CSP) D - 3 feet above critical stress point E - One foot below base of crown
Replicates	15 trees per damage class
Response Variable	**Procedure**
Mechanical properties	Toughness (ASTM D143-93) Tension perpendicular to the grain (ASTM D143-93)
Physical properties	Specific gravity
Reaction Wood	Present or absent

the five 24-inch stem sections (see Figure 1) were cut on center at:
A - Breast height
B - 3 feet below critical stress point
C - Critical stress point (CSP)
D - 3 feet above critical stress point
E - One foot below base of crown.

It was expected that internal damage to the trees was in the form of compression failures, ring shake and reaction wood. Compression failures would be indicated by toughness testing as specified in ASTM D-143-93. Ring shake would be indicated by tension perpendicular to grain tests as specified in ASTM D-143-93, while the presence of reaction wood was determined by visual inspection of the outer 2 growth rings.

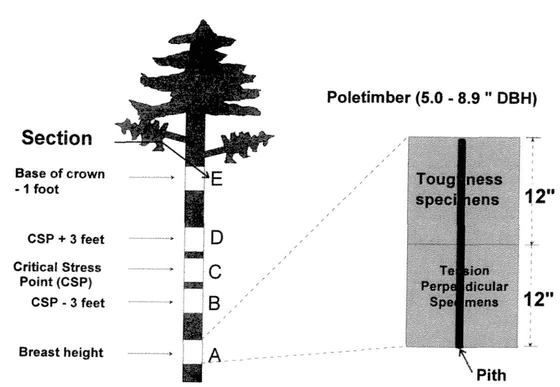

Figure 1--Location of sections within the tree stem.

The five stem sections were cross-cut into two 12-inch sections. Toughness specimens were taken from one of these 12-inch sections and tension perpendicular specimens from the other (Figure 2). Each section was divided into 4 quadrants on the cross-sectional plane such that 2 quadrants were parallel to the wind direction during the storm and the other 2 were consequently perpendicular to the wind direction. The quadrants parallel to the wind direction experienced the severest tension stress on the side of the tree facing the wind and severest compression stress on the side away from the wind. Toughness and tension perpendicular specimens were cut from each quadrant. Only straight-grained specimens free of knots were kept for testing. Reaction wood was present in many of the position 1 (specimen closest to cambium and bark) toughness specimens. Care was taken during processing to remove as little wood from the bark side of the specimens as possible. Occurrence of reaction wood was visually observed in the outer 2 growth rings and recorded for each quadrant and section of each tree.

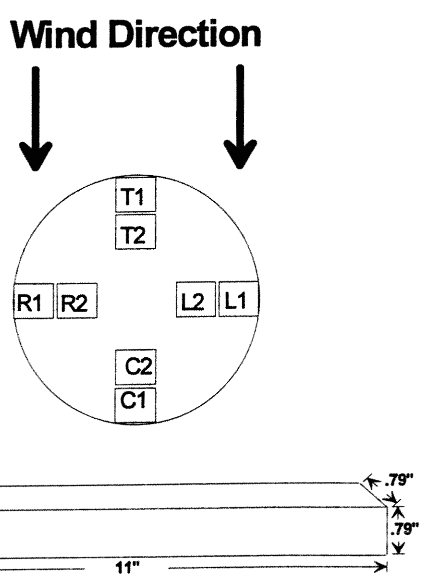

Figure 2--Orientation of Toughness specimens in the tree stem.

Toughness specimens were taken from positions 1 and 2, except in the higher sections of some stems with smaller diameter trees where it was not possible to obtain both specimens (see Figure 2). The toughness testing was done on 1821 samples with a Wiedemann-Baldwin Impact machine.

To test for ring shake it was necessary to stress the entire length of the tension perpendicular to the grain specimen since the location of the ring shake was unknown. The position and orientation of specimens is shown in Figure 3. Since the traditional throated tension perpendicular specimen described by ASTM D143 does not stress the entire length of the specimen, the specimen was modified by using high strength epoxy to bond hard maple blocks to the bark and pith faces of the tension perpendicular to the grain specimens. Appropriate hardware was bolted to the maple blocks and tested as per ASTM standards. Only sections at DBH and critical stress point were tested first, since there was a higher probability of ring separation due to shear stress in these specimens. The tension perpendicular testing was done on 273 specimens with a Tinius Olsen 5000 universal testing machine.

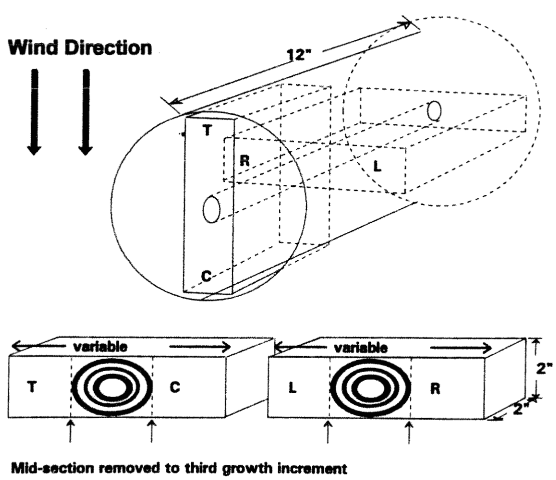

Figure 3--Orientation of tension perpendicular specimens in the tree stem.

EXPERIMENTAL DESIGN

This study was analyzed as a split-plot design where the whole-plot factor was the four tree-damage classes each represented by a sub-sample of trees. Whole-plot replication was by means of blocks defined as the three sites. The subplot factor was a factorial combination of the five tree sections by four quadrants of each tree. The design was unbalanced which led to a complicated analysis. At the whole-plot level, there were no trees in one damage class for one of the sites. This resulted in a missing cell and, hence, only 5 degrees of freedom for the site by damage class effect instead of the typical 2x3=6. In addition, the number of trees sub-sampled in each site by damage class was unequal. At the subplot level, there were several missing observations at various section-by-quadrant treatment combinations. Due to the unbalanced nature of this study, approximate F-tests were performed in the typical split-plot design fashion using the whole-plot and sub-plot error terms. The expected mean squares obtained from SAS (SAS Institute Inc., 1988) indicated that these tests were close to those in the typical balanced situation. Mean separation tests were performed on the main factor effects with Tukey's test. General mean comparisons were not performed since they would require synthesized error terms using Satterthwaite's procedure which was not attempted because of the complexity of the design.

RESULTS AND DISCUSSION

Toughness and Specific Gravity Analysis

Results from the analysis of variance on toughness and specific gravity are shown in Table 2, while treatment means and Tukey's multiple comparisons for all main effects are shown in Table 3. The analysis was performed on the position 1 and position 2 specimens both separately and combined.

The effect of juvenile wood is evidenced by the lower values of toughness and specific gravity of the position 2 specimens as compared to the position 1 specimens. The position 2 specimens should exhibit more juvenile properties of lower toughness and specific gravity because of their closer proximity to the pith.

FIA Damage Class Effects

The damage class factor was not quite significant for toughness (P=0.07). Generally, toughness decreased with increasing damage class (i.e. highly damaged trees had lower toughness). Similarly, Tukey's comparison tests showed a trend of increasing specific gravity with damage classification. Damage class effects on specific gravity were significant at the 0.05 level. This trend supports the conclusion that trees with higher specific gravity and hence higher strength were better able to survive the effects of the storm. Perhaps this trend is due to the development of root systems. A better root system provides better support for the tree stem and is important in resisting windthrow and root upheaval. It seems logical that they develop denser wood tissue, since better developed root systems provide more nutrient and moisture uptake.

The interaction of damage class and quadrant also had a significant effect on toughness (P=0.02). Figure 4 illustrates this interaction. The highest toughness values are concentrated near the tension (T) quadrant, the lowest values near the compression quadrant, and intermediate values are predominantly associated with the left and right quadrants. The trend is increasing toughness from damage class 1 to 4. The tension quadrant at damage class 4 caused the interaction effect by not having higher toughness than the other quadrants. This may be explained by the low occurrence of reaction wood and higher specific gravity in this combination of damage class and quadrant.

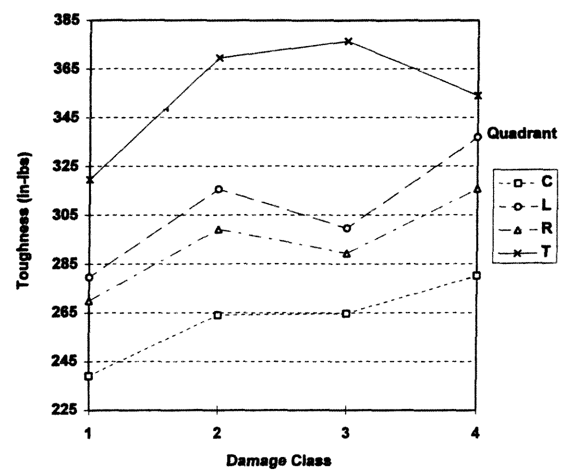

Figure 4--Interaction of Damage Class and Quadrant.

The purpose of the toughness test was to detect compression failures occurring on the transverse axis of the wood. While a trend in toughness with damage class was observed, it was probably due to the significant trend in specific gravity rather than the detection of internal damage. Compression failures were observed in several samples that were tested. However, these compression failures were extremely localized and their effects lost in the large sample of specimens.

Table 2--Results from the analysis of variance (P-values)[1] based on a split-plot design.

Source	Position 1 and 2			Position 1			Position 2		
	df[2]	Toughness	SG	df	Toughness	SG	df	Toughness	SG
Site	2	---[3]	---	2	---	---	2	---	---
Damage Class (DC)	3	.07	.05	3	.08	.07	3	.17	.14
Site*DC	5	---	---	5	---	---	5	---	---
Tree (Site*DC)	49	---	---	49	---	---	49	---	---
Sect	4	.00	.00	4	.00	.00	3	.00	.00
Quad	3	.00	.00	3	.00	.00	3	.00	.26
Sect*Quad	12	.42	.06	12	.07	.66	9	.06	.95
DC*Sect	12	.55	.31	12	.11	.00	9	.78	.77
DC*Quad	9	.02	.59	9	.00	.11	9	.98	.04
DC*Sect*Quad	36	.90	.93	36	.88	.57	27	.80	.94
Error(b)	1015	---	---	1011	---	---	554	---	---
Total (Corrected)	1150			1146			673		

[1] Probability that main effect or interaction has no effect on the measured reponse.
[2] Degrees of freedom.
[3] -- means not of interest or cannot be calculated.

Table 3--Means for toughness and specific gravity with Tukey's mean separation.[4]

Factor		Position 1 and 2		Position 1		Position 2	
		Toughness (in-lbs)	SG	Toughness (in-lbs)	SG	Toughness (in-lbs)	SG
Damage Class	1	278a	.526b	295a	.556b	246a	.471a
	2	313a	.557ab	322a	.582ab	296a	.518a
	3	306a	.S60ab	322a	.586ab	286a	.517a
	4	321a	.589a	329a	.605a	307a	.565a
Section	A	347a	.599a	358a	.630a	331a	.551a
	B	305b	.574b	323b	.604b	280b	.524b
	C	301bc	.558c	314bc	.588c	275b	.507c
	D	284cd	.537d	304c	.566d	242c	.485d
	E	283d	.516e	283d	.516e	-----	-----
Quadrant	T	354a	.547c	383a	.577c	315a	.512b
	L	308b	.569a	314b	.584ab	296ab	.531a
	R	296b	.562b	301b	.579bc	281b	.526a
	C	261c	.556b	270c	.590a	251c	.515b

Means in the same Factor for a given variable not followed by the same letter are signifcantly different at the a = 0.05 level using Tukey's test.

Section and Quadrant Effects

The section variable reflects tree height and shows significant effects on toughness as expected (P=0.00). The lower toughness associated with juvenile wood is evidenced by decreasing toughness with increasing section height. Toughness specimens become closer to the pith and tree crown higher up the stem. These specimens have wood tissue with more juvenile characteristics. The trend is identical for specific gravity which is a primary measure of juvenility.

Quadrant had a significant effect on toughness and specific gravity (P= 0.00). Quadrant indicates the location of the specimen around the tree stem relative to the wind direction during the storm. The windward side of the stem (T) shows the highest toughness while the side of the stem undergoing compression (C) showed the lowest toughness. The L and R quadrants were always intermediate in toughness and closest in actual value. This observation is logical since the L and R quadrants experienced similar stresses. The trends are more complex for specific gravity with quadrant. It would be logical that specific gravity would be constant around the tree stem at a specific tree height. Therefore, we would not expect the quadrant to have a significant effect on specific gravity. The T quadrant of the section was significantly lower in specific gravity than the other quadrants at position 1 and 2. This is contrary to accepted relationships between wood strength and specific gravity. However, the occurrence of reaction wood offers some explanation of why this trend occurs. Reaction wood has higher specific gravity but lower strength.

Occurrence of Reaction Wood

Low average toughness values of the compression side specimens may be attributed to the high occurrence of reaction wood. Figure 5 illustrates the frequency of reaction wood occurrence in damage class by quadrant. The C quadrant had highest occurrence of reaction wood as would be expected. However, extensive reaction wood was occurring on damage class 4 trees which were standing straight. Residual stress from the storm must have triggered reaction wood formation in the following growing season. Considering toughness values with Quadrant as a factor, compression-side toughness values were considerably lower than all others due to partial rings of reaction wood which in many cases had been growing since the storm. In some cases reaction wood extended into the left and right quadrants. The overall effect of reaction wood in the left and right quadrants, however, was less pronounced for two reasons. There were fewer occurrences of reaction wood in these quadrants since the reaction wood bands did not always extend into the left and right quadrants. Secondly, the reaction wood bands generally became thinner as they proceeded away from the compression quadrant so the strength reduction due to the reaction wood band was diminished in the left and right quadrants.

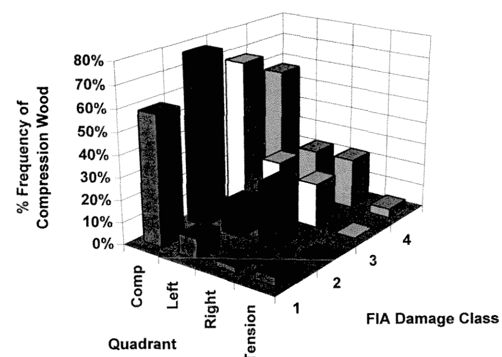

Figure 5--Reaction wood frequency for quadrant by damage class.

Perhaps more importantly, reaction wood was observed in trees of all four damage classes. This is significant since even trees appearing to have no wind damage (i.e. not leaning), those of damage class 4, have a frequency of reaction wood as high as damage class 1. Stress from the wind has caused formation of reaction wood in the two growing seasons after the storm even in trees which are straight and have no visible damage. The formation of reaction wood in leaning stems should continue until harvesting, however it is unknown how long reaction wood will continue to form in damage class 4 trees which are essentially straight. The formation of reaction wood occurred almost uniformly with tree height as shown in Figure 6.

Evidence of Ring Shake

Observations of failures in tension perpendicular to the grain showed no evidence of ring shake which was confirmed by the test results of tension strength perpendicular to the

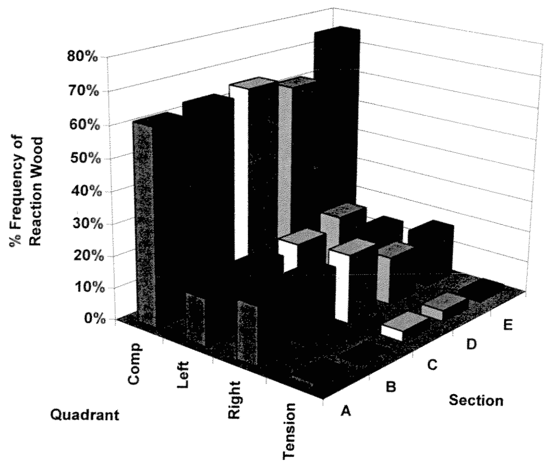

Figure 6--Reaction wood frequency for quadrant by stem section.

grain. There were no significant differences found in tension strength for damage class or quadrant. The section variable was significant with section A significantly higher in tensile strength than section C (see Table 4). This trend is consistent with observations of decreasing toughness with tree height. Table 5 shows tension strength means for damage class by quadrant. It is noted that these average tension strength values are consistent with the literature (Wood Handbook, 1987).

SUMMARY AND CONCLUSIONS

The results of the study offer inconclusive evidence that the FIA damage classes are indicative of internal damage to storm-stressed trees. It was expected that compression failures and micro-fractures would be found to have a varying effect on toughness and that ring shake would have a similar effect on tension perpendicular to the grain in a manner consistent with the FIA damage classes; but this relationship was marginally significant for toughness strength and nonexistent for

Table 4--Mean tension strength values by stem section

Damage Class	Section A	Section C	Damage Class Means[5]
1	500.9	480.6	488.8
2	518.4	514.9	516.3
3	519.9	457.4	485.4
4	504.5	490.8	496.8
Section Means[6]	511.5	485.5	496.5

[5] Damage class means were not significantly different at the 0.05 level.
[6] Section means were siginifcantly different at the 0.05 level.

Table 5--Mean tension strength values by Quadrant

Damage Class	Quadrant C	Quadrant T	Quadrant L	Quadrant R	Damage Class Means
1	505.9	509.9	487.7	456.3	488.8
2	491.7	503.4	557.0	511.8	516.3
3	471.2	499.2	488.0	483.3	485.4
4	499.4	490.3	517.4	486.5	496.8
Quadrant Means[7]	490.7	500.2	512.1	483.1	496.5

[7] Quadrant means were not significantly different at the 0.05 level.

tension strength perpendicular to the grain. Several interesting patterns did arise however. Specific gravity was a factor in determining the extent of damage. The specific gravity measurements made on the toughness specimens do offer some explanation as to the nature of wind damage. In particular, with damage class as the whole plot factor, the specific gravity values of position 1 specimens fall into a pattern. Here again we consider only the position 1 specimens to avoid the highly variable juvenile wood present in most position 2 specimens. Moving from damage class 1 to 4 specific gravity shows an increasing trend and significantly different means between damage classes 1 and 4 at the .05 level using Tukey's test. The trees most resistant to wind damage, those classified in damage class 4, were found to have the highest average specific gravity. Thus there is a negative relationship between wind damage, as defined by the FIA damage class system, and wood density. Other studies (Foster, 1988 and Studholme, 1989 for instance) have shown this negative relationship between sustained wind damage and specific gravity. The variation of toughness and specific gravity could be explained in part by the occurrence and extent of reaction wood observed. The relatively higher specific gravity and lower strength of reaction wood will impact the utilization of these trees.

In conclusion, with dwindling timber resources it will become more important to correctly determine the short-term as well as long-term effects of catastrophic storms on our timber resources. While the FIA visual damage classification system was developed to predict risk of mortality, it has been shown not to be an indicator of internal damage as measured by loss of mechanical properties. FIA damage class was a good indicator of the wood quality in the tree as measured by specific gravity.

The high occurrence of reaction wood as measured in this study indicates that residual stress from the storm caused reaction wood in all damage classes. It is likely that reaction wood formation will continue in leaning stems (damage classes 1 to 3). Further study is needed to determine if non-leaning trees will continue reaction wood formation. The formation of reaction wood appears to be the major damage to trees still standing after the storm.

ACKNOWLEDGEMENTS

Support for this study was provided by the Southeastern Forest Experiment Station, USDA Forest Service, Asheville, North Carolina, 28802. Gratitude is expressed to Michael Thompson (Forester, Forest Inventory and Analysis, Asheville, NC) for evaluation of the standing poletimber in the Francis Marion National Forest.

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OCCURRENCE OF COMPRESSION WOOD IN HURRICANE-STRESSED PINE POLETIMBER

Timothy D. Faust[1], Mark Fuller, and Robert H. McAlister

Abstract--Occurrence of compression wood in hurricane-stressed pine poletimber was evaluated by Forest Inventory Assessment (FIA) storm damage class, tree height and tree radius (orientation to the wind). As expected, occurrence of compression wood was highest on the radius of the tree subjected to compression stress from the wind and the lean of the tree. However, trees that had no visible damage from the wind (i.e. not leaning) had the same occurrence of compression wood as the most severely damaged trees (FIA damage class 1). This would imply that stress from the storm induced the tree cambium to form compression wood even though the main stem was not leaning. Compression wood occurrence was slightly higher at the base of the crown where strain on the stem was greatest. Stands with leaning poletimber will probably continue to form compression wood and should be harvested instead of allowing it to mature into sawtimber.

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A METHOD OF TESTING THE FULL CROSS-SECTION OF WOOD IN TENSION PERPENDICULAR TO THE GRAIN

Timothy D. Faust, Mark Fuller, and James T. Rice[1]

Abstract--This report describes a method of testing wood specimens in tension perpendicular (TP) to the grain whereby the entire cross-section of the wood may be subjected to stress. This method makes it possible to use tension perpendicular testing to detect internal tree damage such as ring separation through the entire radius of the tree. The testing procedure is performed on a solid 2- by 2-inch variable length test specimen where tensile stress is transferred to the test specimen through hard maple blocks which are glued to the pith and bark faces of the test specimen. The work was prompted by a study of storm damaged trees in the Francis Marion National Forest[2]. As part of the study sections were removed from sixty tree stems. A total of 273 specimens were tested. Tensile strength and break location were the primary variables of interest. Although the results show no conclusive evidence of internal damage, the test may be a useful alternative to the standard ASTM 143-83 for full cross-section testing of tension perpendicular to the grain.

INTRODUCTION

The evaluation of storm damage to timber as a result of Hurricane Hugo has prompted work in accessing not only the damage in terms of felled timber but also damage to timber that is still standing and will continue to mature. Of particular interest to forest managers are the poletimber-size (5.0 to 8.9 inches DBH) trees that will mature into the sawtimber of the future. Winds in excess of 135 miles per hour caused considerable stress to even poletimber-size trees. There is the potential for internal damage to these trees in the form of compression failure, ring shake (ring separation) or development of compression wood which would reduce their utility for higher value solid wood products such as stress graded lumber and plywood veneer.

To test the tree stem for internal damage in the form of ring shake, a modified method of ASTM D143-83 was devised[3]. The standard method for testing tension perpendicular to the grain uses the outer material of the test specimen for gripping purposes and the material is not subject to tension stress (see Figure 1). Since the actual location of potential ring shake in the tree stem is unknown, it is desirable to subject the full cross-section of the wood to tensile stress. This paper describes the methods and equipment that were devised to accomplish this.

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[1] The authors are Associate Professor, Graduate Research Assistant and Associate Professor, Warnell School of Forest Resources, University of Georgia, Athens, Georgia. Support was provided by the US Forest Service Southeastern Forest Experiment Station, Athens, Georgia under contract #12-11-008-876.

[2] Faust, T.D., Mark Fuller, and Robert H. McAlister. 1992. Assessing Storm Damage to Standing Pine Poletimber in the Francis Marion National Forest. Final Report for Cooperative agreement #12-11-008-876 by Southeastern Forest Experiment Station and University of Georgia Agricultural Experiment Station.

[3] ASTM D143-83, Tension perpendicular to the grain. Small clear specimens of timber. American Society for Testing and Materials, Philadelphia, PA. V04.09, pp. 55-56.

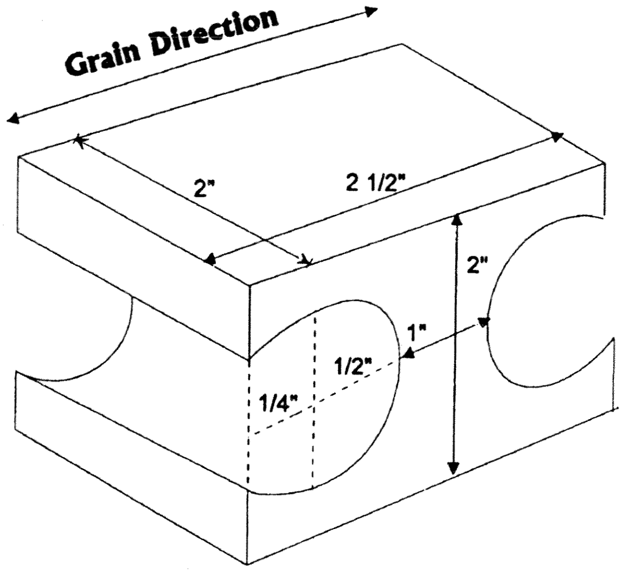

Figure 1--ASTM D143-83 test specimen for tension perpendicular to the grain.

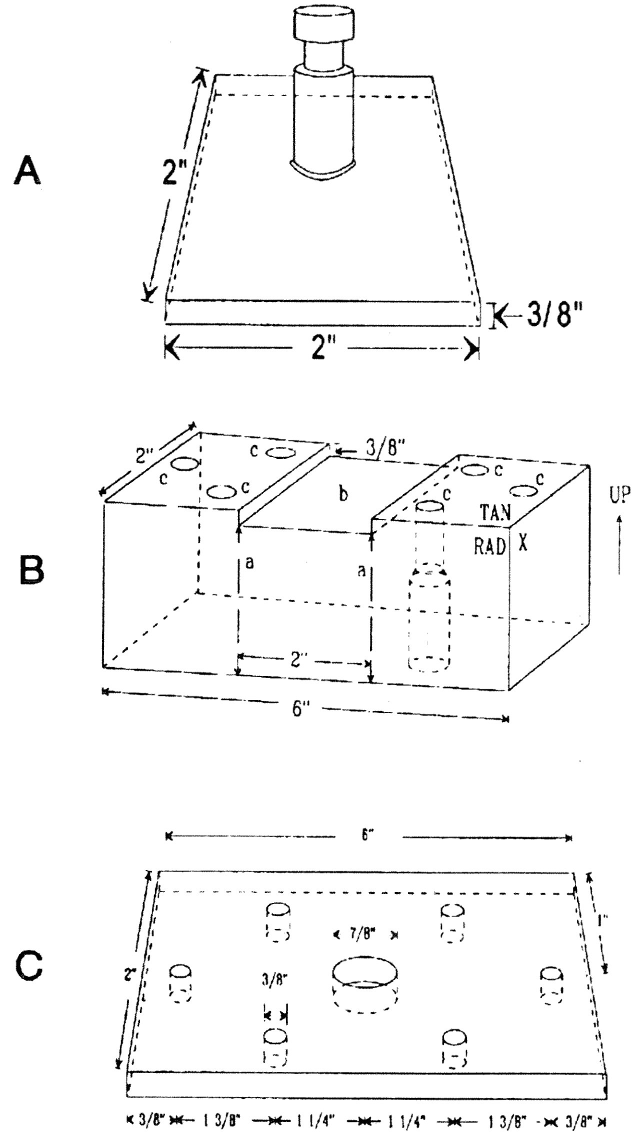

Figure 2--A. metal tab; B. hard maple block; C. backing plate.

OBJECTIVES

This research was conducted to develop a method of testing loblolly and longleaf pine in tension perpendicular to the grain across the full cross-section of the wood. To accomplish this several objectives were defined.

1. Evaluate various adhesives in bonding the test jig to longleaf and loblolly pine to exceed its tensile strength.
2. Develop a test jig to grip a wood specimen to transfer uniform tension stress through the full cross-section and cause it to fail in tension perpendicular to the grain.

METHODS

Initially the test jig consisted of a 2- by 2-inch steel tab with a grippable pin welded onto the back as shown in Figure 2a. These pull tabs were described by Knowles (1981)[4].

In this case, each TP specimen is prepared by bonding one tab to the bark side and one tab to the pith side of the wood specimen and tensile stress is applied to the test specimen through the pins. Several hot melt and epoxy adhesives were used to bond the plates to the wood specimens. We found that the metal to wood interface did not provide sufficient adhesive strength. Virtually all failures of these TP specimens occurred at the adhesive-plate interface. In some cases a few wood fibers were removed from the wood specimen, but, in no cases did failure occur at a significant distance from the bark or pith side face of the specimens. The metal plates were abandoned in favor of a wood to wood interface. A method was designed whereby the pine specimens could be glued to hard maple blocks and with some appropriate hardware the

[4] Knowles, Lorence. 1981. Rapid method to determine internal bond and density variations of particleboard. **Forest Products Journal** 31(12):51-53.

blocks could then be used to transmit tensile stress to the pine specimens. Hard maple was chosen since it has a higher TP strength value than the pine species. The adhesives tested here were PVA, several hot melts, and a high-strength epoxy. Epoxy was chosen since it provided the needed bonding strength and did not require clamping due to its gap-filling ability. The test block design is shown in Figure 2a and its construction and use are described below.

Construction

First machine eight-quarter maple lumber into 2- by 6-inch blocks where the grain runs along the 6-inch axis. This grain direction utilizes the maximum strength of the maple block during testing. Next machine the 2-inch-wide slot 'b' into the center of a tangential face of the block as shown in Figure 2a. This tangential face will be considered the upper face. The metal tab of Figure 2a should fit snugly into the groove and its top side should be flush with the upper face of the block as shown in Figure 3. Now referring again to Figure 2, drill the six 3/8-inch holes 'c'. Next drill the larger holes for the heads of the bolts to fit into. These holes are drilled concentrically with the 3/8-inch holes but from the lower tangential face of the block. The outline of one of the holes is shown in Figure 2b. The drill press should be set so that the 3/8-inch holes remain intact to a depth of about one inch from the upper face. A large drill bit may be spun by hand to remove any loose wood material from the edge of the holes after drilling. Now the test block is ready to be assembled. Insert the metal tab into slot b and insert the six bolts from the lower tangential face so that the threads extend out of the top tangential face as shown in Figure 4. A #10-32 x 1 1/2-inch bolt works well. Place the 1/4-inch steel backing plate over the screws and fasten it into place.

Use

The first step is to glue the wood specimens onto the lower face of the maple blocks. The grain direction of the block and wood specimen should be parallel. In aligning the pine samples in the jig it was helpful to place pencil marks along the radial face of the test blocks. These marks are shown as lines 'a' in Figure 2b and may be seen also in Figure 5. A

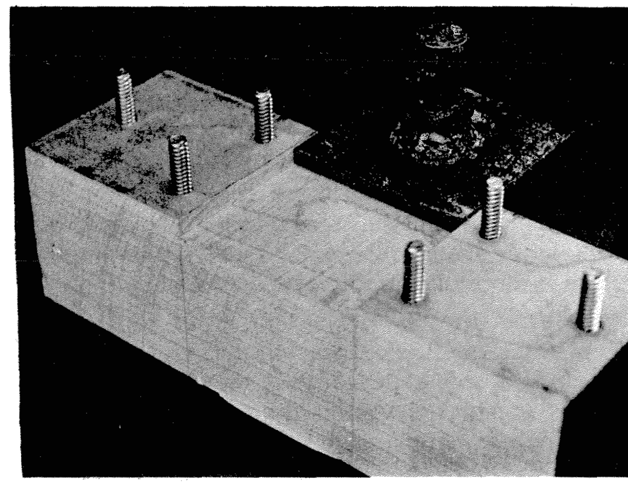

Figure 3--Maple block with inset for metal pull tab.

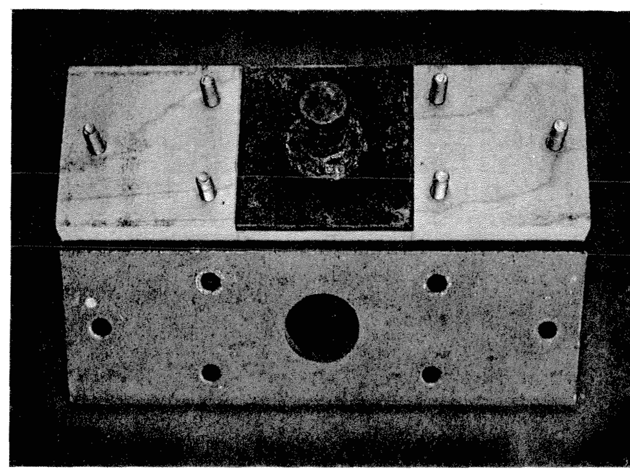

Figure 4--Metal tab in position with backing plate.

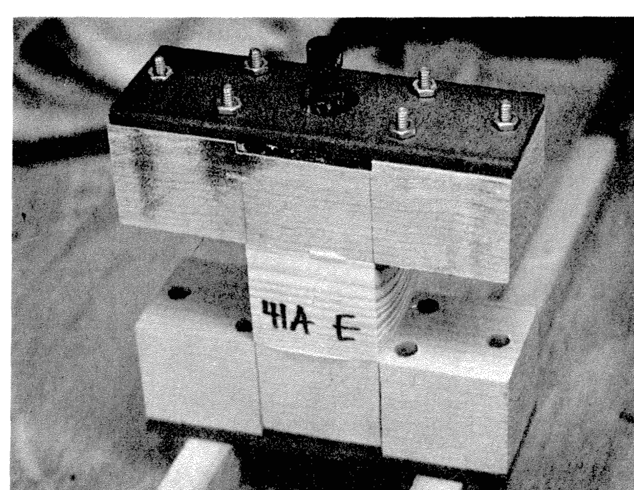

Figure 5--Completed assembly ready for testing.

holding table may be easily constructed with a flat piece of plywood or fiber board and thin pieces of wood on which the block can rest with its upper face turned downward. This arrangement can be seen in Figure 5. Many blocks may be prepared simultaneously using the holding table. To inhibit movement of the specimens during adhesive cure, dowels which are long enough to span the full length of the holding table may be placed on the lower face of the blocks and clamped against the end grain of the TP specimens. In our case, we glued the first block, allowed it to dry, and then glued the second block. Depending on the clamping assembly used, it may be possible, and certainly more desirable, to glue both blocks at once. An epoxy-type adhesive was used to attach the pine specimens to the blocks. The completed test specimen is shown in Figure 5 and is ready to be tested. After testing, the two halves of each specimen may be placed next to each other on the holding table and conveniently interpreted.

Before a test block can be reused it is necessary to remove wood and adhesive material from the lower tangential face to ensure a good bond with the next TP specimen. This may be done by sanding the center of each block to remove most of the material and then jointing to ensure a flat surface. Care should be taken to keep the top and bottom faces parallel so the stresses induced during testing are in fact perpendicular to the grain of the test specimens. By removing just enough material from the lower face of the blocks they may be used thirty to forty times. Also the bolts may need to be tightened after each of the first few uses as the heads of the bolts become seated.

RESULTS

Specimens were stressed to failure and data was recorded for tensile strength and location and type of break. A total of 273 specimens were tested. The tensile strength statistics for the 273 test specimens are shown in Table 1.

The following conventions were adopted in describing the type and location of break in Table 2.

Any given test specimen may require one or more codes to be fully described. For instance a fracture described by the mnemonics "P, 20%" would indicate that the specimen fractured near the pith side and that 20% of the surface exposed by the fracture was along the glueline.

Interpretation of the results could take one of several paths. Ideally the glueline should be as strong as the test specimen. A measure of the relative strength of the glueline to test specimen, and hence the success of the testing procedure, is the percentage of glueline exposed in the tested samples. The following table illustrates one possible breakdown where the percentage categories were arbitrarily chosen.

Table 1--Average tensile strength for all specimens.

# obs	Tensile Strength [lbs./sq. in] Mean	Minimum/ Maximum	STD	COV
273	495.7	243.3/727.0	88.3	0.1782

Table 2--Summary of codes defining failure mode.

Code	Break position/type
G	Fracture along growth increment
P	Break near pith-side glueline
B	Break near bark-side glueline
M	Break near mid-section of specimen
R	Break along radial plane
X%	'X'% of fracture surface along a glue line
PP	Fracture at pitch pocket

Table 3--Summary of average tensile strength by percent glueline failure.

% glue line failure	0 to 10%	>10% to 30%	>30% to 60%	>60%
% of observations	53.8%	14.7%	12.8%	18.7%
Average tensile strength (psi)	489.73	520.91	512.75	481.63
Coefficient of Variation	0.1815	0.1456	0.1537	0.2038

At first glance, these results may seem unsettling in that 18.7% of all specimens tested resulted in >60% glueline failure; however, the average tensile strength of these observations was 495.7 lbs/sq. in. with a range of 243.3 lbs/sq. in. to 727 lbs./sq. in. The average strength is not significantly different with reported tensile strength of 470 psi for both longleaf and loblolly pine (Wood Handbook, 1987)[5]. Differences in strength between failure classes are also not significant ($\alpha = 0.05$).

CONCLUSIONS

Although the results are open to interpretation, the test assembly as described was able to impart sufficient stress to the longleaf and loblolly pine specimens to reveal internal damage in the form of ring shake. This is supported by the fact that the average TP strength of the test specimens exceeded reported average TP strength in the literature. There were some problems with glueline quality where failure did not occur through the test specimen. Glueline quality may restrict the use of this method for use as a measure of tensile strength but this problem is not insurmountable. Clamping would have helped to reduce variation in glueline quality by forcing more intimate contact between test blocks and pine specimens and by reducing the frequency of air bubbles. Other adhesives such as straight resorcinol could also be explored.

This procedure is not intended to replace the present ASTM method of tension perpendicular testing. Its intent was to reveal ring-separation in wind damaged poletimber, and although no evidence of internal damage was found, the results seem to show that the test is appropriate for this purpose.

Reprinted with permission from *Forest Products Journal* 44(3):23-26. Dr. Art Brouner, Editor, 2801 Marshall Ct., Madison, WI 53705.

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[5] Wood Handbook: Wood as an Engineering Material, 1987. USDA Agricultural Handbook No. 72. Forest Products Laboratory, US Dept. of Agriculture. Washington, DC. 466 p.

EFFECTIVENESS OF WATER SPRINKLING FOR LONG-TERM STORAGE OF HURRICANE-DOWNED PINE TIMBER

John H. Syme and Joseph R. Saucier[1]

Abstract--Loblolly pine sawlogs were stored under water sprinklers for a two-year period to determine the effectiveness of different sprinkling schedules on preventing infestation by insects and fungi. One-hundred-twenty freshly-harvested test logs were selected from the same timber tract for the project. One-half of the logs were placed under water sprinklers immediately after harvest, while the other half were dry-stored from one to six months and then placed in the sprinkled decks. The test logs were stored in four separate sprinkled decks, each with a different sprinkling schedule. The test logs were sampled periodically to determine moisture content, presence of fungi and insects, and change in mechanical properties. At the end of the two-year sprinkling period, the test logs were processed in a sawmill and veneer plant to determine the extent of degradation by fungi and insects. The continuous-heavy sprinkling schedule afforded the best protection to the logs of the four sprinkling schedules; there was no visible evidence of blue stain fungus, pine sawyers, or ambrosia beetles after two years of sprinkler storage. Logs in decks with other sprinkling schedules with lower water volumes showed various amounts of fungal and insect degradation, relative to the volumes of water applied. Some mechanical properties appeared to be affected by long-term sprinkling: tangential toughness was significantly lower at the end of the test period, while modulus of rupture, modulus of elasticity, and radial toughness were not reduced by a significant amount. The logs which were dry-stored prior to sprinkling, became infested with fungi and insects during the second month of dry-storage, and were heavily infested by the fourth month.

INTRODUCTION

The temporary surplus of sawlogs resulting from the large volume of blow-down timber by Hurricane Hugo in 1989, has raised several important questions about the long-term effects of storing southern pine logs under water sprinklers. Beyond general guidelines, inadequate information is available concerning the rate of deterioration of logs stored under water sprinklers for long periods of time.

Previous research indicates that water sprinkling provides protection from insects and fungi if the sapwood moisture content is maintained above 100 to 120 percent, oven-dry basis (Liese 1984, Volleman 1966). Logs which have lost moisture, prior to placing them in sprinkler storage, are subject to

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attack by insects and fungi until the moisture content reaches the above threshold level. Information relating to the rate of moisture pickup by logs under sprinklers was not found in the literature. Also, some researchers suggest that continuous sprinkling is necessary to reach and maintain the desired moisture content (Mason and others 1963, Wagner 1976), while others believe that intermittent sprinkling is adequate (Miller and Swan 1980, Roff and Dobie 1968).

Another important question relates to possible strength losses due to sprinkling. Anaerobic bacteria may invade the sapwood of logs in sprinkler storage and degrade the cell walls, thereby increasing the porosity of the sapwood. It is not clear whether or not the strength of the wood is affected, since past research results were controversial and involved relatively short periods of storage (Lutz and others 1966, Scheld and DeGroot 1971).

The purpose of this research was to develop more information related to the effects of different sprinkling configurations on the long-term storage of southern pine sawlogs. The study, conducted at a sawmill in Cameron, South Carolina, began in April 1991 and ended in May 1993.

METHODOLOGY

The loblolly pine (*Pinus taeda*) test logs were from trees harvested in the upper coastal plain of South Carolina. The trees were approximately 35 years old. A 34-foot-long butt sawlog was cut from each of the 120 trees harvested. Immediately following harvest, the test logs were trucked to the research site and prepared for the sprinkling experiment. Each log was assigned a permanent identification number and all test data were recorded on the basis of individual logs. Moisture content and specific gravity discs were taken from both log ends, large- and small-end diameters were measured and recorded, and a three-foot section was removed from the large end of every fifth log for strength tests.

One-half of the sawlogs were divided, at random, into four groups of 15 logs each. Each group of logs was placed under a different water sprinkling schedule:

Group 1. Intermittent Sprinkling, "Heavy" Water Volume

Group 2. Intermittent Sprinkling, "Light" Water Volume

Group 3. Continuous Sprinkling, "Heavy" Water Volume

Group 4. Continuous Sprinkling, "Light" Water Volume

The remaining 60 logs were stored unsprinkled in the logyard. At one-month intervals, over a six-month period, a portion of the unsprinkled logs was placed in each of the above sprinkled decks. At the end of six months, all of the test logs were in the four sprinkled decks. Prior to placing each monthly set of logs under sprinklers, the logs were sampled for moisture content and specific gravity determination and for degree of fungal and insect infestation.

The sprinkling site was located at a sawmill, where the research sprinkling system was connected to the logyard sprinkling system. A closed-loop system was utilized with runoff water collected and recirculated. Standard impact irrigation sprinklers were used with water pressure maintained at 40 psi at the sprinkler head. A 1/8-inch diameter nozzle orifice, rated at 2.9 gallons per minute, was selected for the "Light" sprinkling; and a 3/16-inch diameter nozzle orifice, rated at 6.4 gallons per minute, was selected for the "Heavy" sprinkling condition. The intermittent sprinkling schedule, for both "Heavy" and "Light" conditions, was 60 minutes on and 120 minutes off, 24 hours each day. The system was monitored closely throughout the two-year test period to ensure that all sprinklers were operating properly and that the proper water pressure was maintained. Actual sprinkler output, in inches of water per day, was measured with rain gauges:

Sprinkling Schedule	Inches of Water per 24-Hour Day
Intermittent-Light	0.7
Intermittent-Heavy	1.3
Continuous-Light	2.2
Continuous-Heavy	4.0

At three-month intervals, moisture content discs were cut, at random, from both ends of one-third of the logs in each of the sprinkled groups. Outer sapwood and inner sapwood (near the center of the log) sections were taken from each large-end disc. Because of the smaller diameter, only outer sapwood sections were taken from the small-end discs. The sections were weighed, dried in an oven (105 degrees F.), reweighed, and the oven-dry moisture content calculated. Specific gravity was determined by the immersion method. The discs were also visually inspected for evidence of fungal and insect infestation.

At the beginning and end of the two-year test period, a three-foot-long section was cut from the large end of one-third of the logs in each sprinkled group for strength, stiffness and toughness testing. The green test specimens (four replications for each test) were left over-sized and dried to approximately 10 percent moisture content. They were then jointed to final dimensions and stored at ten percent EMC prior to testing.

The static bending tests were conducted using 1-by 1-by 16-inch specimens with center loading over a 14-inch span following the procedures in ASTM D143 pp. 245-252. Specimens were weighed and measured at mid-point prior to testing. Load deflection data were taken at three second intervals, the slope of the load-deflection line was determined using linear regression (minimum acceptable $R^2 > 0.95$), and the modulus of elasticity and modulus of rupture were calculated. These data were summarized for each storage period. Specimens were oven-dried after testing and moisture contents at time of test calculated.

The toughness tests were conducted using 0.79-by 0.79-by 11-inch specimens over a 9.47-inch span following procedures in ASTM D-143 pp. 71-76 and FPL Report No. 1308 Forest Products Laboratory Toughness Testing Machine. Tests were performed with the weight in position 4 and an initial angle of 60 degrees. All specimens were weighed and measured in the radial and tangential directions at mid-point prior to testing. Specimens were tested in both the radial and tangential modes. Specimens were oven-dried after testing and moisture contents at time of test were calculated.

At the end of the two-year sprinkling period, the surface of each test log was visually examined for insect and fungal infestation. Additionally, a section from each test log was processed in a veneer plant or sawmill. A veneer bolt, 103 inches in length, was taken from the large end of one-half of the test logs for processing into veneer. The green sheets of veneer from each bolt were examined and the degree of blue stain (*Ceratocystis pini*), ambrosia beetle (*Platypus flavicornis*), and pine sawyer (*Monochamus titillator*) infestation was recorded. A 12-foot-long sawlog was cut from the large end of the remaining one-half of the test logs for processing in the sawmill. Each sawlog was sawed in half on a sawmill headrig, the exposed surface was examined, and the degree of fungal and insect infestation was recorded.

A rating system was devised by which to classify the extent of fungal and insect infestation in the test logs, the veneer from the veneer bolts, and the sawlogs. This was based on the percent of surface area infested, estimated visually:

Slight	--	Less than 10 percent
Light	--	10 to 24 percent
Medium	--	25 to 39 percent
Heavy	--	40 percent or higher

RESULTS

The initial data gathered on the freshly cut 34-foot-long test logs were in agreement with the typical moisture and specific gravity relationships which have been previously reported (Koch 1972). For example, the specific gravity of the outer sapwood specimens from the large end averaged 0.59 as compared with the small-end average of 0.48. Outer sapwood moisture content at the large end averaged 68 percent versus 107 percent at the small end. Moisture content was inversely proportional to specific gravity. Average moisture content and specific gravity determinations of samples from the test logs are summarized in Table 1.

Table 1--Moisture content and specific gravity of samples from all 120 test logs at beginning of test.

	Moisture Content (O.D.)		Specific Gravity	
	Mean	Range	Mean	Range
Large End				
Outer Sapwood	68%	49- 99%	0.59	0.45-0.71
Inner Sapwood	93%	55-184%	0.50	0.37-0.64
Small End				
Outer Sapwood	107%	76-138%	0.48	0.41-0.59

The initial moisture content and specific gravity of the samples from the large end of the 60 test logs, by sprinkled deck, are summarized in Table 2. Differences in average initial moisture content among sprinkler decks were small, as were differences in average specific gravity.

Table 2--Initial moisture content and specific gravity of samples from the large end of 60 test logs under different water sprinkling schedules for two years.

Sprinkling Schedule	Large End Log Diam.	Moisture Content Inner	Moisture Content Outer	Specific Gravity Inner	Specific Gravity Outer
	(inches)	(percent)		(percent)	
IH	12.4	97	72	0.49	0.58
IL	12.0	92	74	0.50	0.59
CH	11.9	90	69	0.50	0.59
CL	11.1	93	68	0.51	0.59
Average	11.9	93	71	0.50	0.59

IH = Intermittent - Heavy
IL = Intermittent - Light
CH = Continuous - Heavy
CL = Continuous - Light

Results from Logs Placed Under Sprinklers at the Beginning of the Test Period

Moisture Increase

After the initial three months of sprinkling, the outer sapwood reached an average moisture content of 99 percent and the inner sapwood an average of 111 percent. This represents a 29 percent increase in moisture content for the outer sapwood and an 18 percent increase for the inner sapwood. The average moisture content after three months of sprinkling ranged from 92 to 111 percent among sprinkling decks for the outer sapwood and 104 to 116 percent for the inner sapwood. Monthly moisture sampling during this period showed a different rate of moisture increase in both the outer and inner sapwood for each of the four sprinkling schedules:

Sprinkling Schedule	Initial Monthly Moisture Increase Outer Sapwood	Initial Monthly Moisture Increase Inner Sapwood
	(percent)	
Deck 1: Intermittent-Heavy	sapwood	sapwood
Deck 1: Intermittent-Heavy	16	7
Deck 2: Intermittent-Light	9	5
Deck 3: Continuous-Heavy	30	13
Deck 4: Continuous-Light	21	9

During the second three-month period, the moisture content of samples from the large end of the test logs increased at a much slower rate than the initial period, with the outer sapwood reaching an average of 104 percent and the inner sapwood 120 percent. The moisture content levels reached equilibrium by the end of the third three-month period of sprinkling for the outer sapwood and by the end of the fifth three-month period for the inner sapwood. No significant increase or decrease in moisture content was seen for the remainder of the two-year period. Table 3 shows the beginning and ending moisture content and moisture gain during the two-year period under the different sprinkling schedules.

Table 3--Beginning and ending moisture content and moisture gain of samples from the large end of 60 test logs under different water sprinkling schedules for two years.

	Beginning MC	Ending MC	Ending MC Gain
	------------	percent	------------
Outer Sapwood			
Intermittent - Heavy	72	106	34
Intermittent - Light	74	107	33
Continuous - Heavy	69	105	36
Continuous - Light	67	101	34
Inner Sapwood			
Intermittent - Heavy	93	135	42
Intermittent - Light	92	126	34
Continuous - Heavy	90	136	46
Continuous - Light	90	130	40

Fungal and Insect Infestation

Results from the visual examination of the test log surfaces which were under water sprinklers for the entire two-year period are shown in Table 4. None of the test log surfaces, regardless of sprinkling schedule used, showed evidence of blue stain or pine sawyer infestation. All logs in the two decks with intermittent sprinkling schedules had heavy levels of ambrosia beetle damage, while there was no indication of ambrosia beetle damage in the logs in the two decks with continuous sprinkling schedules.

Table 5 gives the results of the visual examination of the veneer from the veneer bolts and the sawlogs from the test logs which were under sprinklers for the entire two-year period.

"Slight" to "light" amounts of blue stain were present in logs in all sprinkled decks except the continuous-heavy deck, where none was found. Logs in both continuous sprinkled decks showed no signs of infestation by ambrosia beetles, while both intermittent sprinkled decks had significant amounts of ambrosia beetle infestation. None of the logs in the four sprinkled decks showed any evidence of pine sawyer infestation.

Table 4--Visual examination of the exterior surface of test logs which were under four sprinkling schedules for the two-year test period.

	Degree of Infestation*		
	Blue Stain	Ambrosia Beetle	Pine Sawyer
Log Deck:			
Intermittent - Heavy	None	Heavy	None
Intermittent - Light	None	Heavy	None
Continuous - Heavy	None	None	None
Continuous - Light	None	None	None

* None, Slight, Light, Medium, or Heavy

Table 5--Visual examination of lumber and veneer from test logs which were under four sprinkling schedules for the two-year test period.

Sprinkling Schedule	Type of Infestation		
	Blue Stain	Ambrosia Beetle	Pine Sawyer
Intermittent - Light	Light	Medium	None
Intermittent - Heavy	Slight-Light	Light-Medium	None
Continuous - Light	Slight	None	None
Continuous - Heavy	None	None	None

Mechanical Properties

The results of the strength tests, from samples from the same logs, at the beginning and end of the two-year test period shows that there was no significant change in modulus of rupture, modulus of elasticity, and radial toughness. Tangential toughness was significantly lower at the end of the sprinkling period than at the beginning. Data from the mechanical tests are summarized as follows:

	Results (Mean)	
	Beginning	Ending
Specific Gravity	0.58	0.55
Modulus of Rupture (10^3 psi)	17.4	15.0
Modulus of Elasticity (10^6 psi)	1.62	1.58
Unit Toughness - Radial (psi)	40.1	30.7
Unit Toughness - Tangential (psi)	63.5	39.2

Results from Logs Which Were Dry-Stored Prior to Sprinkling

Moisture Change

The test logs which were dry-stored for one to six months, prior to being placed in the four sprinkled decks, showed an increasing loss in moisture content as the dry-storage time was increased. The average moisture loss in the outer sapwood of samples taken from the large end of the test logs at the beginning and end of the dry-storage period are shown below:

Dry Storage Time (Months)	Outer Sapwood Moisture Loss (Percent)
1	5
2	16
3	25
4	27
5	29
6	30

The gain in moisture content, after the dry-stored logs were placed under sprinklers, took place at a different rate for each of the four sprinkling conditions. Generally, the rate of moisture gain was directly related to the volume of water applied to the logs. The rate of moisture gain was highest during the initial sprinkling period and slowed as log moisture content increased.

The average outer sapwood moisture gain, after the first month under sprinklers following dry storage, is summarized as follows for each sprinkling schedule:

Sprinkling Schedule	Percent Gain in Moisture Content
Intermittent - Light	13
Intermittent - Heavy	22
Continuous - Light	27
Continuous - Heavy	38

An important factor is the time required for the outer sapwood to reach the threshold moisture content (assumed to be 100 percent) after the logs have been placed under the sprinklers. An analysis of the rate of outer sapwood moisture gain among the four sprinkling schedules, based on stratified sampling of logs dry-stored three months and five months prior to placing under sprinklers, is shown in Figures 1 and 2. This comparison shows that logs under the Continuous-Heavy sprinkling schedule reached the threshold moisture content sooner than the logs under the other schedules. Logs under the Intermittent-Light schedule did not reach the threshold moisture level.

Fungal and Insect Infestation

Sections were removed from the dry-stored logs and taken to the laboratory for visual inspection of two 10 x 10 centimeter areas from each log section. The areas were examined for presence of blue stain, pine sawyers, and ambrosia beetles. Twenty-eight logs were sampled after dry storage from one to six months and again at the end of the sprinkling period. Blue stain was found in all samples, at the end of one to six months of dry storage; however, at the end of the sprinkling period, the amount of blue stain had not increased in any of the samples. No evidence of pine sawyers was found in samples from logs dry-stored for one and two months; however, logs dry-stored for three to six months were heavily infested with a total of 18 entrance holes and 7 exit holes in the 56 sample areas examined. At the end of the sprinkling period, samples from logs under the two intermittent schedules showed an increase in pine sawyer infestation, while samples from logs under the two continuous schedules showed no increase. Ambrosia beetles were present in 25 percent of the samples from logs dry-stored from one to three months, as compared to 100 percent for logs dry-stored three to six months. At the end of the sprinkling period, eight log sections showed no evidence of ambrosia beetle infestation, while evidence was found in the remaining twenty log sections; the eight logs not infested had been stored in decks with the two continuous sprinkling schedules.

The mill processing of the veneer bolts and sawlogs from the test logs which were in dry storage for up to six months, prior to being placed under sprinklers, revealed increasing amounts of infestation by blue stain, ambrosia beetles, and pine sawyers as dry storage time was increased. Generally, logs in dry storage for one month had light levels of infestation, while logs in dry storage for five and six months had heavy levels of infestation. It should be noted that the dry storage occurred during the summer months when fungal and insect activity is normally higher than in other seasons.

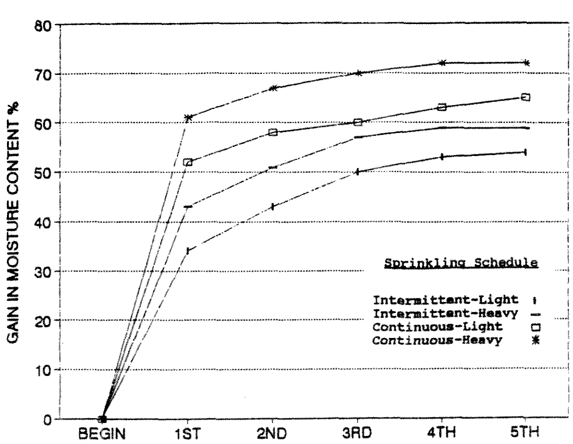

Figure 1--Average gain in moisture content of outer sapwood samples from the large end of test logs which had been dry-stored and then placed in sprinkled decks with different sprinkling schedules.

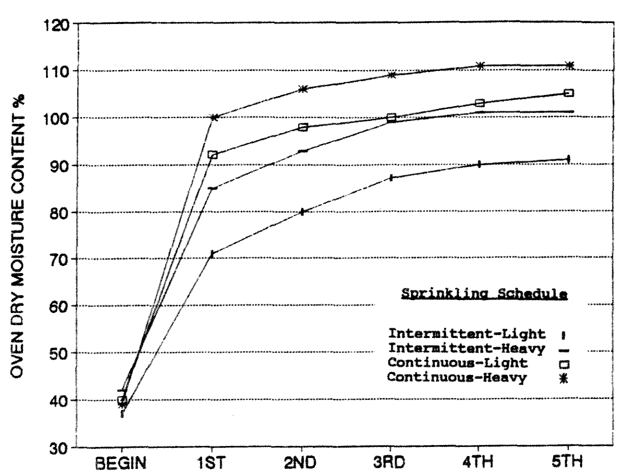

Figure 2--Average moisture content of outer sapwood samples from the large end of test logs which had been dry-stored and then placed in sprinkled decks with different sprinkling schedules.

The data from the dry-stored logs indicate that the continuous sprinkling schedules were more effective than the intermittent schedules, and the heavy sprinkling schedules more effective than the light schedules. Apparently, logs under the higher sprinkler water volumes reached the threshold moisture level, where fungal and insect activity ceases, more quickly than the lower water volume schedules. Logs which were dry-stored longer than two months before sprinkling had serious levels of fungal and insect damage, regardless of the sprinkling schedule used.

DISCUSSION

The results show that freshly-harvested southern pine sawlogs can be stored under water sprinklers for a two-year period without serious degradation, provided an adequate volume of water is applied to the logs on a continuous basis. The combination of these results indicate that the degree of protection of the sprinkled logs from fungal and insect infestation is directly related to the volume of water applied. The moisture content of logs under the heavier water volume sprinkling schedules reached the threshold moisture content more quickly, which prevented infestation by insects and fungi. The continuous-heavy schedule, which had the highest water volume, provided the best protection. The intermittent-light schedule, which had the lowest water volume, provided the poorest protection. Continuous sprinkling was superior to intermittent sprinkling, but this difference appears to be more related to water volume than to the difference between continuous and short-cycle intermittent sprinkling schedules.

The mechanical properties of samples from the sprinkled logs were lower at the end of the test period than at the beginning. Part of this difference can be attributed to the lower specific gravity of the final samples which were further from the original large ends of the logs. After adjustment for specific gravity difference, tangential toughness was the only property tested which was reduced significantly.

The results also show that ambrosia beetle and pine sawyer activity and blue stain and brown rot fungal activity, in logs which have been dry-stored prior to sprinkler storage, can be arrested by water sprinkling. It appears that heavier water volumes stop the activity more quickly than lighter water volumes. Moisture content of logs under the heavier sprinkling volumes increases more rapidly than logs under the lighter sprinkling volumes; thereby reaching the threshhold moisture content, where insect and fungal activity stops, more quickly.

Blue stain was present in all logs sampled after only one month of dry storage. Significant presence of ambrosia beetles and pine sawyers was not evident during the first two months of dry storage, but increased rapidly thereafter. These results demonstrate the importance of placing logs under water sprinklers as soon as possible after blow-down to avoid early deterioration from fungi and insects.

Of the four sprinkling schedules, the Continuous-Heavy sprinkling schedule produced the best results. The sprinkler output on the logs in this deck was four inches of water per 24-hour day. The deck contained 30 logs, stacked to an approximate height of five feet. Although the four inches of water per day was adequate to protect the logs in the test deck, larger-sized commercial decks where logs are typically stacked to heights of up to 30 feet, will require additional inches of water output to protect the stored logs. The amount of water required will vary with the height of the log deck and other conditions.

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MANUFACTURE OF SOUTHERN PINE PLYWOOD FROM HURRICANE HUGO SALVAGE LOGS STORED UNDER WATER SPRINKLERS[1]

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ABSTRACT--The study documented and analyzed the activities which occurred during the water storage and plywood processing of Hurricane Hugo salvage logs at the Georgia-Pacific Corporation's Plywood Plant in Russellville, S.C. It was observed that in log decks where adequate water was properly applied, the log storage program was effective in preserving sound logs and in stopping further damage from insects and fungi in logs which were already infested when placed in storage. No major problems were encountered in processing the sound logs which had been properly sprinkled; however, severe production problems were experienced in processing logs which were not sprinkled or which were heavily infested with fungi and insects prior to water storage. Additionally, the incoming logs to the plywood plant were made up of a varying mixture of cull (severely infested) and sound logs. The extreme variation in log quality and moisture content created processing problems from the water vats to the hot press. Process and adhesive adjustments were made on a continuous basis in order to stay within process control limits. Regardless of the processing problems, the plant consistently produced plywood from the salvage logs which met industry panel glueline and strength specifications.

INTRODUCTION

On September 22, 1989, Hurricane Hugo struck the South Carolina coast with the full force of 135 mile-per-hour winds. Hugo swept through central South Carolina into North Carolina, creating extensive damage to timber and property, in a swath 50 miles wide from Charleston to Charlotte. The greatest overall economic loss was to the timber resource in the path of Hugo. Twenty-three counties in South Carolina reported substantial timber devastation (Figure 1). Trees were uprooted, broken off, and otherwise damaged. Estimates placed the total timber destruction in the state at $1.18 billion (Table 1), with the equivalent of four years harvest of sawtimber destroyed.

South Carolina Governor Campbell moved rapidly to bring the forest industry public and private sectors together, by creating a Forest Disaster Salvage Council on October 5, two weeks after Hugo struck. The Council was charged with coordinating activities related to the timber salvage efforts. Early action included temporary waiving of sprinkler and water storage permits for log storage, increasing the maximum highway gross weights for log trucks,

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and recruiting of loggers from other states. A salvage goal of 625 million cubic feet was established, or 25 percent of the total estimated volume destroyed of 2.5 billion cubic feet.

The salvage program was hampered by a combination of wet weather and the difficult logging conditions created by the downed timber. Emphasis was given to the salvage of pine over hardwoods, because pine stands were more easily accessible. Despite the establishment of several sprinklered storage sites, the increased harvest of timber exceeded the industry's processing capacity. By early spring of 1990, the price of pine sawtimber had dropped to $89 per thousand board feet, from $175 prior to Hugo, while the pulpwood price dropped to $11 per cord from $22 previously. Saturation of the pine timber market slowed the salvage program and, as a result, many of the loggers from outside the area returned home. Conversely, hardwood sawmills and veneer plants experienced a shortage of logs, because of the number of loggers moving to the salvage area to log pine.

By mid-March, 1990, approximately 255 million cubic feet, or 40 percent of the goal of 625 million cubic feet, had been salvaged. Softwoods comprised 87 percent of the total. As the weather warmed, the quality of the downed timber began to deteriorate rapidly due to increased insect and fungal activity. By June, 1990, most pine salvage logging had ceased. Total estimated volume of timber salvaged as of November, 1990 was 383 million cubic feet or 61 percent of the original goal. Softwoods, mostly pine, comprised 86 percent of the total volume.

Summary of Timber Damage by Hugo

During the first half of 1990, the Southeastern Forest Experiment Station, U.S. Forest Service, conducted a special inventory of the forest resource in the Hugo-devastated areas of South Carolina. The purpose of this inventory was to assess the volume of timber damaged by the hurricane. A total of 2,530 permanent plots in 23 counties were measured. The 23 counties contained 6.5 million acres of timberland, of which 4.5 million acres were damaged by Hugo. In six of the counties --- Berkeley, Clarendon, Florence, Lee, Sumter, and Williamsburg --- more than 90 percent of the timberland sustained damage.

The 1990 inventory included all merchantable trees that were alive. Each tree was placed in one of four classes:

1. Class 1: Severe damage, high probability of dying in the near future.
2. Class 2: Moderate damage, questionable probability of surviving.
3. Class 3: Light damage, high probability of surviving.
4. Healthy: No obvious hurricane damage.

Because the future mortality rate in each class is unknown, the actual long-term loss of timber due to Hugo can only be estimated at this time.

Based on the survey, the softwood growing stock inventory of 4.8 billion cubic feet was reduced by about 21 percent or 1.0 billion cubic feet (Figure 2). One-third of the lost softwood volume was salvaged, two-thirds was killed but not salvaged. Softwood sawtimber volume was reduced from 19 to 14 billion board feet, a decline of 26 percent. Large-diameter trees were most prone to hurricane losses, while reductions were more modest for smaller trees. Volume was reduced by 6 percent in the 6-inch diameter class, 11 percent in the 8-inch class, and 16 percent in the 10-inch class; while reductions of 22 to 32 percent were calculated in the 12-, 14-, 16-, 18-, and 20-inch categories. All yellow pine species showed severe damage, while cypress was least affected by Hugo.

The hardwood growing stock inventory of 5.1 billion cubic feet was reduced by 6 percent or 319 million cubic feet (Figure 3). This inventory reduction was attributed to 270 million cubic feet of Hugo-related mortality and 49 million cubic feet of timber salvage. About one-third of the post-Hugo hardwood inventory was damaged to some degree. Damage to hardwoods by Hugo was much more difficult to assess than was softwood damage. Severely damaged hardwoods did not die as quickly after the hurricane as did softwoods. The extent of damage to the hardwood resource is, therefore, understated.

The larger trees suffered the greatest Hugo-related mortality. Red oaks were the hardest hit species with 42 percent of the inventory damaged, with 50 percent in Class 1.

In summary, Hugo-related mortality will continue to accumulate for several years. According to the U.S. Forest Service, a reasonable estimate of long-term softwood loss is about 30 percent of the pre-Hugo inventory, or 1.4 billion cubic feet. It is estimated that total hardwoods damage is about 20 percent of pre-Hugo volume, or 1.0 billion cubic feet.

Water Storage of Hugo Logs

One of the initial proposals by the Governor's Forest Disaster Salvage Council was the wet storage of harvested logs. It was assumed that the wet storage facilities would maximize the salvage of Hugo-damaged timber by providing a safe place for storing a large volume of harvested logs which exceeded the short-term capacity of processing plants. Less than one month after Hugo, the Council alerted the forest industry about the importance of developing wet storage facilities. Government disaster funds were requested to provide wet storage sites for small businesses and landowner cooperatives. The industry was requested to identify potential storage areas, including rock quarries, lakes, ponds, and dry-land sprinklered sites, which could be reached by truck or rail transport. A survey in early December, 1989, revealed that 30 potential sites had been identified with a planned log storage capacity of 160 million board feet, or 20 percent of the anticipated pine salvage volume of 800 million board feet. Additional sites were also proposed in the Francis Marion National Forest.

A 1989 year-end survey indicated that few logs had been placed in water storage. Wet weather had hampered logging operations, and mills were able to immediately consume almost all of the salvage logs harvested. Further, it was reported that the securing of government funds for log storage had been unsuccessful. Government agencies had also failed to respond to requests for approval to store logs in lakes and ponds. Another barrier was the lack of available information related to the design of log sprinkling systems for dry-land storage, although sprinkling logs is commonly practiced by many hardwood mills. The Department of Health & Environmental Control (DHEC) in South Carolina approved a temporary program to allow mills to sprinkle stored logs without going through the permit procedure, provided the sprinkling facility was a closed-loop, recirculating system with a 24-hour rain capacity.

Beginning in January, 1990, the response to the program was positive in that an estimated 140 million board feet of salvaged pine logs and 6 million board feet of hardwood logs were stored under sprinklers over the following six-month period. Typically, logs (both tree-length and cut-to-length) were stored in long rows or piles, from 10 to 25 feet in height. Standard irrigation sprinklers were used to apply a continuous spray to the log piles. The logs were normally stored for several months and, in some cases, over one year, prior to processing.

Sprinkler storage proved to be a very effective and low-cost method for storing the salvaged logs. Sprinkling prevented insect and fungal attack on freshly-harvested logs, and stopped further insect and fungal activity on logs which were infested prior to storage, provided adequate water was applied to the logs to maintain the required moisture levels. No serious problems were encountered in processing the sprinkled logs into lumber, veneer, and plywood, and no product degrade could be attributed to sprinkler storage.

Literature Review: Wet-Storage of Logs

A survey of existing literature revealed a large number of articles on the subject of water log storage, both softwoods and hardwoods. Although underwater storage in ponds or lakes was once a popular storage method, dry-land sprinkler storage is the most popular current method for preserving stored logs. Little detailed information was found on the practical aspects of log sprinkling or on the design of sprinkling systems. Most of the articles are general in nature, or report the results of research on a specific topic.

In summary, sprinkling piles of logs with water is reportedly the most practical method of preventing or stopping insect and fungal attack in stored logs. Air in the wood is replaced by water, and at a certain moisture content (threshold level) the insects are drowned or driven from the wood and the fungi become inactive due to lack of oxygen. Scheffer (1969) hypothesized that water sprinkling controls ambrosia and other beetles because the water on the log surface masks the natural attractants that lure the insects to the log for reproduction. If the logs are already infested when placed in storage, the insects or fungi will remain active until the sapwood moisture content is raised to the threshold level by the water sprinklers. Liese (1984) and Miller (1979) found that a sapwood moisture content of 100-120 percent (O.D. weight basis) will reduce the available oxygen below the level required to sustain fungal growth. Less is known about threshold moisture levels required to stop insect activity; one reference (Mason et al. 1963) indicated that attacks by Ips engraver beetles and sawyers were prevented as long as the log surfaces were kept wet. Koch (1972) reported that blue stain fungi become less active at temperatures below 50 degrees F. A later study on ponderosa pine sapwood reported that blue stain fungi continued to be active at temperatures down to 37 degrees F. and the greatest amount of staining occurred at 45 degrees F (Miller and Swan 1980).

Pine logs, properly sprinkled, apparently can be stored for long periods of time without degrade. According to Wagner (1978), successful sprinkler storage of up to two years for S. pine logs appears to be fairly common, with storage up to six years reported in a few cases. References reported on the storage of storm-damaged logs in several foreign countries. Pine logs, for example, have been stored under water sprinklers in Germany (Liese 1984) and New Zealand (Clifton 1978) for as long as five years without measurable degrade.

Certain types of bacteria (anaerobic) do not require oxygen to survive and will continue their activity in the sprinkled logs; however, the presence of these bacteria normally does not cause a problem. The lumber or veneer from logs which have been stored several years may have grayish streaks, have an unpleasant odor before being dried (Clifton 1978, Volkmann 1966), and may exhibit increased permeability (Miller 1979, Rayner 1988). The stain can be eliminated by dipping the green lumber or veneer in a chemical solution. The odor disappears when the lumber or veneer is dried. Basic strength properties are not materially affected (Lutz et al. 1966, Shefter 1969, Liese 1984).

On balance, there appears to be little difference in cost and problems experienced between processing sprinkled logs and fresh logs. The wetter bark on the sprinkled logs may present problems in immediate use for boiler fuel (Miller 1979, Djerf 1969); additionally, much of the bark tends to slough off in the storage yard (Liese 1984). Sprinkled logs reportedly can be sawn and peeled at faster rates (Liese 1984), but the green veneer and lumber may require slightly longer drying times.

Approach, Method, and Data Collection

Although most of the activities related to storing and processing the sprinkled Hugo-logs took place at the Plywood Plant, several other organizations were deeply involved throughout the program. Georgia-Pacific's Timber Division procured and stored the salvage logs. The Company's Chemicals Division supplied the various plywood adhesive formulations required to obtain the best glue-bond results. The American Plywood Association provided continuous glue-bond evaluation, panel strength testing, and technical advice. The Southeastern Forest Experiment Station, U. S. Forest Service, performed periodic moisture content and specific gravity tests on samples from logs in storage and stiffness tests on the finished plywood panels produced from those logs.

The project study team's general approach was to collect pertinent information and data from the Plywood Plant and from each of the other organizations involved. In-depth personal interviews were conducted with management and supervisory personnel in the Plywood Plant and with key personnel in the other organizations. Production, quality control, technical, and other reports were also obtained. Special reports were requested in instances where available data were not adequate. Weather data (Figures 4a, 4b) for the Russellville area, covering the Hugo-log storage period, were also obtained from the National Climatic Data Center.

Information from the personal interviews was analyzed and edited. Reports and other data were analyzed and summarized; graphs were prepared comparing results for three periods: prior to, during, and after the processing of Hugo logs. The project study team reached conclusions and developed recommendations from the data gathered and analyzed and from the literature review.

MANUFACTURE OF PLYWOOD FROM WET-STORED HUGO LOGS AT GEORGIA-PACIFIC'S RUSSELLVILLE PLYWOOD PLANT

Georgia-Pacific Corporation responded aggressively to the Hurricane Hugo disaster. The company's Eastern Wood Products Manufacturing Division mounted a full-scale timber salvage program which resulted in the harvesting and storage of a large quantity of S. pine logs for manufacture of plywood at its Russellville plant. A substantial additional volume was also harvested and shipped to several of the company's other plywood plants. A thorough review of the company's Hugo log salvage program indicates that it was, by and large, very successful. The many serious problems encountered were overcome through effective coordination within the company, its Building Products Group, and its Eastern Wood Products Manufacturing Division; and with valuable assistance from outside organizations such as the American Plywood Association.

Unfortunately, lack of or slow action by government organizations created serious problems in implementation of timely salvage programs by the industry. For example, if permission had been granted to store logs in Lake Moultrie, it is estimated that more than twice as much timber could have been salvaged and stored for future consumption. After the company made the decision to go to dry-land sprinkler storage, its salvage program was also impaired because permission to draw sprinkling water out of the Rediversion Canal was slow in coming. On the other hand, the fact that the Hurricane occurred late in the year (September 19, 1989), when cool weather was starting, provided more time to implement a salvage program before rapid log deterioration set in. In fact, little deterioration was seen in the Hugo logs during the first three months after Hugo. However, the fact remains that government's lack of action resulted in a much smaller volume of timber being salvaged than otherwise could have been.

As mentioned earlier, there is a lack of specific information on how to design a program for harvesting and storing large volumes of logs damaged by hurricanes or windstorms. Further, very little information was available relating to the manufacture of plywood from salvaged logs. Therefore, the company's salvage program, at least in the beginning, was largely experimental. It is difficult to look back and recount the number and severity of problems encountered (on an hour-to-hour and day-to-day basis) in producing plywood from the wet-stored salvaged logs. It is obvious, however, that in spite of all the problems, the plywood plant did an outstanding job of producing a satisfactory product from the salvaged timber. This was accomplished through effective leadership and coordination, and plain hard work by everyone involved.

The major manufacturing problems were created by the wide variation in incoming log quality and moisture content. This was particularly difficult during two periods:

(1) during processing of logs that were received during the last two months of salvage operations (May & June, 1990), when the quality of the logs had severely deteriorated before harvesting; and

(2) during processing of logs from the first decks built, where the initial sprinkler system design did not provide adequate coverage to protect the logs from deterioration.

Log Receiving, Storage, and Sprinkling

The suddenness of the hurricane, plus the huge amount of damage to the timber in the area, forced Georgia-Pacific's Eastern Wood Products Manufacturing Division to react quickly. The original goal was to salvage 20 million board feet (Doyle) of S. pine veneer logs, but this was later increased to 30 and then to 40 million board feet. A total of about 60 million board feet was actually salvaged and stored for the Russellville plywood plant (Figure 5), plus additional volumes were shipped by rail to other company plywood plants in North and

South Carolina, Georgia, Florida, and Virginia. The overall objective was to salvage the largest and highest-grade timber as rapidly as possible.

Log Receiving and Storage

Within three weeks after Hugo, the company began receiving salvage logs. This continued through June of 1990, when it became obvious that the logs contained too much rot and insect damage to produce plywood. Approximately 60 percent of the volume came from Berkeley County (mostly from the Francis Marion National Forest); a significant volume also came from Clarendon County, with lesser volumes from Sumter and Williamsburg Counties.

As the salvage operation increased in volume, the company added log receiving and storage personnel and increased the number of receiving scales from one to four. At peak times, the company was receiving as many as 300 truckloads of logs per day and physically could not handle any more. Incoming loads of logs at the Russellville plant are normally weighed, unloaded, with some loads stick-scaled (Doyle). Deductions are made for defect, which normally runs about 3.5 percent. However, because of the large volume of incoming logs during the Hugo salvage period, the loads were visually inspected on the trucks (logs were counted and both ends of logs inspected) with deductions estimated.

The company's timber personnel established salvage log specifications and worked closely with contract loggers to make sure that the log specifications were understood and followed. The log specifications were:

- 8' 9" multiples in length (average log length was 35', ranging from 17 to 54')
- small-end minimum diameter 8" (raised to 14" near end of program)
- no visible cracks, splits, or ring shake
- no visible rot or insect damage
- tight bark

Although loggers adhered to the specifications fairly closely, a significant volume of reject logs were delivered to the logyard. The reject logs were purchased as pulpwood and placed in sprinkler storage mixed with good logs. An original objective was to put the better logs in storage and send the worst logs directly to the plywood plant for processing; but, in reality, the huge volume of incoming logs made it impractical to do any sorting. After unloading, the logs were stacked on the ground in decks to a height of 27-28 feet. Approximately 30 acres of land was required to store the 63 million board feet of logs.

Log Sprinkling

Problems with government "red tape" and the lack of internal knowledge about the parameters of log sprinkling created initial delays in getting the logs under water. Although DHEC (Department of Health and Environmental Control) temporarily waived the normal, long-term approval process, it still required that any log sprinkling installation be a closed-loop, recirculating system meeting certain rain-capacity requirements. Also, obtaining permission from the Corps of Engineers for pumping the sprinkling water from the Rediversion Canal proved to be a time-consuming problem. The proper design of a log sprinkling system itself was not known, relating to pump type and volume, pressure, filtration, pipe sizes, sprinkler head design and placement, and other factors. Because of this lack of knowledge, the design of an effective sprinkled log storage system was essentially a trial-and-error approach. Some assistance on sprinkler system design was obtained from two sources, (W. P. Law & Company in Columbia, SC and Bill Gomez and Associates in Lakeland, FL) but neither firm was experienced in systems for sprinkling logs.

Sprinkling actually began on the first decks of logs in February, 1990. The initial sprinkling system used very large agricultural sprinkler "guns" covering a wide area. Although the system sprayed an estimated 13.5 inches of water per day, coverage was poor, and the logs deteriorated significantly while in storage. This created severe problems in the plywood plant when the logs were finally processed.

Subsequent sprinkling systems employed a larger number of smaller sprinkler heads (3/16" and 1/4" orifice diameter) on top of the decks at 60-foot intervals and on the ends of the decks. This provided considerable overlap and more uniform coverage with about one-half the volume of water. These systems were equipped with pump strainers and were operated continuously, except for maintenance. Each 40 hp pump, operating at 80 psi (50 psi at sprinklers), provided water for five million board feet of logs. The company operated 16 such pumps, plus a larger one for pumping makeup water. Total water volume pumped was about 12 million gallons per day, with makeup water requirements of 2-3 percent. Two sources of water were used: the main source was from the Rediversion Canal out of Lake Moultrie which supplied over three quarters of the requirements; the balance came from wells. The pH of the water in the circulation ponds remained at about 7.5. A total of approximately 10 miles of pipe was laid during the program.

Two unusual problems were encountered as a result of the sprinkling program. First, the company received many complaints from nearby residents about the foul odor emitted from the log decks. Chlorine tablets were introduced into the sprinkling system, with no apparent improvement. The second problem involved an increased mosquito population which bred in the circulation ponds. About 100,000 mosquito-eating minnows (*Gambusia affinis*) were obtained from the Santee-Cooper Authority and planted in the ponds, which apparently solved the problem.

As time passed following Hugo, particularly after February, 1990, when the weather warmed, insect and fungal damage in incoming logs became progressively worse. Beginning in early April, insect infestation increased at a rapid rate, and Clemson University scientists were called in to assess the situation. It was recommended that logs be placed under sprinklers as soon as possible after harvest. Random inspections of the condition of incoming logs and their condition after being under sprinklers, showed that sprinkling appeared to be effective in preserving good logs and stopping further damage by insects and fungi in infected logs.

Moisture samples, taken from logs in storage by the company during the summer of 1990, showed wide variation: from 9 to 126 percent (oven dry basis), with an average of 60 percent. Moisture tests on incoming logs also showed wide variation, from 14 to 105 percent, also with an average of 60 percent. The wide variation in moisture content of the logs resulted from harvesting trees that were (1) still standing, (2) blown over, but with some roots intact, and (3) trees that had been blown over or broken off with no source of moisture. Timber site (swampy or dry) also affected log moisture content.

The company estimates that the additional cost of installing the sprinkler system and storing and sprinkling the Hugo logs amounted to approximately $45 per thousand board feet (Doyle). The incremental direct costs for operating the storage and sprinkler system, once the installation is made, is approximately $2.00 per MBF.

Plywood Processing

The plant began processing Hugo logs in October of 1989. Processing of sprinkled logs began in mid-1990 and continued through January of 1992. The salvaged logs were transferred from the sprinkled decks to the plywood operation on a last-in/first-out basis. This was done in order to process the logs with the greatest amount of deterioration first, since the effectiveness of water storage in stopping further damage was not known. The result of this program was that the driest logs were under the sprinklers for the shortest length of time. Also, since the logs were stored as they were unloaded from the trucks, with no sorting, the logs from the storage decks were delivered to the plywood plant in the same random manner. From time to time, fresh logs were also processed along with the Hugo logs in order to produce the veneer mix needed by the plant.

Green End

Several problems were encountered in producing green veneer from the Hugo logs. Because of the variation in moisture content and extent of fungal and insect damage from log to log, constant adjustments had to be made "on the run".

The blocks from the dry logs floated in the water vats, which required the water level to be dropped so the floor chains would pull the blocks out of the vats. Vat water temperature was reduced, block dwell time increased, and less caustic was required to maintain the proper pH (7.5-8.0). Blocks on the infeed chain between the vats and lathe had to be sprinkled to wet the surface so they would center properly in the XY charger.

The plant's boiler fuel costs also increased when Hugo logs were processed. Much of the bark sloughed off during log handling and storage and could not be recovered for fuel. This resulted in the purchase of increased volumes of supplemental fuel from outside sources (Figure 6).

Veneer blocks from the dry logs produced a very rough peel with a large amount of shelling. The dry blocks also required a different lathe set-up than green blocks, to obtain the proper veneer thickness. Veneer thickness from the dry blocks was increased slightly due to less "spring-back", as compared to veneer from green blocks. Clipping width of veneer from the dry blocks was reduced to compensate for less shrinkage in the dryers. Stacks of green veneer from the dry blocks did not produce mold growth when stored prior to drying.

The influence of the Hugo logs on green veneer volume recovery is difficult to assess, because of the mixing of the cull logs with grade logs and the lack of accuracy (on a short-term basis) in determining the volume of logs transferred to the plywood plant from the sprinkled decks. On the other hand, the negative effect on veneer grade recovery (Figures 7a, 7b, 7c) was obvious from the prevalence of insect holes, blue stain, brown rot, stress cracks, splits, shake and rough peel. At times, the production of siding and other higher-grade panels was substantially reduced due to lower face veneer yield from the Hugo logs (Figure 8).

Veneer Drying

Variation in moisture content from log to log and within a log, created serious problems at the veneer dryers. Proper control of dry veneer moisture content was a constant problem throughout the Hugo program due to the wide fluctuation, on a short-interval basis, in moisture content of the green veneer. The dryer speeds were constantly adjusted to try to compensate for the green veneer moisture content variations; the result was the veneer from the dry logs was typically overdried and the veneer from the wetter logs was underdried.

A constant problem was the abnormal exudation of pitch from the green veneer which accumulated on conveyor rolls, dryer rolls, etc. This also could be seen on the dry veneer in the form of black streaks and spots. A greater-than-normal amount of wood "trash" also accumulated in the bottom of the dryers, creating a fire hazard.

Panel Production

Panel layup presented the greatest challenge in processing because of the uncontrollable variables which had to be dealt with. Dry veneer moisture content, roughness, and absorptive properties were constantly changing. This required continuous modification of the adhesive formulation and spread rates to try to compensate for the changing conditions. For example, between November, 1989 and June, 1991, the adhesive mix was changed 17 times. Extenders were modified, resin solids was increased, the base resin changed, the mix "dried-up or greened," flow enhancer increased, etc.

Panel thickness variation was also a problem, due to the variation in log moisture content. This was controlled by adjusting both the peel thickness and press schedule (single-stage).

Product Quality

The plant faced a myriad of severe processing problems which directly impacted product quality in manufacturing plywood from the Hugo logs. Most of these problems resulted from the wide variation in quality and moisture content of the incoming logs. The severity of the problem was increased by the fact that (1) log quality varied from hour-to-hour, and (2) the total production process was affected, from the water vats through the hot press.

During the Hugo-log utilization period, the plant experienced an increase in gluing problems (Figure 9). Basic reasons for the glueline problems include (1) dried-out glueline due to overdried veneers, rough veneer, and blue stain; (2) over-penetration of glue due to increased porosity and permeability associated with blue stain and decay; (3) heavy, light, and spotty spreads attributable to glue application procedures; and (4) thick and thin veneer due to inconsistency in log moisture content and quality, block conditioning, and lathe setup. The mixing of fresh logs with Hugo logs, modification of the glue formulation, and process adjustments helped to alleviate these gluing problems and enabled the plant to produce plywood which consistently met product standards.

Panel strength/stiffness tests were carried out during the Hugo-log utilization period by both the American Plywood Association (Figure 10) and the Southeastern Forest Experiment Station, U.S. Forest Service (Figures 11a and 11b). The test results showed that the panels consistently exceeded minimum product standards and, in most instances, were better than the controls. The increase in panel strength/stiffness is attributed to the larger logs processed from the old-growth Hugo-damaged timber. Minimum small-end diameter specifications for the salvage logs was gradually increased from 8 to 18 inches during the period when Hugo logs were received.

In summary, the plywood plant was able to overcome these major obstacles associated with the Hugo logs and, through effective leadership and teamwork, consistently produce a product which met or exceeded minimum panel standards. The company's Chemical Division (adhesives supplier) and the American Plywood Association worked closely with the plant throughout the Hugo program and provided valuable assistance in maintaining product integrity.

RECOMMENDATIONS

Two extremely important messages emerged from this project. First, the slowness of some government agencies in responding to industry's needs delayed and sometimes prevented the implementation of critical programs. Second, the lack of experience and readily-available information, related to dealing with a timber disaster such as Hugo, prevented the private and public sectors from responding in a timely and effective manner. These obstacles delayed or prevented needed action and resulted in (1) much less timber being salvaged than should have been, and (2) higher costs and greater problems in storing and processing the Hugo logs. Also, the full impact of these problems was not experienced because of the timing of Hugo, which provided more response time than if it had occurred, for example, in the spring.

Based on past history, it can be assumed that another hurricane will strike a timbered area in the South, and that quick and effective action by the private and public sectors will be required to salvage as much timber as possible. At least two major steps are recommended before another hurricane strikes. First, all available information related to harvesting, storing, and processing storm-damaged timber should be compiled and stored where it is readily available. The existence of such an information center(s) should be communicated to appropriate public agencies and the forest industry. (This report is an example of the kinds of information needed.) Second, public agencies and the forest industry need to develop a disaster plan which identifies decisions and critical actions which must take place and describes how these will be made and implemented on a timely basis.

Information for Future Consideration

The following suggestions are offered to alleviate some of the most serious problems experienced in harvesting, storing and processing the Hugo timber, if a similar situation were to occur in the future.

Adequate Log Storage Capacity

One of the most serious problems encountered with salvaging Hugo timber, was the lack of planned water-storage sites for large volumes of logs. As harvesting volume increased beyond the processing capacity of mills, the market became flooded with pine logs because of lack of alternative storage sites. This caused some loggers to leave the area and discouraged others from coming to the salvage area. The use of Lake Moultrie for temporary log storage would have been of great benefit, with minimal environmental problems created. Also, the U.S. Forest Service considered offering to wet-store logs from all sales on the Francis Marion National Forest, with payment to be made when the logs were removed from storage. This potentially beneficial program was never implemented.

These are examples of actions which should have been taken, but were not. If the maximum volume of timber is to be salvaged, adequate storage facilities must be provided, and financial assistance should be available to carry the increased log inventories.

Log Specifications

The volume of cull logs mixed with the grade logs, caused problems in plywood processing. Also the economics of going to the expense of hauling and wet-storing cull logs should be questioned. Practical and easily understood log grade rules, which will omit the undesirable logs, should be established. Loggers should be trained to follow the established rules and monitored to make certain the rules are being followed and cull logs are not brought to the storage site or mill.

Sprinklered Log Storage Practices

Sites for sprinklered log storage should be carefully selected to meet DHEC regulations for runoff collection, recirculation, and rainfall capacity. Adequate makeup water should be available, and three-phase electrical power is needed. Based on Georgia-Pacific's experience, approximately two million board feet (Doyle) of logs can be stored per acre.

The large variation in log quality and moisture content contributed to the bulk of problems encountered in plywood processing. If practical, some sorting of incoming logs should be done. Cull logs which are delivered should be chipped, if possible; if chipping is not feasible, the culls should be marked and stored separate from grade logs. Dry logs should also be identified if possible, and stored separately.

Maximum height of log decks should not exceed 20 feet, in order to get adequate moisture to all logs. Piling density should also be considered, since closely-piled logs require more water. Decks should be laid out so that ends of logs in adjoining decks are as close together as practical. Decks should be built directly on the ground. Logs will gradually pick up moisture in wet-storage and moisture content variation among logs will be reduced. Therefore, logs should remain in wet-storage as long as possible and removed for processing on a first-in/first-out basis.

Log Sprinkling System

The critical factors in successfully storing logs under sprinklers are to (1) get water on log decks as quickly as possible, with a continuous spray which is adequate to keep log surfaces completely wet at all times, and (2) reach and maintain a sapwood moisture content high enough to prevent or stop insect and fungal infestation. Sprinklers should be placed on top of the log decks so there is adequate overlap to maintain coverage when the wind blows. Sprinklers should also be placed between decks to keep the log ends wet. Sprinklers should be operated continuously around the clock, 365 days per year. The sprinkler system should be monitored on a daily basis to ensure that all sprinklers are operating properly and all log surfaces are wet. Provision should be made for a backup system in case of pump failure. Moisture sampling of the logs in sprinkler storage should be done periodically to ensure that adequate water is being applied. Research is being carried out currently by the U.S. Forest Service and Clemson University on the long-term storage of pine logs under water sprinklers. This research will provide more specific information about the design and operation of log sprinkling systems.

In most closed-loop systems, the runoff water carries a large amount of dirt, bark, and other debris back to the circulation pond, which makes it necessary to install an efficient filtering system at the pump. A settling pond in front of the pump pond is also beneficial. The pumps should be sized to maintain a pressure at the sprinklers of 40-50 psi. A typical system uses full-circle impact irrigation sprinklers, with 3/16- or 1/4-inch orifices, placed 60 feet apart. For example, a 3/4- or 1-inch sprinkler with a 3/16-inch nozzle will spray 6.4 gallons per minute at 40 psi nozzle pressure. Also, prevailing winds affect water distribution and should be considered in placing the sprinklers.

Log sprinkling produces some unusual "side effects" which should be considered in designing and operating the system. After a few weeks under sprinklers, the log ends become coated with a layer of slime fungi, algae, and moss. Bark will tend to slough off the logs. As the sprinkling water is recycled, it will develop an unpleasant odor which may cause complaints from nearby residents. The circulation ponds may become a breeding place for mosquitos. If the log decks are located near a paved road, the windblown water may freeze in cold weather, creating a hazard for motorists. Sprinkled logs also become extremely slippery, which makes them more difficult to handle when removed for processing, and also creates a serious safety problem for personnel maintaining the sprinkler system. Caulked boots are required for anyone walking on the decks.

Processing

As mentioned above, logs should be removed from the sprinkled decks for processing on a first-in/first-out basis. Log input to the plant should be planned so that manufacturing variables are minimized as much as possible. For example, rather than processing sound and defective logs or green and dry logs together, it would be preferable to keep them in separate categories and make production runs on each log type. If the logs to the processing plant contain wide variations in moisture content and cannot be presorted, then it would be desirable to sort the green veneer or lumber (by moisture content) for drying purposes, to reduce moisture variation in the dried lumber and veneer.

Proposed Forest Disaster Plan

The South is periodically struck by a major storm which causes extensive damage to an area's timber resource. Hurricanes have been the most destructive force striking the southern coastal states in the past, and continue to be the major threat in the future. A review of the timber salvage programs related to some of the past hurricanes in the South, including Hugo, show a similar scenario. Typically, a task force is formed to coordinate salvage activities; timber harvesting is increased rapidly; in a few weeks, inventories at using mills are filled to physical and financial capacity; it is discovered that government assistance is not available for facilitating the development of large wet-storage sites for salvage logs; sawtimber is salvaged as pulpwood; harvest rates decline because of the saturated market and reduced prices; and much of the remaining timber is destroyed by insects and fungi before it can be harvested. Not only is the market value of the unharvested timber lost, the damaged timber increases the fire danger and hampers reforestation.

For example, Hurricane Camille damaged 285 million cubic feet of timber when it struck the Mississippi Gulf Coast in August, 1969. A total of only 77 million cubic feet, comprised of 818,000 cords of pulpwood and 109 million board feet of sawtimber, was harvested. Within two months after the hurricane, it was reported that mill inventories were filled and that government funds were being requested for wet storage of surplus logs. A month later, the forest industry was notified that government funds for storing logs were not available. Timber harvest rates slowed and most timber harvested was sold for pulpwood. Almost three-fourths of the damaged volume was lost. Mississippi's Forest Disaster Salvage Council was dissolved in July, 1970. In its final report, the Council made a number of recommendations for use <u>after</u> the occurrence of a future forest disaster. Nothing was recommended regarding planning before the next hurricane.

Need for Planning

Based on past history and the recent Hugo experience, there appears to be a real need for the development of a forest disaster plan involving southern coastal states. Because of the rapid deterioration of downed timber, particularly during warmer weather, time is critical to a successful timber salvage program. The damaged timber should be harvested as quickly as possible, and the surplus logs placed immediately in wet storage. Most mills are not prepared, either physically or financially, to develop large water storage facilities on short notice. Therefore, planning before the storage facilities are needed is an absolute necessity. Most government agencies use time-consuming decision-making processes and, therefore, have difficulty in responding to urgent requests. Since several government agencies perform key roles in timber salvage programs, preplanning is necessary to accelerate decision-making and enable the agencies to make positive, timely responses to timber salvage program needs.

In summary, most timber salvage activities have been reactive, with many decisions made quickly without adequate planning or information. In situations where government agencies were involved, critical decisions were sometimes delayed or not made at all. Further, most states do not have the resources to mount an effective timber salvage program without outside assistance.

Recommended Action

A consortium of southern states should be formed, including the southern coastal states from Virginia to Texas. This consortium should take a proactive stance in developing a timber disaster plan which would be applicable to any member state when the next disaster occurs. The plan should provide a framework for effective and timely implementation and decision-making, and should identify the major resources that will likely be needed and the providers of those resources. States who are members of the consortium should pledge to provide assistance to one another in implementing the plan when a disaster occurs.

A consortium regional forest disaster task force should be established, consisting of a representative from each consortium member state, and representatives from the private sector and from each regional government agency directly involved in environmental regulation, transportation, financial assistance, and other functions involved in timber salvage. The logical representative from each member state would be its State Forester. Industry would be represented by an executive from each of two or three firms which have operations in several of the consortium states. A representative from each of the appropriate regional government agencies would represent the public sector. The regional task force would be responsible for establishing a regional disaster plan and coordinating related activities among the member states.

An important objective of the regional disaster plan would be to eliminate barriers between states so that the resources and markets for a timber salvage program would be available beyond the state or states in which the disaster occurred. An example would be the development of an economic model which would establish fair market prices for salvage timber products throughout the region, and which would provide incentives to harvest, store, and process the maximum volume of salvage timber. Additionally, reciprocal agreements should be made between states to facilitate the transportation of timber products across state lines.

A forest disaster task force also should be established in each state, under the umbrella of the regional task force, and headed by the state forester. Appropriate representatives from the private and public sectors in that state would be selected to serve on the individual state task forces. Each state task force would develop a forest disaster plan for its state, within the framework established by the regional task force. Examples of key areas which should be addressed in the state plan are:

1. Development of a rapid method (satellite imagery, for example) for quickly assessing the extent and characteristics of the timber damaged.
2. Creation and maintenance of a current listing of all timber producers (loggers), dealers, and buyers in the state, along with their capabilities.
3. Pre-approval by regulatory agencies, related to harvesting the damaged timber, transportation of logs, wet-storage of logs, and other vital activities associated with the timber salvage program.
4. Formulation of an emergency financing plan, involving both the public and private sectors, which would provide needed funding for harvesting, transportation, storage, and processing of the salvage timber.
5. Development of information relating to the detailed design of log sprinkling systems and other methods of wet-storing salvaged logs.
6. Designation of a university forestry school (Department of Forest Resources at Clemson University, for example) as the information center for timber salvage technical information, such as wet-storage of logs.

In summary, past salvage programs for timber disasters have resulted in the recovery of a relatively small volume of damaged timber. A timber disaster plan of the type described above can result in the recovery of millions of dollars of additional valuable timber than typically has been salvaged in the past.

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APPENDIX
TABLE/FIGURES AND DESCRIPTIONS

Table 1. Estimates of damages, reimbursements, and unreimbursed losses ($ million) from Hurricane Hugo. (Source: Office of Economic Research, 1991).

Category	Damages	Reimbursements Insurance	Reimbursements Public Assistance	Unreimbursed Losses
Residences	2,960	1,349	22	1,589
Commercial/Industrial	1,029	829	0	200
Federal Flood Insurance		365	0	(365)
Autos, Misc.	215	182	0	33
Utilities	197	0	74	123
Ports Authority	17	16	1	0
Forest	1,181	150*	0	1,031
Agricultural Structures	294	0	0**	294
Agricultural Crops	87	0	2	85
Charleston Naval Base	250	0	250	0
Shaw Air Force Base	50	0	50	0
Other Govt. Agencies	142	0	142	0
Total	6,422	2,891	541	2,990

* Estimated value of salvaged timber.
** Funds received by farmers from FEMA are included under reimbursements for residences.

It is estimated that South Carolina sustained more than $6 billion in damages due to Hurricane Hugo. Hardest hit were the residential, forestry, and commercial/industrial sectors, which suffered damages of $2.96 billion, $1.18 billion, and $1.03 billion, respectively. Taking into account the reimbursements received by the different sectors, it is clear that forestry is the big loser with only $150 million worth of timber recovered through the salvage operation. This recovered amount represents only 13% of the total damages. In comparison, residences and commercial/industrial businesses recovered 46% (or $1.4 billion) and 80% (or $829 million) of the damages, respectively, through insurance claims and public assistance.

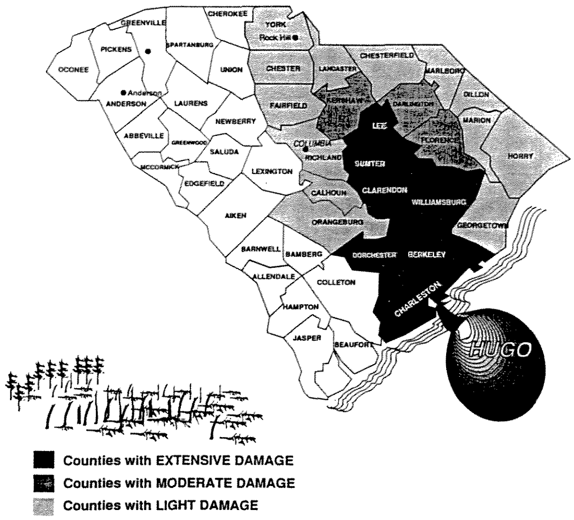

Figure 1--Relative degree of forest destruction caused by Hurricane Hugo in South Carolina counties. (Source: South Carolina Forestry Commission, Columbia, SC)

Twenty three counties reported substantial timber damage, with seven of the counties--Berkeley, Charleston, Clarendon, Sumter, Williamsburg, Lee, and Dorchester--accounting for 70% (or 918 million cubic feet) of the total volume of timber lost in these areas. An additional 98 million cubic feet of timber were lost in Kershaw, Darlington, and Florence counties. The 23 counties contained 6.5 million acres of timberland, of which 4.5 million acres (or 69%) were damaged by Hurricane Hugo.

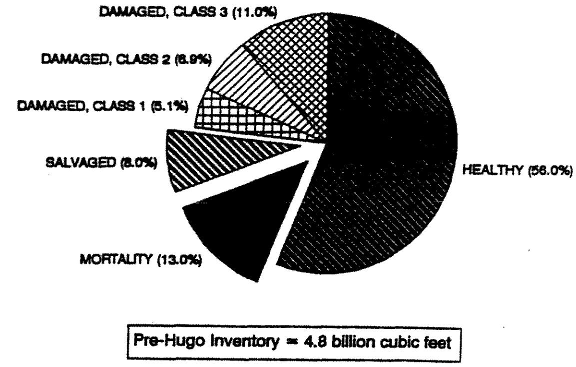

Figure 2--Softwood stock inventory in the 23 South Carolina counties which suffered substantial timber destruction due to Hurricane Hugo. (Source: Sheffield and Thompson, 1992)

The pre-Hugo inventory of 4.8 billion cubic feet was reduced by about 21 percent or 1 billion cubic feet. One-third of this lost softwood volume was salvaged; while two-thirds was killed but not salvaged. Twenty-nine percent, or approximately 1.1 billion cubic feet, of the growing stock classified as live timber sustained damage to some extent. Roughly 245 million cubic feet of this damaged volume were categorized as having class 1 or such severe damage that it was recommended they not be retained in the stand. Almost 330 million cubic feet were categorized as having class 2 or moderate damage; while about 530 million cubic feet sustained class 3 or light damage.

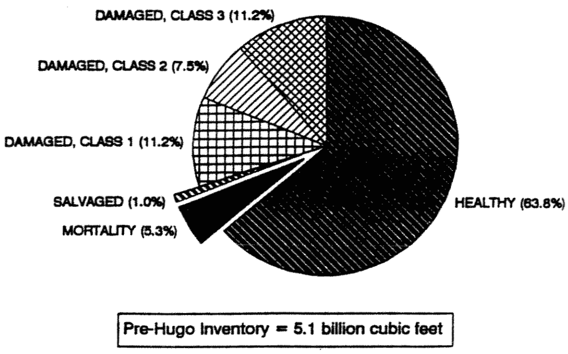

Figure 3--Hardwood stock inventory in the 23 South Carolina counties which suffered substantial timber destruction due to Hurricane Hugo. (Source: Sheffield and Thompson, 1992)

The pre-Hugo inventory of 5.1 billion cubic feet was reduced by about 6 percent or 319 million cubic feet. This inventory reduction was attributed to 270 million cubic feet of Hugo-related mortality and 49 million cubic feet of salvaged timber. About one-third, or 1.5 billion cubic feet, of the post-Hugo hardwood growing stock was damaged to some degree. Almost 610 million cubic feet of this damaged volume were categorized as class 1 (severely damaged); while 351 million cubic feet and 565 million cubic feet were classified as class 2 (moderately damaged) and class 3 (lightly damaged), respectively.

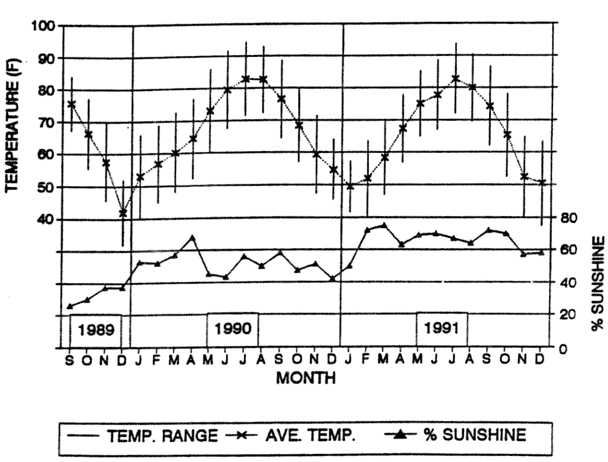

Figure 4a--Monthly averages of temperature (°F) and sunshine (% of total possible) for the Russellville, SC area during the Hugo-log storage period. (Source: National Climatic Data Center, Asheville, NC)

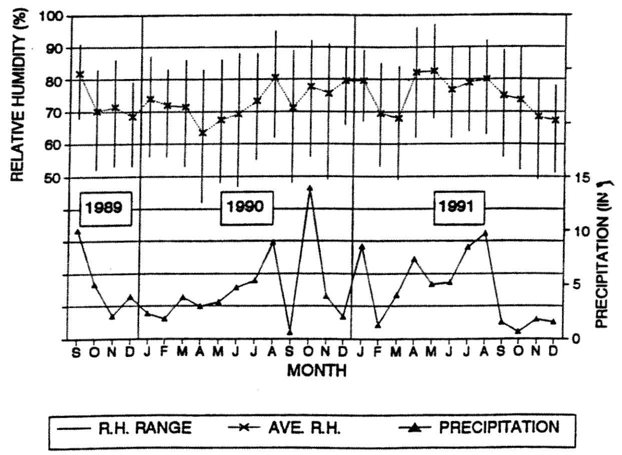

Figure 4b--Monthly averages of relative humidity (%) and precipitation (in.) for the Russellville, SC area during the Hugo-log storage period. (Source: National Climatic Data Center, Asheville, NC)

The occurrence of Hurricane Hugo late in the year when cool weather was starting provided the company a few months of salvage operation before rapid log deterioration set in. The decision to extend the salvage operation until June 1990 is debatable considering that the weather conditions were such that the logs would have already deteriorated badly by then. Weather conditions in the area during the storage operation were also favorable to the growth and development of fungi and insects. Even during winter, the temperature was mild and not low enough to prevent fungal and insect attack. The percentage of sunshine was high throughout the year so that moisture evaporation from the logs required continuous and adequate water sprinkling; precipitation was not high enough to supplement the water spray.

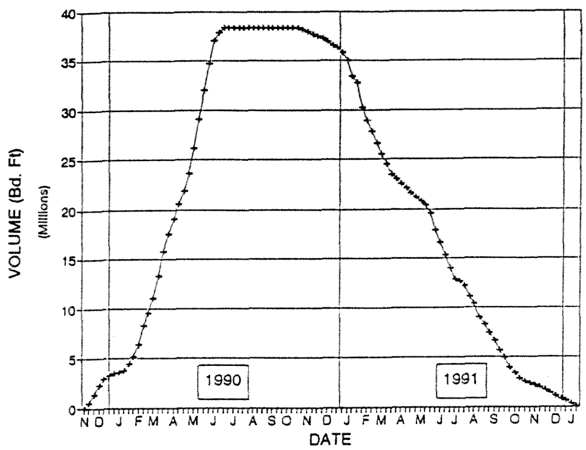

Figure 5--Inventory of Hugo logs (bd. ft.) in four sprinklered sites set up by the Georgia-Pacific Timber Division in Russellville, SC.

A total of about 40 million board feet was stored in these sites. Not reflected in the figure are the additional 7 million board feet wet-decked in the plywood mill yard and the 13 million board feet stored in the GP Jamestown yard. The plateau in the curve between June and October 1990 indicates that logs from the other sites were processed into plywood during this period.

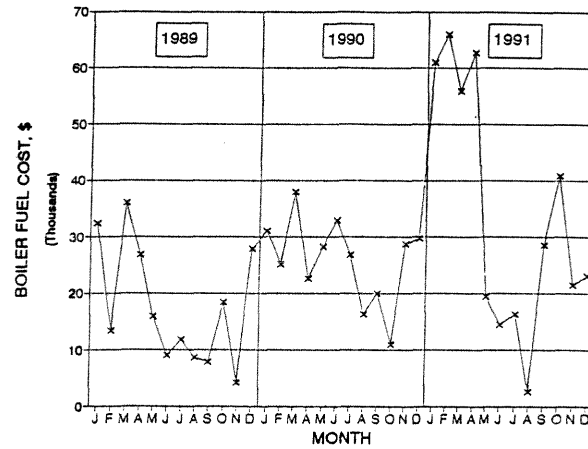

Figure 6--Cost of supplemental boiler fuel at the Georgia-Pacific Russellville plywood plant during the period when Hugo logs were processed into plywood.

Since much of the bark normally used as fuel was lost due to sloughing off during storage and handling, the cost of supplemental boiler fuel went up during the Hugo-log utilization period, particularly in early 1991. The subsequent reduction in cost was probably due to better bark recovery when the plant started mixing fresh logs with the Hugo logs.

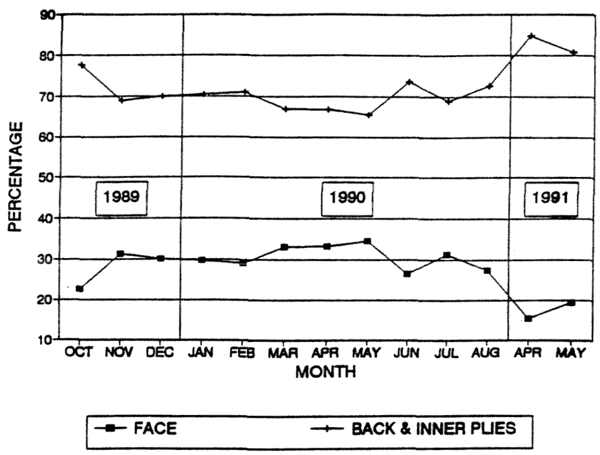

Figure 7a--Percentage of face and back/innerply veneers produced from Hugo logs.

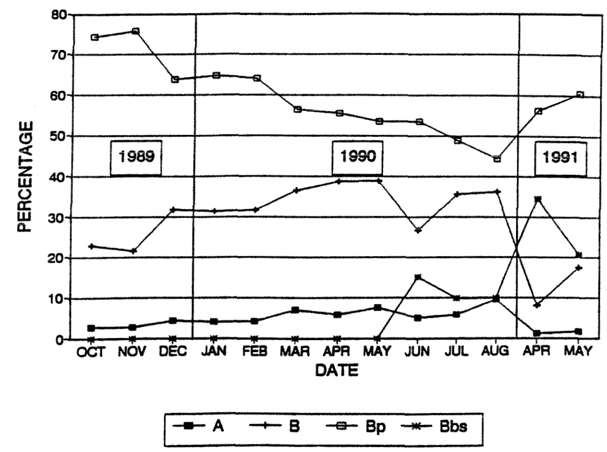

Figure 7b--Grade classification of Hugo-log face veneers. Note: Bbs is a special grade of B-veneer containing more than 50% blue stain.

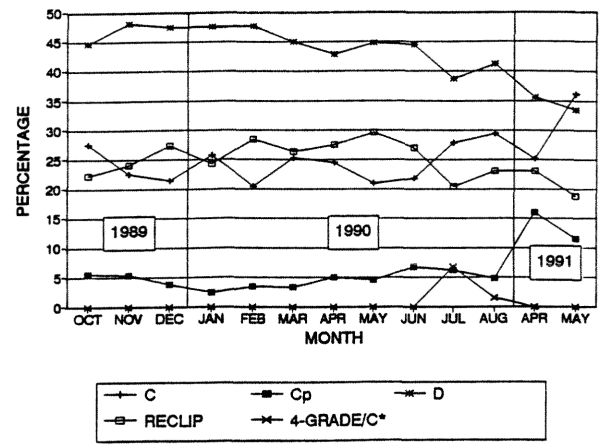

Figure 7c--Grade classification of Hugo-log back/innerply veneers. Note: C* represents veneers of lower value than Cp grade due to insect boreholes.

Figure 7a shows the percentage of face and back/innerply veneers produced from Hugo logs. The recovery of face-grade veneers declined, while that of back/innerply-grade veneers increased during the period when Hugo logs were peeled. The negative effect on veneer grade was mainly due to the prevalence of insect holes, blue stain, brown rot, stress cracks, splits, shake, and rough peel. A breakdown of face-grade veneers in Figure 7b shows that the high-quality A- and B-grade veneers declined tremendously; while the Bbs grade increased significantly during the later part of the Hugo-log utilization period. Bbs, a special grade, was created to accommodate B-grade veneer which has more than 50% blue stain. Among the four face-veneer grades, almost 60% were classified as B-plugged; while only about 5% were considered A-grade veneers. Figure 7c gives a breakdown of the back/innerply veneers into the different grades. Majority of the veneers (approximately 45%) were of the D grade. C* grade veneers started to appear in July 1990, representing as much as 7% of the back/innerply veneers produced. C* indicates veneers which are of lower value than the Cp grade due to insect boreholes.

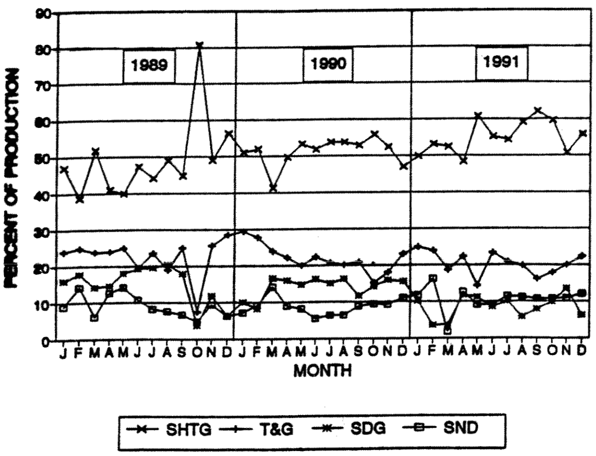

Figure 8--Product mix at the Georgia-Pacific Russellville plant during the period when Hugo logs were processed into plywood. Note: The October 1989 increase in sheathing (SHTG) was in response to Hurricane Hugo protection and repair needs.

The production of siding and other high-grade panels was reduced at times due to poor veneer quality. Sheathing panels represented approximately 55% of the total production, while T & G panels comprised 25%.

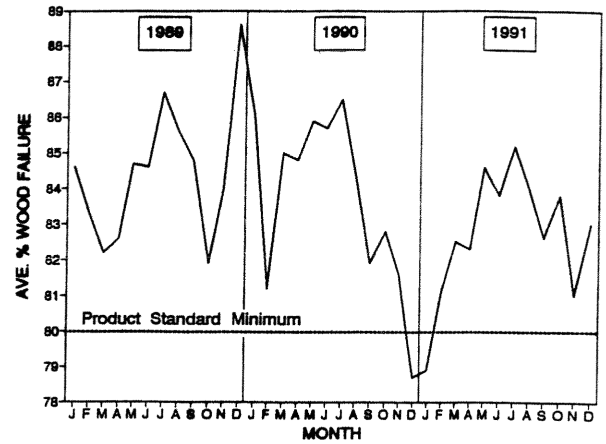

Figure 9--Average percent wood failure during vacuum-pressure testing of CDX-grade panels produced from Hugo logs at the Georgia-Pacific Russellville plant.

The best indicator of glueline quality is the average percentage of wood failure following a stringent vacuum-pressure-soak cycle. Figure 9 depicts the glueline test performance of Russellville immediately prior to and through the processing of Hugo-downed timber. The Product Standard for Construction Grade Plywood (PS-1) sets a lower limit of 80% wood failure for conformance to the Standard. Remarkably, despite all the processing hurdles the mill had to overcome, the mill met or exceeded the Standard requirement, except for December 1990 and January 1991. Mill management and the adhesive supplier monitored this problem closely during these critical winter months to insure that deficient panels were identified and trademarks indicating conformance to the Standard were removed from the panels.

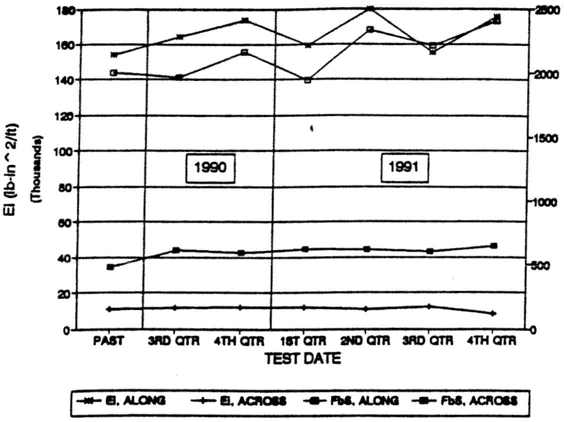

Figure 10--Full-panel bending properties (stiffness, El; and maximum bending moment, F_bS) along and across the major panel axis of Hugo plywood produced at the Georgia-Pacific Russellville plant.

The figure presents the panel stiffness (EI, lb-in²/ft of panel width) and maximum moment (F_bS, lb-in/ft of panel width) of 15/32", 3-layer Southern pine plywood produced from Hugo logs and tested during routine quarterly sampling using the American Plywood Association flexure machine. Data for past production include those from 1983 to 1990. No apparent upward nor downward trend was indicated by the data, suggesting that the wet storage of Hugo logs had no negative effect on the strength properties of the panels produced from the said logs. In fact, the stiffness and maximum moment along and across the major panel axis of the Hugo plywood were, in general, higher than those of the panels from past productions due to the larger, old-growth Hugo logs processed. Note, however, that the average EI across the major panel axis of the Hugo plywood produced during the fourth quarter of 1991 was noticeably lower than the average from previous samplings.

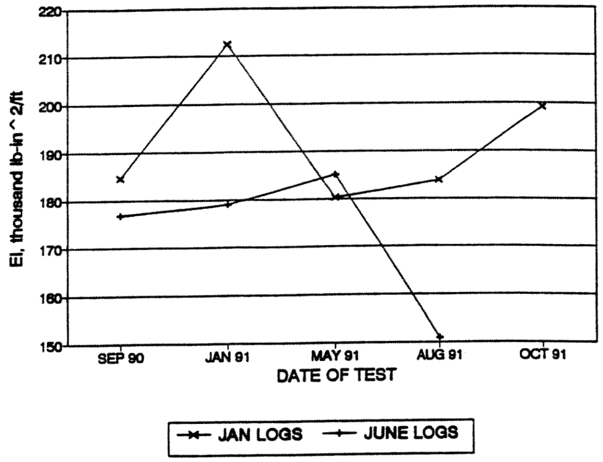

Figure 11a--Dead-weight panel stiffness (lb-in²/ft) of plywood produced from Hugo logs at the Georgia-Pacific Russellville plant.

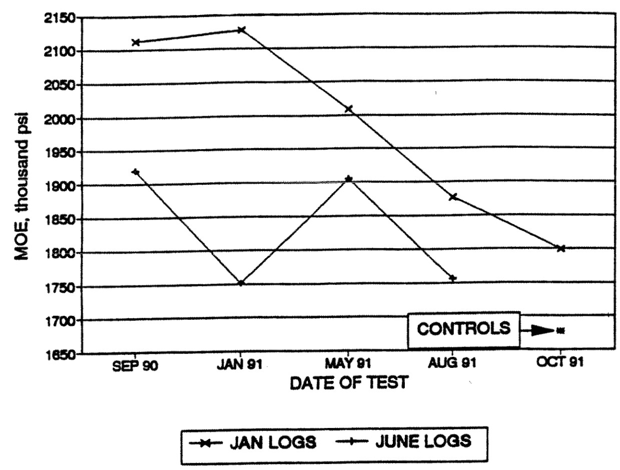

Figure 11b--Dead-weight modulus of elasticity (psi) of plywood produced from Hugo logs at the Georgia-Pacific Russellville plant.

Figures 11a and 11b present the results of dead-weight testing conducted to determine the effect of the delay in the sprinkling of the salvaged logs on the quality of the panels produced. The tests were performed at various times to evaluate as well how the bending properties of the panels changed during the Hugo-log wet-storage period. The controls were from logs harvested from standing trees; the January and June logs were from trees downed by Hurricane Hugo. The January group consisted of panels made from logs stored in January 1990 with water applied in April 1990; while the June group was from logs stored in June 1990 with water applied in July 1990. The EI and MOE of the June-log panels were, in general, lower than those of the January-log panels suggesting that significant deterioration had occurred in the logs which were left unprotected longer in the forest and were not immediately placed under water. The EI value of the January-log panels remained more or less steady throughout the test period; while the EI of the June-log panels took a 19% reduction from 185,000 lb-in^2/ft in May 1991 to 150,000 lb-in^2/ft in August 1991. The average EI values of both the January- and June-log panels were above the minimum acceptable limit (116,000 lb-in^2/ft) established by the American Plywood Association. With regard to the MOE, the average for the January-log panels showed a steady decline from about 2.12 million psi to 1.8 million psi; while that of the June-log panels fluctuated between 1.75 million psi and 1.9 million psi. All MOE averages for the January- and June-log panels were above the control-panel average of 1.68 million psi.

EFFECT OF LOG WET STORAGE TIME ON THE STIFFNESS OF SOUTHERN PINE PLYWOOD (A CASE STUDY)[1]

Robert H. McAlister, Alexander Clark III, and Joseph R. Saucier

INTRODUCTION

Hurricane HUGO, which struck the South Carolina coastline on September 22, 1989, was one of the most destructive storms of the past 200 years. One of the effects of HUGO was devastation of standing timber in the Coastal Plain of South Carolina. After the storm, it was estimated that the downed and damaged timber represented over 5 years of normal capacity for the wood products mills in the area. Salvage of the damaged pine timber began immediately after the storm and continued for about 9 months when it became unusable for most products. Salvage of damaged hardwood timber was hampered by wet logging conditions and limited markets, but continued on a limited basis for 18 months. Approximately 20 percent of the storm-damaged timber was salvaged.

The major concerns which may have deterred more extensive salvage efforts were the uncertainty concerning the deterioration of logs stored under water sprinklers beyond one year and the effect of storage on logs which had already undergone considerable deterioration.

STUDY OBJECTIVES

We designed this study 1) to determine the storage time at which plywood produced from stored logs begins to lose stiffness to a measurable degree; and 2) to determine if increased storage time results in a significant increase in spinouts or broken veneer.

MATERIALS AND PROCEDURES

Logs salvaged immediately after HUGO (January stored logs) and logs salvaged 9 months after HUGO (June stored logs) were sampled at 3-month intervals beginning one year after HUGO.

[1] Presented at 46th Annual FPRS; Charleston, SC. June 24, 1992.

The logs were pulled from the storage piles, spread on the log yard and measured for length and large and small end diameter. The logs were then placed on the merchandiser butt end first. Disks approximately 1 to 3 inches thick were removed from the tree length logs at the butt and at the top of each 102-inch veneer block on the merchandiser cross-cut saw. These disks were placed in plastic bags and taken to Athens, Georgia, for moisture content and specific gravity determinations. Specific gravity was computed from green volume and ovendry weight. Moisture content was computed on a dry basis after samples were dried to constant weight at 215°F.

The study blocks were tagged on the ends with aluminum tags before being placed in hot water vats for conditioning. The two log storage groups (January and June) were separated in the vats by a marking system using both rope wrapping and the end tags. Blocks were conditioned for about 18 hours at 170°F prior to peeling. This was standard conditioning time for the mill. The blocks were peeled into nominal 1/6-inch veneer. Before the blocks from each group were peeled, the green chain was cleared of all veneer. The diameter of each dropped core was measured and recorded.

The integrity of the veneer from each group was maintained through the drying, layup and pressing procedures. Veneer from each group was used to manufacture CDX (3-ply, 15/32", unsanded) peformance-rated panels.

Ninety panels from each group were randomly selected and tested for panel stiffness using the American Plywood Association portable panel tester. Full size panels were supported over a span of 84 inches. They were preloaded with a 20-pound full panel width bar. The deflection of the panel was measured at the center to the nearest 0.001 inch with a dial gauge. The panel was then loaded with a 20.5-pound full-panel width bar. The deflection at the center point of the panel was read and recorded. These deflection values together with the average thickness of the panel were used to calculate the panel EI or stiffness value.

The stock of June stored logs was exhausted after the August 1991 test sample. A group of fresh logs of approximately the same diameter as the stored logs was substituted for the June stored logs in the October 1991 study sample. These fresh logs were included as a comparison (control) group for log moisture content and panel properties.

RESULTS AND DISCUSSION

The timber salvaged after Hurricane Hugo was of very high quality. Most of the storm-damaged timber was old-growth longleaf pine (*Pinus palustris* L.) with dbh over 16 inches. This raw material would be expected to produce plywood of above average properties.

From the start of the study, the difference in appearance between the January stored and June stored logs was striking. The January stored logs had some intact bark and appeared to be firm. The June stored logs had no bark and had obvious spongy areas on the surfaces and the ends. When the tree-length logs were bucked to length, the June stored logs showed extensive bluestain and some radial drying checks; the January stored logs showed practically no bluestain and no radial checking. There was little change in appearance over the period of the study, except that for the August 1991 sample, the June stored logs showed extensive decay pockets and zone lines. The January stored logs showed some light bluestain but otherwise remained bright and sound throughout the study. There were practically no spinouts throughout the study. There was no increase in core diameter for either the January or June logs.

During the course of the study, the plywood mill was continually adjusting process variables such as veneer thickness, drying time, adhesive formulation, and pressing conditions. These adjustments were required to maintain quality in the light of subtle changes in veneer surface characteristics, porosity and wettability. These process adjustments were initiated primarily because of the characteristics of the June stored logs.

The specific gravity and moisture content of the January and June logs for the study period are shown in Table 1. Essentially, there was no change in moisture content or specific gravity for the study period. The 10- to 15-percent variation in moisture contents are quite common in large log piles. Generally, the January stored logs had slightly higher moisture contents than the June stored logs. The control logs had the lowest moisture content of all. This indicates that the sprinklers were maintaining acceptably high moisture contents in the stored logs. It also shows that veneer from the stored logs would probably require longer drying time than that from fresh logs.

The average and standard deviation values for panel stiffness and panel thickness for the study material are shown in Table 2. The minimum value for panel EI as established by the U.S. Product Standard PS-1 for Construction and Industrial Plywood is 116,00 lbs-in^2. Generally the January stored log group shows higher EI values than the June stored log group (May 1990 test is an exception). The January stored log group also had a slightly higher EI than the Control group tested at the same time.

CONCLUSIONS

Logs can be stored under water sprinklers for up to 2 years with no measurable degrade in panel properties. Changes in the process of producing plywood may be required. Depending on the time of year and the weather, damaged timber can be salvaged for a period of up to 6 months. Bluestain can develop very quickly in downed timber especially in warm weather. Generally bluestain affects the appearance but does not reduce the strength or stiffness of wood products. It is important that the salvaged logs be put under water sprinklers as soon as possible.

Table 1--Average (standard deviation) moisture content and specific gravity for disks removed from test logs during the study. There were no June stored logs for Oct 1991 tests.

Test Date	January Stored Logs			June Stored Logs		
	Sample Disks	MC %	SG	Sample Disks	MC %	SG
Sep 1990	169	101(20)	0.486(0.044)	164	96(19)	0.496(0.044)
Jan 1991	91	104(20)	0.476(0.049)	83	105(22)	0.490(0.047)
May 1991	62	105(26)	0.486(0.046)	67	92(24)	0.471(0.056)
Aug 1991	99	110(21)	0.456(0.052)	85	93(23)	0.474(0.049)
				control	**control**	**control**
Oct 1991	70	104(22)	0.473(0.050)	73	83(21)	0.525(0.049)

Table 2--Average (standard deviation) panel EI and panel thickness for the plywood log storage study. Each value represents 90 panels. There were no June stored logs for Oct 1991.

Test Date	January Stored Logs		June Stored Logs	
	EI ($lbs\text{-}in^2$)	Thickness (inches)	EI ($lbs\text{-}in^2$)	Thickness (inches)
Sep 1990	184,618(18,790)	0.404(0.010)	176,713(35,080)	0.452(0.011)
Jan 1991	212,496(26,443)	0.464(0.009)	178,946(49,877)	0.467(0.008)
May 1991	180,179(24,457)	0.448(0.009)	185,127(22,609)	0.460(0.008)
Aug 1991	183,795(27,042)	0.461(0.008)	150,967(22,061)	0.442(0.012)
			control	**control**
Oct 1991	199,160(19,383)	0.480(0.007)	193,056(34,116)	0.486(0.008)

Note: the minimum EI value for Performance Rated, 15/32-inch sheathing panels is 116,000 $lbs\text{-}in^2$ (U.S. Product Standard PS-1).

DISTURBANCE EFFECTS OF HURRICANE HUGO ON A PRISTINE COASTAL LANDSCAPE: NORTH INLET, SOUTH CAROLINA, USA

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Abstract--Despite its intensity and landfall at high tide, Hurricane Hugo (22 Sept. 1989) had only a modest impact on the geomorphology of the undeveloped coastal landscape at North Inlet, South Carolina. Pre- and post-Hugo aerial photographs (April 1987 and October 1989) showed no change in the salt-marsh creek network, nor could changes be seen in the size or shape of sand bars within the creeks. Several new, small washover fans formed on the adjacent barrier islands. These lobate fans extend 50 to 100 m from the dune line into the back barrier area and are deposited on older but recently formed fans in areas where the islands are thin and devoid of large shrubs and trees. Hugo's failure to have a more dramatic geomorphic effect was probably related to the rapid approach of the storm along a path perpendicular to the coast. This allowed minimal time for the surge to build and for wave attack to modify the shoreface.

In contrast, the nearby coastal forest experienced extensive wind damage as well as tree mortality due to soil salinization by the surge. Wind damage was a function of tree species, diameter and soil type. The most severe damage occurred in mixed bottomland hardwood sites on Rutledge (sandy, silicious, thermic Typic Humaquepts) soils. Salt-induced foliage discoloration and defoliation became fully evident in the surge-inundated area by January 1990. Above-normal salt concentrations were found in shallow groundwater samples from sites up to the 3.0-m contour (MSL). Salt concentrations generally decreased inland from the forest-marsh boundary and with the passage of time. Trees standing along the forest-marsh boundary and in swales suffered the most severe salt-induced mortality. As of June 1991, new understory vegetation and pine seedlings appeared to be flourishing in the salt-affected area. Salinization also mobilized ammonium from soil storage as a result of ion exchange with seawater cations and disruption of nitrogen cycling processes.

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There was a virtual absence of insects and terrestrial vertebrates in the surge-affected forest immediately following Hugo. Flying insects and birds were the first to return but six months after Hugo, the abundance of reptiles and amphibians remained significantly lower than populations observed prior to the storm. Scouring and high salinity had a catastrophic effect on benthic invertebrates in the blackwater streams of the forest. Population density dropped by 97% and biomass declined from 542 mg dry mass·m^{-2} to only 2.0 mg dry mass·m^{-2}. The community recovered quickly, however, as density and biomass returned to pre-storm levels in three and six months, respectively.

1. INTRODUCTION

The role of disturbance in the structure, function and evolution of ecosystems has long been a topic of interest to ecologists (Sousa, 1984). Since disturbances generally lie near the extremes of a continuum of natural perturbations, the concept is difficult to define precisely. Sousa (1984) suggests that 'a disturbance is a discrete, punctuated killing, displacement or damaging of one or more individuals (or colonies) that directly or indirectly creates an opportunity for new individuals (or colonies) to become established'. Against this background, we report our observations of the ecological impact of Hurricane Hugo on a coastal landscape.

1.1. Hurricane Hugo

Hugo made landfall at Charleston, SC at 0001 hours EDT on 22 September 1989 (Figure 1). The hurricane, which started as a depression off the west coast of Africa on 9 September, was the most devastating storm to hit South Carolina in modern times. Hurricane Hugo reached its maximum strength several hundred kilometres east of the Leeward Islands on 15 September, with a central pressure of 918 mbar and observed surface wind speeds of 72 m·s^{-1} (National Hurricane Center, 1989). Hugo wreaked havoc on the islands of Guadeloupe on 17 September and on Puerto Rico the following day. The hurricane lost some strength as it moved away from Puerto Rico towards the southeastern United States, but gathered renewed energy as it crossed the Gulf Stream. It advanced towards the South Carolina coastline at a rapid 12 m·s^{-1}, exhibited a central pressure of 935 mbar, and had measured sustained winds of 39 m·s^{-1} with gusts up to 48 m·s^{-1} upon landfall in Charleston (National Hurricane Center, 1989). Hugo struck South Carolina near high tide, which is the reason for the massive property damage along the coast. Fortunately, the hurricane-associated rainfall was relatively low. Sullivans Island, just east of Charleston, received only 21 mm of rain, and Myrtle Beach, to the north of North Inlet, received only 6 mm. An unofficial rain gauge at North Inlet, SC registered 65 mm. Had it rained more, coastal flooding would have been far greater.

2. METHODS

2.1. Study Area

North Inlet, located 90 km northeast of Charleston (Figure 1), is one of 18 sites in the Long-Term Ecological Research (LTER) network sponsored by the National Science Foundation. The site covers about 80 km^2 and consists of barrier islands, intertidal salt marsh, and low-lying coastal forest (Figure 1). The site has been the focus of studies on coastal ecology, forestry and geology for over twenty years. At North Inlet, the storm surge traversed the Holocene barrier islands, flooded the Spartina marshes and temporarily caused ocean water to flood over a large area of the coastal forest. Fragments of Spartina caught in tree branches indicate that the maximum surge elevation was 3 to 4 m above mean sea level (MSL), or approximately 2 to 3 m above mean high tide.

The forest ecosystem at North Inlet has developed on sandy Pleistocene beach ridges and swales, which trend northeast-southwest (Gardner and Bohn, 1980). The highest ridges lie about 6 m above MSL. Approximately 30% of the forest ecosystem lies at elevations below the 3-m contour and was thus subject to the effects of salt-water inundation. The bulk of the forest system consists of variably-aged pine forest growing on the ridges. The

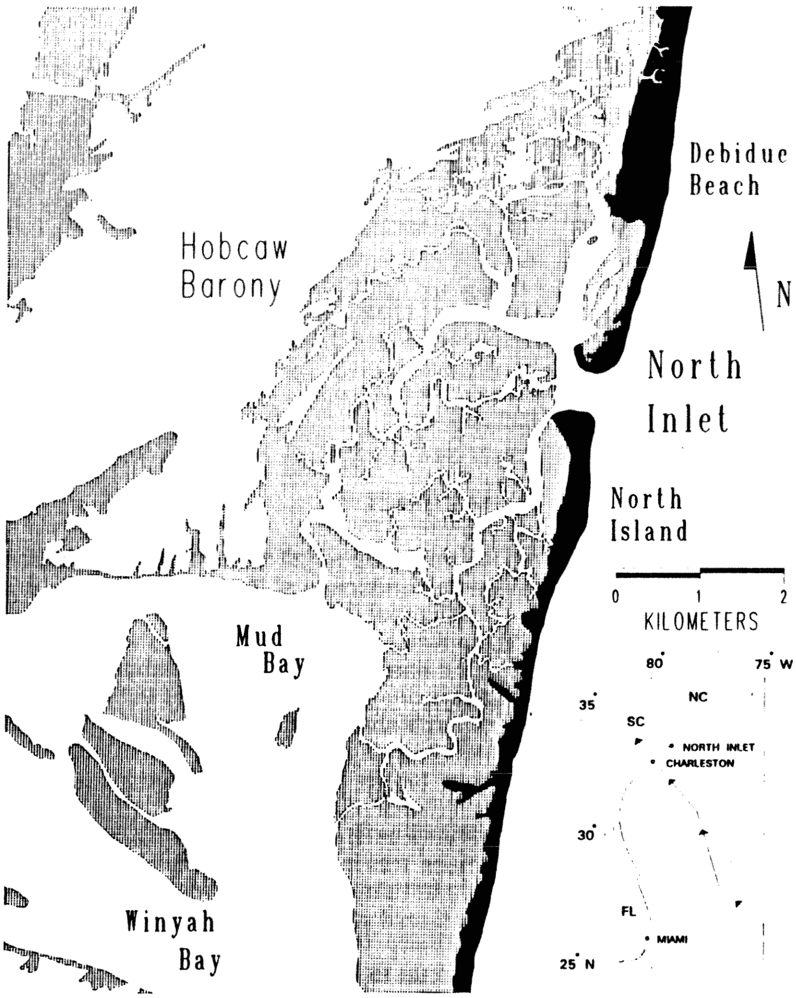

Figure 1--Map showing path of Hurricane Hugo and geographic features of the North Inlet area. Barrier islands, black; marsh, shaded; Hobcaw Barony forest and open water, unshaded.

swales between ridges typically contain intermittent blackwater streams, support stands of cypress and gum, and have fringes of mixed bottomland hardwoods.

2.2. Air Photo Surveys

Three aerial photography surveys of the study area were conducted in order to assess the effects of Hugo on the geomorphology and forest resources of the study area. Contract missions were flown in early October 1989, early February 1990 and late October 1990, just prior to leaf-fallout of the deciduous trees. Photographs were taken with a 23 cm x 23 cm aerial camera suspended in a pod from a Cessna 150 aircraft, using Kodak Aerochrome 2443 infrared film. Photographs were taken in a stereoscopic mode with about 60% overlap and at an altitude that gave an approximate scale of 1:6000, allowing distinction of individual uprooted and broken trees. Scale-correct portions of each photograph were obtained by constructing overlays from a forest overstory map which had been rectified to 1:4800-scale cadastral maps produced for the Georgetown County Tax Assessors Office using ARC/INFO GIS software (Lipscomb and Williams, 1990). A map of discoloured and defoliated trees was then produced by digitizing information from the photographs to the GIS mapping system. These maps delineate the extent of salt-induced mortality in evergreen species.

In early May 1990, large populations of pine bark beetles (*Dendoctonous frontalis* and *Ips* sp.) were found in the areas adjacent to both salt-killed and wind-thrown pines. Infestation continued throughout the summer of 1990. The October 1990 photographs were used to map the mortality due to insect attack as well as the extent of salt-induced mortality in deciduous trees that could not be done on the February photos.

For mapping geomorphic changes, the October 1989 photographs were compared with true colour aerial photos of 1:12000 scale taken in April 1987. Using a GIS base map, geomorphic features on the two sets of photographs were digitized into GIS files for rectification and adjustment to a common scale.

2.3. Ground Surveys

We sampled wind damage to trees in 293 of the 362 Hobcaw Forest stands from November 1989 to May 1990. Stand sizes range from 6 to $440 \cdot 10^3$ m^2. Stands without 10-cm diameter-at-breast-height (DBH) trees or in which timber was salvaged were not sampled. Within each stand, we inventoried a randomly located 100 x 10 m^2 plot by recording species, DBH and damage class of all live, woody stems greater than 10 cm DBH. If a stand was greater than 0.2 km^2, two plots were inventoried. If a plot contained less than 25 trees, it was extended until 25 trees were inventoried. We visually estimated wind-related tree damage and assigned trees to one of the following damage classes:

1. Undamaged: Bole not bent and vertical with little crown damage;
2. Bent: Roots intact, lower bole vertical, upper bole not vertical;
3. Limbs broken: Many limbs broken, terminal leader intact;
4. Defoliated: Sparse foliage, with brown or dying foliage;
5. Top broken: Many limbs broken, terminal leader broken;
6. Broken: Bole broken between ground and crown base;
7. Uprooted: Tree partially uprooted with bole leaning;
8. Downed: Tree partially uprooted with bole lying on ground.

These damage classes were grouped as follows for discussion purposes: undamaged trees (class 1); light damage, bole bent or limbs broken (classes 2 and 3); moderate damage, defoliated or top broken (classes 4 and 5); heavy damage, broken, uprooted or downed (classes 6, 7 and 8). In total, we tallied 16,870 stems in 329 plots covering 1.08% of the Hobcaw Forest.

To study the effects of soil salinization on forest vegetation, ten sampling transects were established around the perimeter of the Hobcaw Barony (Figure 2). Each transect started at the boundary between forest and high marsh (0 m inland) and extended inland up to the approximate limit of surge penetration (~3.0-m contour). Most transects had one or more stations in the first 30 m (0, 3, 10 and 25 m). Thereafter, stations were typically located at 25, 50 or 100-m intervals. The elevations along each transect were surveyed with a transit and compass, and leveled with respect to known bench marks. At Transect 4, only the first 750 m of the 1.6-km long transect could be surveyed because of the large number of downed trees. Sampling along transects consisted of measurements of depth-to-water table at each station, chemical analysis of groundwater samples and descriptions of the type and condition of vegetation. Water table depths were obtained by augering holes at each station and allowing water to rise to a static level. Samples of groundwater from each hole (or standing surface water in some cases) were taken in acid-cleaned plastic bottles. The first transect sampling was conducted two weeks after Hugo. Subsequent samplings were conducted 4, 8, 16, 32 and 52 weeks after the storm. During the first sampling, observations were made of the height of *Spartina* detritus in the tree branches, the location and thickness of detritus deposits on the forest floor and the extent and height of detritus rub marks on tree trunks.

To investigate the effects of soil salinization on forest nutrient cycling, time series measurements of ammonium concentrations in soil waters were made at a pine forest site adjacent to the marsh (Figure 2). Detailed, long-term nutrient cycling studies have been conducted at this site since May 1983. In 1983, the 20-year-old pine stand contained 2200 stems per 10^4 m^2 with a basal area of 25.5 m^2 per 10^4 m^2 and a mean DBH of 14.5 cm. Sparse hardwood vegetation in the stand is composed mainly of wax myrtle (*Myrica cerifera*) in the understory and occasional oaks (*Quercus* spp.) and red maples (*Acer rubrum*) in the overstory. The soils are classified as Spodosols and consist of Aeric Haplaquods in drier portions of the

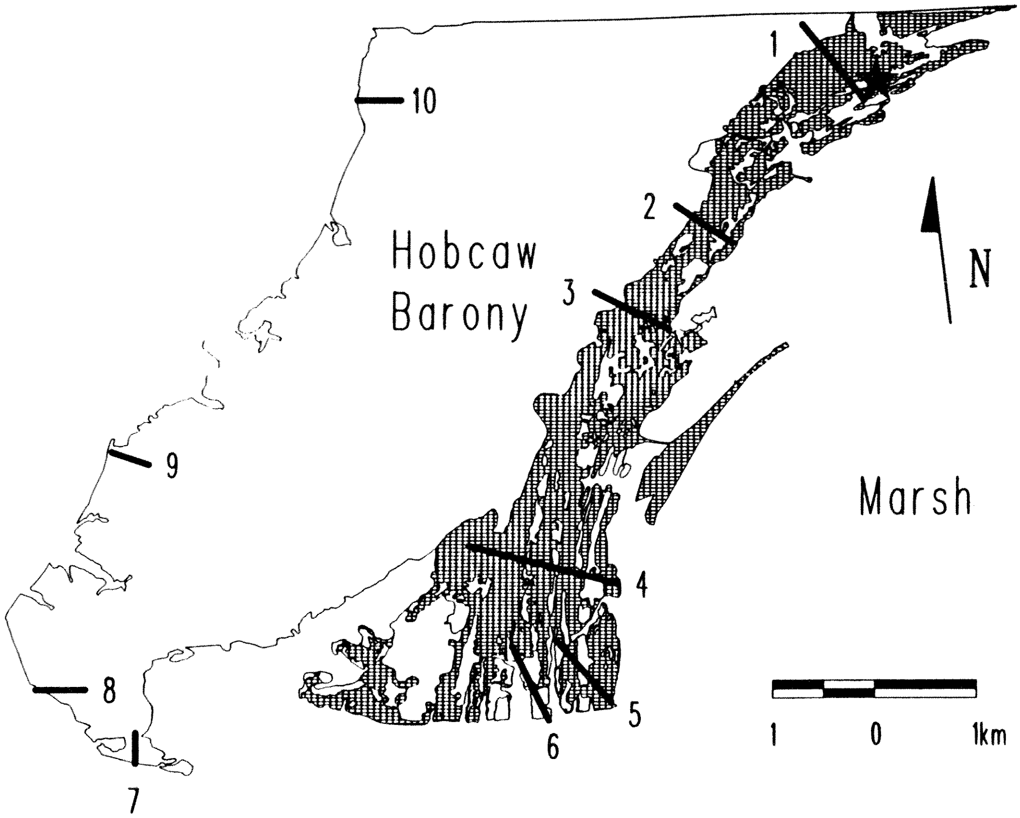

Figure 2--Map showing extent of salt-damaged coastal forest (shaded) and location of study transects on Hobcaw Barony forest including unaffected areas (unshaded). The nutrient cycling site and Third Boundary Creek are located near the star on map.

stand and Typic Haplaquods in wetter areas (Stuckey 1982). The spodic Bh horizon averages 35 cm in thickness and is underlain by parent material of weathered, quartzose sand with occasional intermixed shell. The average slope of the watershed is less than 1 m per km.

At this site, a 1000-m^2 plot was established and subdivided into ten sub-plots. A groundwater well and lysimeters in both the A (organic) and Bh horizons were placed randomly in each sub-plot. The ten replicates from each well and soil horizon were averaged for each sample date.

To study the effects of Hugo on the blackwater streams draining the forest, surveys were made of the pre- and post-storm organic matter storage and benthic invertebrate biomass and species composition in Third Boundary Creek (in the northeast corner of the Hobcaw Barony near Transect 1, Figure 2). Sampling was conducted during the three months prior to Hugo and then monthly beginning two weeks after Hugo. Depth of scour into the stream sediment was determined using the technique of Metzler and Smock (1990). Changes in sediment organic matter storage were obtained from eight cores (4.8-cm diameter) taken during each sampling period. Ash-free dry mass was determined by ignition at 550°C for four hours. The benthic invertebrate community was quantified from eight samples collected with a Hess sampler (0.088 m^2) during each sampling period. Samples were washed through a 0.15-mm pore size sieve; all organisms were identified, counted and measured with an ocular micrometer. Biomass was computed using regression equations relating dry mass to body size.

2.4. Chemical Methods

The concentrations of Na, K, Ca and Mg in water samples were measured by atomic absorption spectroscopy using a Perkin Elmer Zeeman 5100 spectrophotometer (American Public Health Association, 1985). Samples were diluted with distilled, de-ionized water to appropriate concentration ranges for analysis. Sample conductivities were measured with a VWR Scientific Model 604 conductivity meter. Salinities were computed from sample conductivities and temperatures using the equations given in Cox and others (1967). Ammonium was measured by automated colorimetry with a Technicon Autoanalyzer II or Orion Scientific Autoanalyzer System using the phenate method (Technicon Industrial Method No. 154-71W).

3. RESULTS

3.1. Geomorphic Effects

Despite its intensity, Hugo had a modest geomorphic impact on the North Inlet estuarine area. Pre- and post-Hugo aerial photographs show no changes in the salt-marsh creek network, nor can changes be seen in the size or shape of sand bars within the creeks. Changes appear limited to the inlet and the adjacent barrier islands. Several small, new washover fans formed on Debidue Beach to the north of the inlet and on North Island to the south (Figure 1). These fans extend 50 to 100 m from the dune line into the back barrier area and are lobate in form. The largest new fan (on North Island) extends as a finger about 500 m into the back barrier where it encounters a small creek. Nonetheless, no breach developed in the island. New fans appear to have developed on older, but recently formed fans in areas where the barrier islands are thin and devoid of large shrubs and trees. Sand for the fans probably was obtained by levelling and breaching of the pre-storm dunes. The pre- and post-storm configurations of North Island are shown in Figure 3. At North Inlet itself, post-storm photographs show that some of the former offshore bars are diminished or missing. This suggests that the large ebb-tidal delta experienced erosion when the large

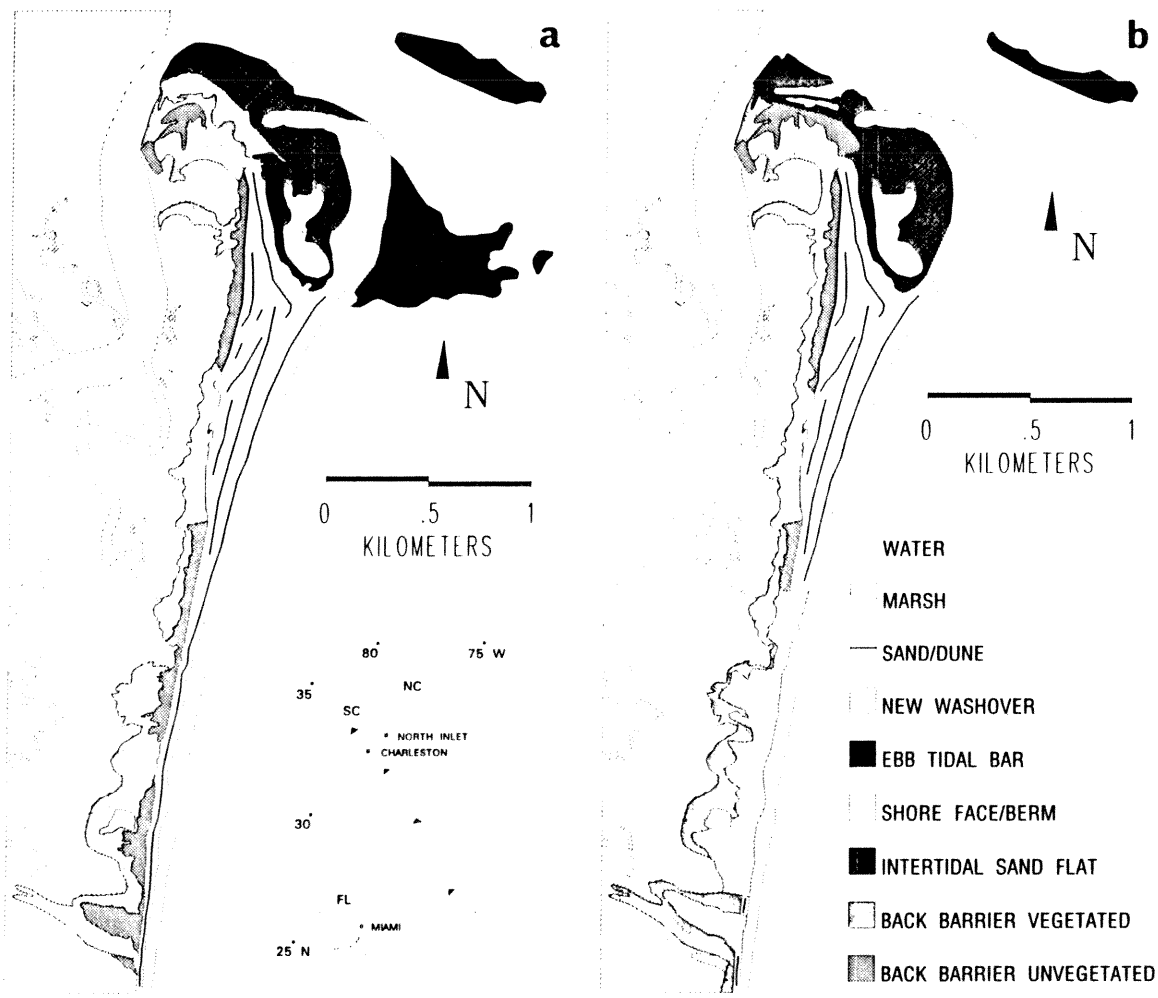

Figure 3--Pre- (a) and post-Hugo (b) geomorphology of the north end of North Island.

volume of surge water drained as sheet flow across the marsh on the following ebb tide, but became constricted and channelized at the inlet.

The main effect of the storm in the marsh was to transport much of the dead *Spartina* stalks and leaves into the adjacent forest, where it was deposited as mats of detritus. The storm had no visible effect on live *Spartina*, which was neither uprooted nor bent. Although a thin film of mud coated the litter in the forest, no measurable erosion or deposition of mud could be detected in the marsh.

3.2. Forest Wind Damage

Wind damage to the forest was extensive and varied with tree species, diameter and soil type. Approximately 73% of the trees sampled was undamaged (24%) or lightly damaged (49%), while 16% was moderately damaged and 11% was heavily damaged. Live oak (*Quercus virginiana*) and swamp tupelo (*Nyssa sylvatica*) were the least damaged of the hardwoods. Longleaf pine (*Pinus palustris*) was the least damaged of the pines with 87.7% of the stems undamaged or lightly damaged. Approximately 84% of the bald cypress (*Taxodium distichum*) stems was undamaged (11.2%) or lightly damaged (73.0%). Laurel oak (*Quercus laurifolia*) and water oak (*Quercus nigra*) were the most heavily damaged hardwoods, while pond pine (*Pinus serotina*) was the most heavily damaged pine. In general, the trees larger in diameter were more heavily damaged. Large water oak and pond pine were more likely to be uprooted while large laurel oak and loblolly pine (*Pinus taeda*) had more bole breakage. Tops were also broken in the larger live oaks. Since tree diameter was related to the degree of damage, losses of basal area are the best indicators of losses due to the hurricane. When basal area is used as a measure of loss, 43% of pond pine, 35% of water oak, 17% of loblolly pine, 11% of longleaf pine and 3% of live oak were heavily damaged. These results agree with previous data on the resistance of these species to wind damage (Touliatos and Roth, 1971; Glitzenstein and Harcombe, 1988; Harcombe and Marks, 1983; Lugo and others, 1983; Putz and others, 1983). A listing of all species-damage estimates and statistical analyses of the wind damage data can be found in Gresham and others (1991).

Heavy damage occurred primarily in mixed bottomland hardwood sites on Rutledge (sandy, siliceous, thermic Typic Humaquepts) soils (Stuckey, 1982). Water oak, which grows on such soils, suffered the greatest proportion of uprooting.

3.3. Surge Effects on Forest Vegetation

Based on surveyed water marks, Schuck-Kolben (1990) estimated that the elevation of the Hurricane Hugo surge at North Inlet was about 3.3 m above MSL. This allowed salt water to penetrate to about the 3.0-m contour in the adjacent maritime forest. At this contour, the maximum distance of penetration is about 1.5 km into the forest from the forest-marsh boundary. Penetration of the surge into the forest resulted in salinization of the forest soils, death to some trees and forest vertebrates, mobilization of soil ammonium and scour of blackwater stream bottoms with attendant disruption of the benthic invertebrate community.

The effects of salt stress on forest vegetation began to appear shortly after the storm and were fully evident by December 1989. Within a few days after Hugo, the pine needles along the edge of the marsh had turned brown. This early browning may have been due to wind burn and/or salt spray during the storm. The most salt-sensitive tree species appeared to be black gum saplings, whose leaves turned brown throughout the surge-affected area within one week of the storm. Wind burn is not likely to be the cause of the browning for these trees since they were protected from wind stress by the taller trees.

Two weeks after the storm, 80 to 100% of the leaves and needles on trees and shrubs located within 10 m of the marsh along the eastern edge of the forest had turned brown or dropped as a result of salt and/or wind stress. At distances of 50 to 150 m from the marsh, 10 to 50% of the pine needles showed signs of browning while all gum and oak leaves had turned brown or dropped. Further inland, the spatial pattern of salt stress became more complex. For example, along Transect 1 (Figure 2), pine needles appeared healthy at the station 467 m from the marsh, although wax myrtle (*Myrica cerifera*) and blueberry (*Vaccinium* spp.) leaves had browned or dropped. At a distance of 626 m from the marsh, approximately 10%

of the pine needles were brown while no indications of salt stress were observed at stations located 784, 943, and 1101 m from the marsh. In general, understory vegetation showed evidence of salt stress at much greater distances inland than large trees.

Tree mortality due to intrusion of salt water became apparent in early December and was mapped using the February 1990 aerial photographs. Salt-induced mortality is distributed throughout the eastern side of the forest (Figure 4) and is about equal in magnitude to the wind damage. Mortality along the southern and western sides of the forest was less severe, probably because the surge there consisted of low-salinity Winyah Bay water. Mortality was most severe along swales and at the boundary between forest and marsh.

3.4. Salinization of Forest Soils

Space does not permit a display of all soil-salinization time series data. Two typical transects of Na concentration, water table depth and station elevation are shown in Figures 5 and 6. Prior to Hugo, Na concentrations in the forest groundwater ranged between 4 and 30 $mg \cdot dm^{-3}$ (T. Williams, unpublished data). Two weeks after Hugo, most stations in the surge-affected forest had Na concentrations in excess of 100 $mg \cdot dm^{-3}$, with many in excess of 1000 $mg \cdot dm^{-3}$. Maximum concentrations approached 4000 $mg \cdot dm^{-3}$ or approximately 40% that of seawater. In general, Na concentrations decreased both inland and with the passage of time. By January 1990, Na had declined at most stations by an order of magnitude, with a few falling back into the pre-Hugo range. Between January and May 1990, concentrations of Na tended to rise at most stations as water table elevations fell during this unusually dry spring. By October 1990, Na concentrations were approximately or slightly lower than those in January. There is some indication that Na concentrations were lower in swales than on ridge sites, but the data are not consistent for all transects. Soil

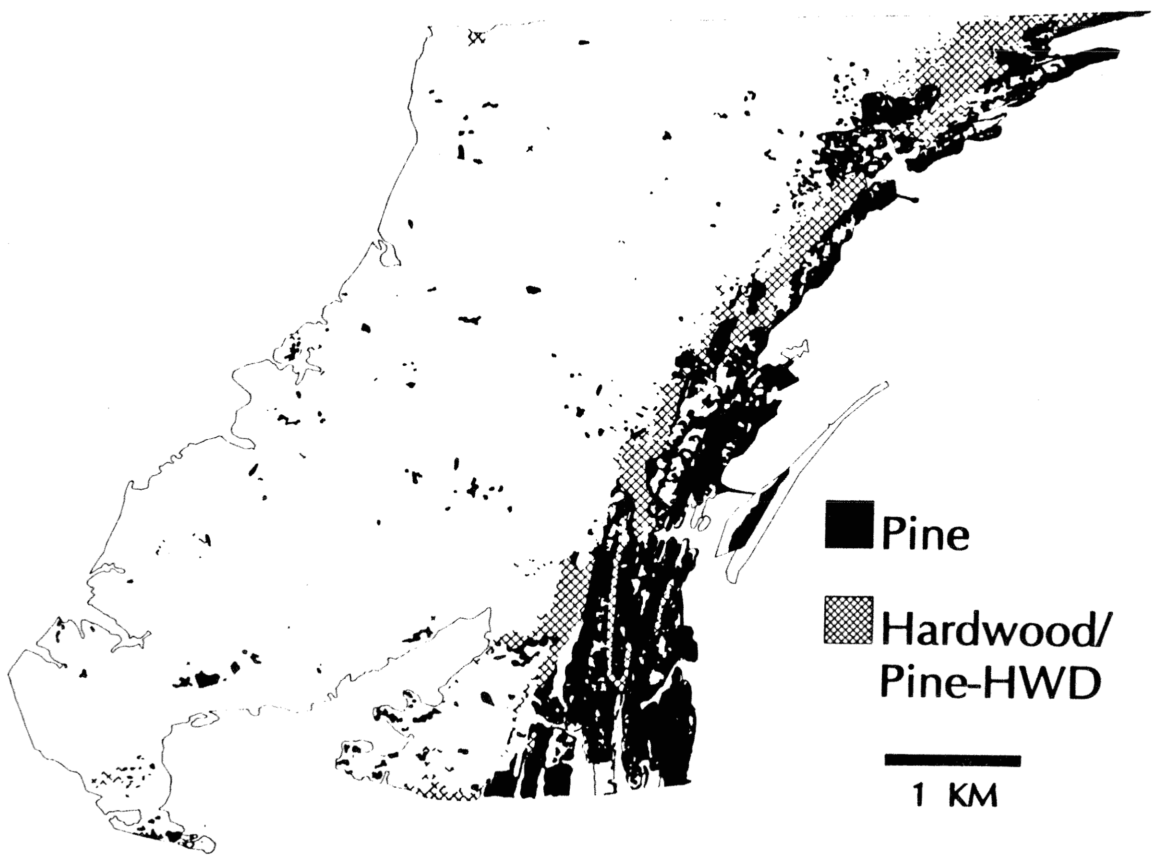

Figure 4--Map of pine and hardwood mortality due to soil salinization and bark beetle attack.

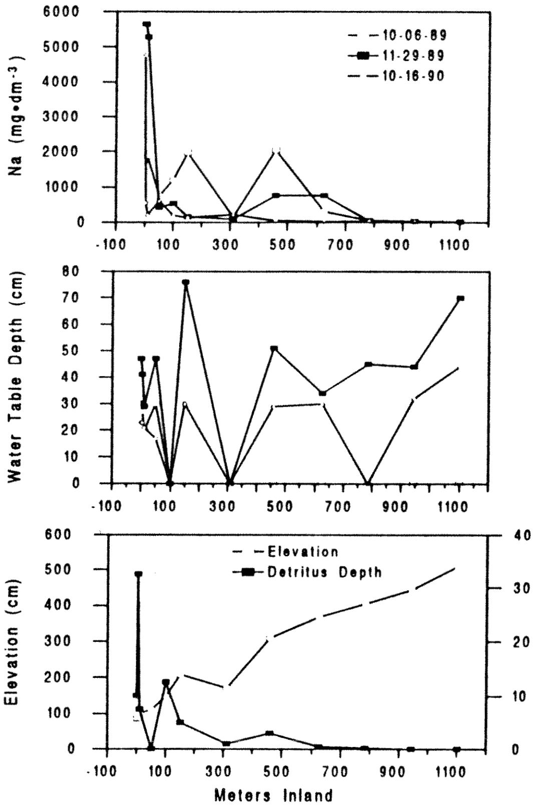

Figure 5--Spatial and temporal variation of Na concentration in groundwater and water table depth (upper two panels) along Transect 1. For clarity, only data for three of the six sampling dates are shown. Profiles of ground elevation and thickness of detrital deposits are shown on bottom panel.

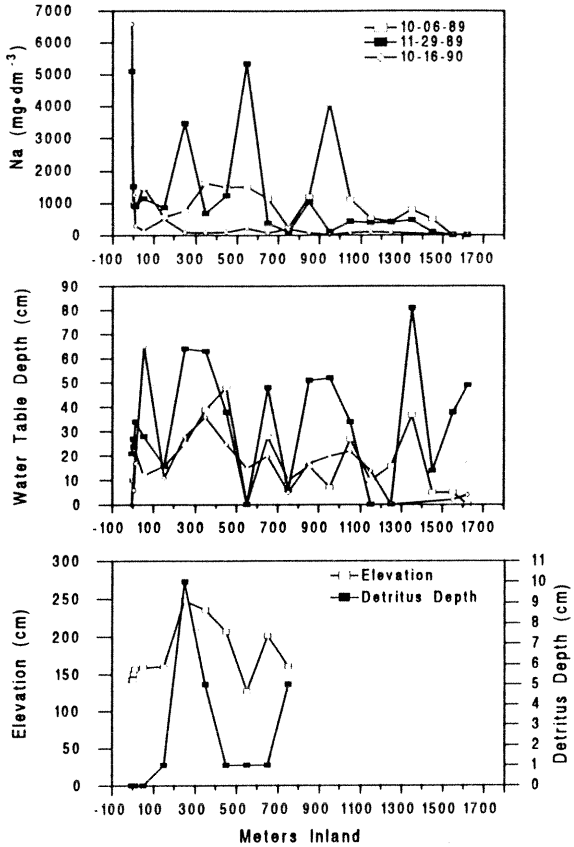

Figure 6--Spatial and temporal variation of groundwater Na concentration and water table depth (upper two panels) along Transect 4. For clarity, only data for three of the six sampling dates are shown. Profiles of ground elevation and thickness of detrital deposits are shown on bottom panel.

salinization extended about 700 m inland along Transect 1 to an elevation of ~4.0 m MSL (Figure 5). Along Transect 4 (Figure 6), salinization extended inland 1500 m, but elevation measurements are not yet available for the landward end of this transect. All other transects across the east side of the forest showed salinization along their entire length. Maximum elevations along these transects are below 4.0 m MSL. Although most ridge sites and some swale sites showed a monotonic decrease in Na with time, there were several exceptions, particularly in the May sampling. Most notable are the ridge sites between 400 and 700 m on Transect 1 (Figure 5) and the ridge site at 250 m on Transect 4 (Figure 6).

At the majority of stations, the water table elevation fell during the first three samplings, but rose again following the recharging rains of December and early January. The water table again fell during the dry spring of 1990 but recovered by the final sampling in October. In general, water table fluctuations were greater on ridge sites than along the marsh edge or at swale sites.

3.5. Mobilization of Soil Ammonium

Salinization also affected the concentrations of ammonium in soil and groundwaters (Figures 7 and 8). Approximately 1.5 m of salt water inundated the long-term nutrient-cycling study site (Figure 2) during

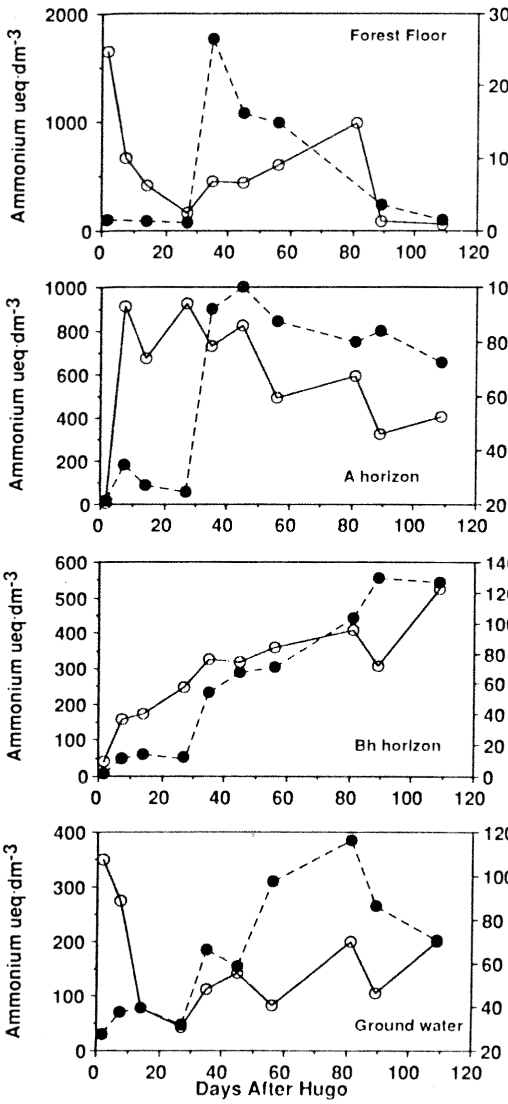

Figure 7--Time series of ammonium and sodium concentrations in standing, soil and groundwaters at the long-term forest nutrient cycling site. Na measurements are unavailable for 1990. Ammonium data for 1990 are shown in Figure 8.

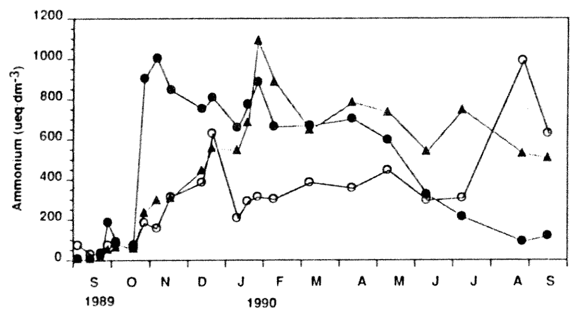

Figure 8--Time series of ammonium concentrations in soil and groundwater at the long-term forest nutrient cycling site for the year following Hurricane Hugo.

the storm surge. Two days after Hugo, water standing on the forest floor had an average salinity of S=21. As the salt water penetrated the soil, significant alteration of the soil solution occurred. Two weeks before the storm, soil-solution total ionic content (TIC) averaged 1.6 $meq \cdot dm^{-3}$ in A-horizon soil water and 3.4 $meq \cdot dm^{-3}$ in groundwater. Two days after the storm, TIC was 227 to 778 meq or a salinity of S=2.3 to 12. Soil-solution salinities were lower than standing-water salinities due to dilution by the underlying fresh groundwater. Maximum soil-solution salinities, ranging from S=9.7 (Bh horizon) to 13.0 (A horizon), were detected one week after the storm. In early October, soil-solution salinities declined due to dilution from rainfall (103 mm) and a rising water table. During the November dry spell, groundwater elevation declined, resulting in an increase in soil salinity. Two months after Hugo, TIC remained elevated by 58 to 142 times the pre-storm values.

Two days after Hugo, Na concentrations in soil solution were 16 (A horizon) to 122 (groundwater) times the annual average concentrations for 1984 to 1987. Initially, Na concentrations (Figure 7) were greatest in water ponded on the forest floor (245 $meq \cdot dm^{-3}$) and in groundwater (107 $meq \cdot dm^{-3}$). The initially higher concentration of Na in the groundwater as compared to that in the overlying soil horizons was due to the fact that surge water flooded down and filled the open piezometer pipes, and then seeped into the surrounding aquifer after the surge retreated. Concentrations of Na in ponded surface water and groundwater declined for the next three weeks and then began to increase until mid-November (Figure 7). Maximum Na concentrations in the A horizon were detected one week after Hugo, fluctuated around 85 $meq \cdot dm^{-3}$ until mid-November and declined erratically thereafter. In the Bh horizon, Na increased almost linearly following Hugo and reached a maximum concentration of ~122 $meq \cdot dm^{-3}$ early in 1990, beyond which our samples have not yet been measured for Na.

If the early contamination of groundwater by flow of surge water down the piezometer pipes is ignored, then these results suggest the downward movement of a saline front that originated in the ponded surge water at the surface. Movement of this front probably was driven by both advection (to replace losses of soil water by evapotranspiration and seepage) and diffusion.

Two distinct phases were observed in the response of ammonium to soil salinization. The first phase developed within two days after the storm and lasted for about one month. Prior to Hugo, average concentrations of ammonium in the A and Bh soil horizons were 0.34 and 1.0 $\mu eq \cdot dm^{-3}$, respectively, whereas the average in groundwater was 14 $\mu eq \cdot dm^{-3}$. Two days after Hugo, ammonium concentrations in the A and Bh horizons were 20 and 10 times greater than their pre-storm averages, respectively. Groundwater ammonium concentration at this time was similar to the pre-storm average. Two days after Hugo, the highest concentration of ammonium was found in water standing on the forest floor (77 $\mu eq \cdot dm^{-3}$). It is unlikely that the original surge water had this level of ammonium because seawater at North Inlet typically contains only 1.0 to 3.0 $\mu eq \cdot dm^{-3}$ (Whiting and others, 1987). Therefore, the excess ammonium observed in the standing water must have been derived from the forest floor during its two days of residence. Ammonium concentrations in the standing water remained nearly constant at about 100 $\mu eq \cdot dm^{-3}$ during the month following Hugo, even though Na concentrations decreased due to dilution by rain and diffusion into the underlying, less saline soil water (Figure 7). About one month after Hugo, ammonium in the standing water suddenly rose to a peak concentration of 1800 $\mu eq \cdot dm^{-3}$, marking the onset of the second phase in the ammonium response to salinization. During the month following Hugo, ammonium in the A and Bh horizons and in groundwater rose to concentrations of 50 to 100 $\mu eq \cdot dm^{-3}$ (Figure 7), but thereafter showed dramatic increases similar to that observed in the standing water. Ammonium in the A horizon reached a maximum concentration of 1000 $\mu eq \cdot dm^{-3}$ about six weeks after Hugo, and thereafter began to decrease gradually but erratically. In the Bh horizon and groundwater, the second phase in the ammonium response was not as dramatic as in the standing water and A horizon, and was somewhat delayed. Ammonium in the Bh horizon increased abruptly from 50 to 250 $\mu eq \cdot dm^{-3}$ about one month after Hugo and then rose in harmony with Na until it reached a peak concentration of 1000 $\mu eq \cdot dm^{-3}$ in early 1990 (Figure 8). Thereafter, ammonium in the Bh horizon decreased gradually in a similar fashion to the A horizon. Groundwater ammonium also showed an abrupt increase (50 to 200 $\mu eq \cdot dm^{-3}$) about one month after the storm (Figure 7) and continued to rise gradually but erratically throughout the year following Hugo (Figure 8). One year after Hugo, ammonium concentrations in the A and Bh soil horizons and in groundwater were still several orders of magnitude greater than their pre-storm averages.

The lag between the A horizon and groundwater in reaching their peak ammonium concentrations suggests the downward movement of a layer of ammonium-enriched water that formed suddenly a month after Hugo on the forest floor and/or in the A horizon. As in the case of the saline front mentioned above, movement of this layer probably was due to advection and diffusion.

3.6. Effects on Freshwater Benthos

The surge also affected the benthic ecology of blackwater streams in the Hobcaw Forest. Measurements made in Third Boundary Creek indicate that the surge scoured the sand bottom to a mean depth of 6 cm, about three to four times greater than the usual month-to-month scour depth. This had a significant effect on detritus storage and the benthic invertebrate community. Detritus storage in the top 5 cm of sediment prior to the storm was 4.2 kg ash-free dry mass$\cdot m^{-2}$. Scouring suspended all of this detritus into the water column. During recession of the surge, 5 cm of sediment and detritus was redeposited in the channel, but detritus storage decreased to 2.4 $kg \cdot m^{-2}$, a net loss of 1.8 $kg \cdot m^{-2}$. This loss of detritus represents a large transfer of energy from the channel to the forest and/or marsh. Scour also transferred detritus from the largely anaerobic sediments of the channel, where decomposition and hence cycling rates were slow, to aerobic environments where decomposition and incorporation into detrital food webs occur more rapidly.

The combination of scour and high salinity initially had a catastrophic effect on benthic invertebrates in the stream. Prior to Hugo, invertebrate density on the sediment was 4580 $ind \cdot m^{-2}$, whereas the density immediately after the storm was only 165 m^{-2}, a 97% decrease. Biomass declined from 542 mg dry mass$\cdot m^{-2}$ to only 2 $mg \cdot m^{-2}$. However, the community recovered quickly as density and biomass returned to pre-storm values three and six months after the disturbance, respectively.

Species composition was greatly altered in the stream. The amphipod *Gammarus tigrinus* had been the most abundant species in the stream, composing 76% of the density and 93% of the biomass. Aquatic insects, primarily Chironomidae (Diptera), also were common. Immediately after Hugo, no amphipods and few chironomids were found: benthic copepods, oligochaetes and ostracods were the predominant organisms, although low in number. In the months following the storm, several species of chironomids (*Chironomus* spp.) became the dominant taxa. Gammarus was initially slow to recover. However, it began steady recolonization four months after the storm, and one year later it composed 93% of the density and 62% of the biomass.

3.7. Effects on Forest Vertebrates

Surveys made of fauna in the marsh and forest following Hugo were marked by the near absence of insects, birds and other organisms. The surge killed or displaced virtually all fauna in the flooded portion of the forest. Numerous carcasses of rice rats (*Oryzomys palustris*), Eastern gray squirrels (*Sciurus carolinensis*), marsh rabbits (*Syvilaqus palustris*), feral hogs (*Sus scrofa*) and various shore and wading birds were found within 100 m of the marsh. Habitat damage to the avian nesting community was severe. Nesting trees for red cockaded woodpeckers (*Picoides borealis*), bald eagles (*Haliaeetus leucocephalus*) and ospreys (*Pandion haliaetus*) were severely damaged. Flying insects and birds were the first organisms to return to the forest and marsh. Observations made six months after Hugo suggest that the abundance of reptiles and amphibians along the eastern edge of the forest remained significantly lower than densities observed prior to the storm.

4. DISCUSSION

In general, the geomorphic effects of Hugo were focused on the barrier-island portion of this coastal landscape whereas the ecological effects were focused on the nearby coastal forest. The intervening marsh displayed no obvious ecological or geomorphic effects, probably because it was protected during the surge by 3 to 4 m of water from wind, wave action and currents.

4.1. Geomorphic Effects

Hurricane Hugo was a category-4 storm (Ludlum, 1989). Despite the extensive property damage that it caused along the coast, Hugo's geomorphic effect on the undeveloped landscape at North Inlet was minimal. In the absence of direct measurements, we hindcast wind and wave characteristics for Hugo at North Inlet as the storm approached landfall, using the procedures of Kjerfve and others (1986). The results, given in Gardner and others (1991), indicate relatively steady 40 $m\cdot s^{-1}$ winds from 30 N for more than 12 hours preceding landfall. Hugo was a rapidly translating storm with a large radius of maximum winds, two reasons why the storm did not become more intense. The calculations yielded a maximum local significant wave period of 11.7 s at the time of landfall, a peak significant wave height of 10.7 m in deep water and a maximum deep-water wave length of 213 m. However, as the South Carolina shelf slopes gently seaward with the 20-m and 50-m isobaths located offshore at 50 km and 100 km, respectively, these waves initially would have broken very far offshore, and thus would have been considerably smaller than the calculated heights at the time they broke again on the barrier beaches at North Inlet.

The landward distance of overwash deposition by Hugo did not exceed the mean distance of 130 m determined by Godfrey (1970) for ten years of storm activity at Core Banks, North Carolina. On the basis of this parameter, Hugo's impact at North Inlet appears to be similar to that of Hurricane Ginger in 1971 (100 m, Dolan and Godfrey 1977), but small compared to that of Hurricane Carla, which made landfall in Texas in 1961 (Hayes, 1978) with a wind speed and surge height similar to Hugo.

Hugo's failure to have a more dramatic geomorphic effect on the North Inlet landscape may be due to several factors. The storm approached normal to the coast at a fast speed. The rapid approach did not allow much time for the surge to build or for wave attack to modify the shoreface. Had the storm travelled parallel to the coast just offshore at a slower pace, the surge may have been larger and the wave attack prolonged. In addition, if the storm had moved along the coast, the wind direction would have shifted suddenly from onshore ahead of the eye to offshore behind the eye. This sudden change of wind direction would have driven surge water out of the back barrier and enhanced the chance for bayside breaches of the barrier (Leatherman, 1982). Finally, the paucity of rainfall associated with Hugo added little to the volume of water draining from the back barrier following passage of the eye.

The lesson to be learned from Hugo is that while man-made structures are prone to catastrophic damage by such storms, natural barrier islands are well designed to cope with the wind and wave energy associated with hurricanes and tropical storms.

4.2. Tree Mortality and Forest Recovery

Damage due to Hugo to the Hobcaw Forest was caused directly by wind, subsequently by soil salinization and finally by insect attack of trees stressed by both wind and salt. Wind damage to Hobcaw Forest was less severe and showed more resistance differences by tree species and size than forests further south, which were in the path of the eye wall (Hook and others, 1991). Subsequent damage to the forest by salinization and bark beetle attack resulted in approximately the same magnitude of tree death as the wind. In early May 1990, large populations of pine bark beetles were found in areas adjacent to both salt-killed and wind-thrown trees. These insects continued to infest pine trees throughout the summer of 1990.

The extreme heterogeneity and patchiness of tree mortality and its continuing nature have made ground-based study of salinization and beetle-caused mortality extremely difficult. In addition, determination of the cause of pine mortality is confounded by infestation of both a primary cause of death (*Dendroctonus*) and insects (*Ips* sp.) that attack trees already dying from another cause. Thus, were the trees killed by the insects or were the insects attracted to trees that were already dying from salt stress?

In any case, subsequent mortality was most severe in hardwood swales and closed depressions that trapped surge water. Pine mortality occurred mostly in areas adjacent to swales. This was true even for beetle-infested trees in the surge-inundated area. This distribution suggests that saline soil either directly killed these pines or so severely stressed the trees that beetle attacks were nearly exclusive to these trees. Outside of the surge area, fatal beetle attacks were primarily by *Dendroctonus*. Field inspection of these sites usually revealed that the initial attack was in bent or broken loblolly pine. Although limited in extent, this mechanism increased the total mortality of loblolly pine due to wind damage.

Recovery of the forest will be a long-term and uncertain process, particularly in the surge area. Extensive areas of hardwoods failed to produce leaves in March 1990 when spring growth normally begins. However, a few leafless hardwood and cypress trees managed to resprout by the summer of 1991. Pine seedlings also appeared in the surge-affected area in the summer of 1990 but most of these turned brown and died shortly thereafter. A new cohort of pine seedlings appeared in the summer of 1991, and appear to be flourishing so far. This difference in survival of the two cohorts is probably due to progressive flushing of salt from the forest soil, but also could be due to the fact that the spring and summer of 1990 were very dry. It remains to be seen whether this year's cohort survives as they send their roots into deeper and perhaps more saline soil. Recovery is likely to be most drawn out and problematic in hardwood swales. Salt leached from ridge soils will seep down-gradient towards swales, thus prolonging saline conditions there. Swale soils are humus rich, water-logged most of the year and thus anaerobic. Sulphate reduction is likely to occur due to high concentrations of sulphate in seawater. In iron-deficient soils such as these, the resulting H_2S will be lethal to both seedlings and surviving adults. Recent analyses of soil waters in swales indicate low levels of sulphide in some samples (Gresham, unpublished data). Should such conditions become more pervasive, the lower ends of some swales may be permanently transformed into *Juncus* marsh.

4.3. Mechanisms of Soil Salinization

There were probably several mechanisms involved in the salinization of the forest soil. When the surge occurred, the water table was near the ground surface along the swales, but 30 to 60 cm below ground level along the ridges. Figure 9 shows the hydrographs of four continuously recording wells before arrival of the surge, along with the record of rainfall from a weighing rain gauge. The surge terminated the records of all four wells, but the rain gauge continued to operate throughout the storm. Wells 12-5 (swale) and 21 (ridge) abruptly went off-scale between 2300 and 2330 hours on 21 September, indicating that the surge entered the forest at about 2300 h and had covered some of the ridges by 2330 h. Just prior to submergence by the surge, the water level in well 21 was about 12 cm below ground level. As one unit of infiltration usually results in a ten-unit rise in the water table in these sandy forest soils, the soil near well 21 probably had enough unsaturated pore space to accommodate about 1.2 cm of salt-water infiltration. Well 12-5, on the other hand, is located in a swale and the water table at this site was nearly at ground level when the surge arrived; thus there was probably little, if any, pore space for salt-water infiltration at this site. The records for the other ridge wells are unclear because either the float caught or the ink smudged. However, using the one-to-ten infiltration-water level response rule, we can estimate the quantity of salt-water infiltration at these sites. The rain gauge record indicates that approximately 41 mm of rain fell up to the time of arrival of the surge, implying a 41-cm potential rise in the ground-water level from the pre-storm base level. This suggests that by the time the surge arrived, well 44 should have risen to about 23 cm below ground level while well 12-1 should have risen to about 15 cm below ground level. This would have allowed 2.3 and 1.5 cm of salt-water infiltration at wells 44 and 12-1, respectively. Thus, one factor controlling the spatial variation in salinization is the depth to the water table at the time of the surge. In turn, this was controlled by elevation, topographic slope and soil permeability. Our experience indicates that ridges underlain by coarse permeable sands have substantially lower average water table elevations than ridges underlain by fine to medium sand even if elevation and topography are similar. Along swales, very little salt water immediately entered the nearly saturated soil. When the surge receded, about 1.0 m of salt water was

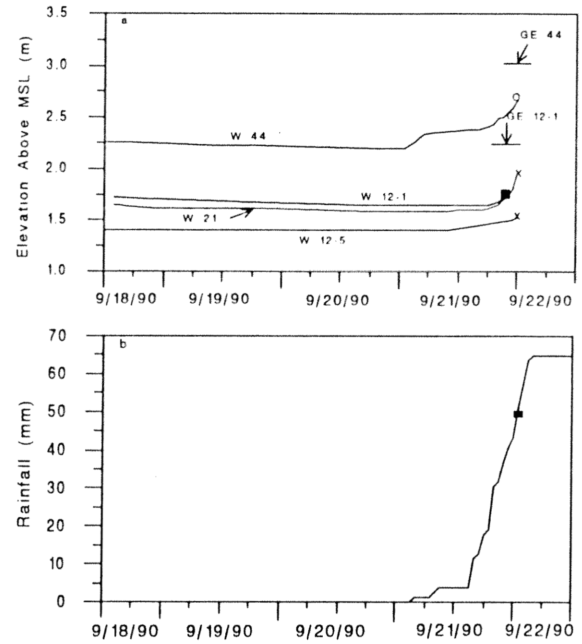

Figure 9--Records of water table elevations (MSL) at four forest well sites up to the arrival of th surge (top panel). Open circle indicates time that float caught. Closed square indicates where ink smudged and records might not be accurate. The X's indicate where records went off-scale, which is approximately equal to ground elevation. The bars above the circle and square show elevation of ground in relation to the last readings. Bottom panel shows record of cumulative rainfall where the closed square indicates cumulative rainfall up to the arrival of the surge.

trapped in the low gradient swales that were obstructed by downed timber and blowdown plates. The water in these depressions remained in the forest for over two weeks after the storm; saline water then moved into the soil to replace water lost by transpiration. Salt also diffused into the underlying freshwater.

Though more salt water initially infiltrated ridge soils than swale soils, trees on ridge sites generally showed less evidence of salt stress than those in or near swales. No clear explanation can be given at this time for this paradox but several suggestions can be offered. During October and November, the water table dropped to greater depths beneath ridge sites than in swales. Several modest rain events during this period may have been sufficient to dilute and/or elute residual salt from ridge soils above the water table. This may have allowed trees there to transpire less saline water from the unsaturated soil zone. The water table remained closer to ground level along swales, entirely covering tree roots in saline water. In addition, salt water that entered ridges should drain down-gradient towards swales. Thus, saline groundwater should disappear from ridge sites more rapidly than from swales.

4.4. Mechanisms and Implications of Ammonium Mobilization

Soil nitrogen dynamics were dramatically affected by exposure to saline water. In general, ammonium concentrations in all soil horizons increased approximately an order of magnitude immediately after Hugo, decreased slightly in the following several weeks and then increased suddenly by about another one to two orders of magnitude one month after the storm. Subsequently, ammonium concentrations in the A horizon began a gradual decline to levels that, one year after the storm, are still an order of magnitude greater than pre-storm values. Ammonium concentrations in the Bh horizon continued to increase until early 1991 and have since declined very gradually to levels that are still two to three orders of magnitude above pre-storm values. Although erratic, groundwater concentrations of ammonium rose throughout the year following Hugo to levels that are now several orders greater than those prior to the storm.

The initial rapid increase in ammonium was most probably due to ion exchange with seawater cations. Ammonium occurs as an exchangeable cation on clay-humus colloids and can be extracted by leaching with NaCl solutions (Armson, 1977).

Three processes may have produced the dramatic second-phase increase in ammonium that occurred about a month after the storm: inhibition of nitrification, increased decomposition of storm-deposited litter and decreased uptake of N by stressed and dying vegetation. Soil solution nitrate concentrations in the A and Bh horizons exceeded ammonium concentrations by three to fourfold prior to Hugo. Two days after Hugo, ammonium exceeded nitrate by up to eightfold. Nitrate concentrations in soil solutions declined rapidly to undetectable levels one month after the storm. Increased ammonium concentrations may have resulted from inhibition of nitrification by chloride. McClung and Frankenberger (1985) observed rapid inhibition of nitrification when soil was treated with 0.1 to 0.6% NaCl. They measured 39 to 83% decreases in nitrification within 21 days. Chloride concentrations after Hugo were sufficient to inhibit the conversion of ammonium to nitrite (Roseberg and others, 1986). These investigators also found greater inhibition at lower pH'S. The pH of the soil solution after Hugo at this site ranged between four and five.

Increased ammonium concentrations may also have resulted from the decay of litter deposited by the storm. Litterfall resulting from wind damage and salt stress was heavy. In some areas, thick mats of *Spartina* litter were deposited by the surge on the forest floor. This large input of litter could have provided ammonium to the soil water by decomposition and leaching. Although we did not measure the amount of litter deposition or its decay rate, we have projected the hurricane-induced nitrogen input by using measured normal litterfall from a 30-year-old loblolly pine stand similar to our site (Blood and others, 1991). Such a stand with a stem density of 2200 stems produces ~0.4 $kg \cdot m^{-2}$ of needle litter per year (Gresham, 1982). Loblolly pines drop ~50% of their annual production each year, thus the standing leaf biomass estimate for this site is 0.8 $kg \cdot m^{-2}$ (R. M. Allen, pers. comm.). Loblolly pine reabsorbs 45% of its leaf nitrogen prior to senescence, making the green needle content 1.36% nitrogen. The projected nitrogen input from hurricane-induced litterfall is thus 10.9 $g \cdot m^{-2}$. This is about four times the nitrogen input that would gradually occur during a normal year. The total annual nitrogen input to this site by precipitation through fall and stemflow is only 0.24 $g \cdot m^{-2}$ (Blood and others, 1989). The lag in the release of ammonium from litter decomposition may have been due to inhibition of decay immediately after the storm by standing saline water and residual salt in the litter.

Decreased vegetative uptake of nitrogen following Hugo also may have allowed the buildup of ammonium in soil waters. Root damage by wind stress (Parrotta and Lodge, 1991) and increased osmotic pressure in soil water may have hindered plant uptake of N during the early weeks following Hugo. Biological uptake of N is normally rapid in undisturbed forests, and the pools of available ammonium and nitrate are relatively small and turn over quickly (Vitousek and Matson, 1985). The continued elevated ammonium concentrations months after Hugo may be partly due to decaying roots and depressed rates of N-uptake.

The continuing increase of ammonium in the groundwater is probably due to its production in, and downward migration from, overlying soil horizons. Being largely below the root zone, it is not clear whether the great amount of ammonium now stored in the deeper groundwater will again be taken up by plants.

The impact of salinization on nitrogen dynamics may have a longer-lived effect on the forest than wind damage. Hurricanes with soil salinization decrease the efficiency of nutrient cycling through the rapid loss of leaves without N reabsorption and decreased N-uptake by vegetation. Microbial immobilization of N and absorption of ammonium ions on soil exchange sites are also reduced by sea-salt cations. Decomposition of hurricane-induced litterfall, together with inhibited nitrification and plant uptake, produces a large pool of soil water nitrogen which may be exported from the forest system by groundwater seepage and surface runoff. Loss of this nitrogen pool might limit the forest nitrogen and delay or prolong recovery.

4.5. Implications for Landscape Evolution

Variability in ecosystem patterns and processes observed at any given point in space or time is a function of controls operating over multiple spatial-temporal scales (Delcourt and Delcourt, 1988). The barrier island and marsh ecosystems at North Inlet have developed during Holocene time under a regime of slowly rising sea level (Gardner and Bohn, 1980). As sea level rises, the boundary between forest and marsh moves inland due to salinization of forest soils. It is not known whether this succession is gradual or occurs in pulses, perhaps triggered by surge events. Thus it will be of interest to observe whether the low-lying forest along the marsh and in swales recovers or is permanently transformed into marsh. If permanent transformation should occur, then Hugo will have been a 'disturbance' in the fullest sense envisioned by Sousa (1984). Only with continued research and data collection will it be possible to determine the range of variation in scale and intensity of natural disturbances (Pickett and White, 1985; Glitzenstein and Harcombe, 1988), and to recognize and interpret community and ecosystem responses to short-term events, such as hurricanes, within the context of longer-term changes such as sea-level rise (Delcourt and others, 1983).

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ESTIMATION OF ABOVEGROUND BIOMASS IN A HURRICANE-IMPACTED COASTAL PLAIN FOREST[1]

Richard K. Myers, David H. Van Lear, and F. Thomas Lloyd[2]

Abstract--This paper describes one phase of a long-term study on the role of fire in post-hurricane forest plant community dynamics. Two years after Hugo but prior to initiation of fire regime treatments, the biomass complex within the 75-ac study area on the heavily damaged Santee Experimental Forest in South Carolina was assessed using a variety of techniques to establish pre-burn data baselines. Overall, downed woody debris comprised the largest biomass component at 57.8% of the total, followed by forest floor (16.3%), living residual trees (15.0%), dead residual trees (8.1%), and regeneration layer vegetation (2.8%). Detailed quantitative pre-treatment descriptions characterize biomass distribution and document variation in post-hurricane vegetative structure and fuel characteristics, and will permit assessments of nutrient pool variation among treatment plots. These baselines will allow for more sensitive testing and evaluation of fire effects on the development of plant communities following devastating hurricanes.

INTRODUCTION

Hurricane Hugo's profound impact on the Francis Marion National Forest in South Carolina has presented the rare opportunity to formally study plant communities as they develop following what is arguably the most severe of natural disturbance factors in the southeastern United States: the combination of strong winds from hurricanes and subsequent wildfires in heavy fuels. This combination has almost certainly been a highly influential force in the evolution of plant species and community successional patterns, and a driving factor in the development of coastal plain landscapes. However, little documentation of the ecological processes involved in this interaction have to date been reported in the literature.

One part of a current research effort (Van Lear 1990, Van Lear and Myers 1992) investigating the role of fire in hurricane-devastated coastal plain forest plant communities has involved the detailed description of the biomass complex of the study area. Measurement and description of post-hurricane/pre-fire biomass components will allow for evaluation of such phenomena as nutrient redistribution and vegetation change following the implementation of burning treatments. One objective of this paper is to document post-Hugo stand conditions and to characterize biomass distribution of forest stands in which the fire-regime treatments are to be applied.

Characterizing post-hurricane forest structure and biomass becomes a difficult sampling problem. Forests severely damaged by windstorms and abetted by two growing seasons of early successional vegetative development are chaotic and highly variable assemblages of both living and dead plant material. Empirical description of the quantity of biomass and nutrients in various

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biomass components has required the use of both standard and improvised techniques. Thus, a second objective of this paper is to report on methods herein employed to describe the post-hurricane biomass complex.

STUDY AREA

This research is being conducted at two sites on the Santee Experimental Forest (SEF) within the Witherbee Ranger District of the Francis Marion National Forest (FMNF). The FMNF is located in the Lower Terraces of the Coastal Flatwoods Region, a part of the Flatlands Coastal Plain Province in South Carolina (Myers et al. 1986). Soils are mostly moderately well drained to somewhat poorly drained, and include Craven, Duplin, Lenoir, and Wahee soil series. These are soils with slow to moderately slow permeability and seasonally high water tables (Long 1980).

Both of the two study sites on the SEF were natural, unevenage mature pine stands prior to Hurricane Hugo, with the oldest trees exceeding 150 yrs in age. Stand records indicate loblolly (*Pinus taeda* L.) and longleaf (*Pinus palustris* Mill.) pine were the predominant overstory species, comprising approximately 70% and 30%, respectively, of pre-Hugo stocking. Fire had been excluded from these stands for decades, except for four small wildfires that burned in parts of both sites in the 1960's (USFS Witherbee R.D. Fire Atlas). Various species of hardwoods, notably the oaks (*Quercus* spp.), sweetgum (*Liquidambar styraciflua* L.), and blackgum (*Nyssa sylvatica* Marsh.), had become well-established in the under- and mid-stories, and were beginning to encroach into the overstory.

Fifteen, 5-ac burning plots, each surrounded by a wide (30 ft) firebreak, comprise the treatment areas in this study. A randomized complete block design was utilized with three blocked replicates of five treatment plots. Four burning regimes plus an unburned control constitute the five treatments, which were assigned at random for each block of five plots. Biomass and structure of vegetation, living and dead, was characterized prior to burning for each treatment plot. Biomass summaries will be presented here on an average per ac basis by treatment (3 reps combined) rather than on a plot by plot basis.

BIOMASS CATEGORIES AND ESTIMATES

Five distinct biomass categories were recognized which collectively comprised the vegetative complex of the hurricane-impacted forest two years following Hugo. These five biomass categories are: the regeneration layer (RL), forest floor (FF), downed woody debris (DWD), living residual trees (LRT), and dead residual trees (DRT). Empirical description of each of these components required specialized and, in some cases, improvised sampling methods.

Regeneration Layer

This biomass component consisted of living vegetation, both woody and herbaceous, much of which has developed in the two years following the hurricane-induced removal of the canopy. The regeneration layer (RL) was defined to include trees and shrubs less than 1-in dbh, woody vines, graminoids, forbs, and ferns. These six lifeform groups were arranged in a diverse assemblage of species associations and developing plant communities across the 75-ac study area.

It was subjectively observed prior to sampling that there was considerable variation in quantity and vegetative makeup of RL biomass within the study area. Nutrient content per unit weight of biomass can also vary greatly from one type of vegetation to another. Because of this perceived variation in amount and form of RL biomass, stratification was considered appropriate to decrease sample size, given the constraints of time, manpower, and funds available for this phase of the study.

A stratification procedure was developed that combined identification and estimation of unit area dry weight of Regeneration Layer Cover Types (RLCT) with measurement of area occupied by cover types within each plot. By combining RLCT weight per unit area with an estimate of cover type area, RL biomass and its composition in terms of lifeform plant assemblages for each pre-burn plot could be estimated. Weight per unit area was determined for each RLCT from destructive (ground) samples, and cover type area was measured on low-level helicopter-obtained aerial photography of each plot, a technique similar to that suggested by Helms and Shain (1981). This method increased sampling efficiency by reducing variability of stratified clip plots, resulting in a smaller sample size for obtaining acceptable weight estimates for each RLCT.

Eight rectangular (6.6 ft x 9.8 ft) quadrates were located in each of the five photo-identifiable RLCT's, and monumented with 5-ft conduit driven 1.5 ft into the ground. Four samples of each cover type (n=20) were placed in dormant season burn plots while the other 20 samples were located in growing season burn plots, allowing regeneration layer development comparisons between these two levels of the season-of-burn main effect. One half (3.3 ft x 9.8 ft) of each clip plot was sampled prior to initial fire treatments in late October-early November of 1991. The remaining unclipped plot-half was reserved for post-burn sampling in 1992 and 1993. Bormann (1953) described the advantages of using rectangular (long/narrow) plot shapes in uneven, discontinuous, and variable vegetation.

All herbaceous and woody plants less than 1-in dbh rooted in the plot were cut at or as near as possible to the groundline, and separated into the six previously-described lifeform groups. Vegetation was placed into separate paper bags by group, labeled, and returned to the lab for dry weight determination. Estimates for dry weight per unit area (T/ac) for each RLCT were obtained from the average of eight oven-dry sample weights, based on the composite weight of all plants clipped on each destructive sample plot. Thus, each RLCT pre-burn biomass estimate is based on 258.7 ft^2 of clipped plot area. Separation of RLCT destructive biomass samples into plant lifeform components allowed for determination and description of pre-burn plant community composition based on biomass proportions (Table 1).

Estimation of area covered by each RLCT for each plot was achieved by dot grid counts on aerial photographs. Photos were obtained on October 16, 1991 using hand-held 35-mm cameras and color slide films (400 ASA) during low-level (500 ft above land surface) helicopter flights over the study areas. Plots were framed within separate, nearly-vertical exposures using zoom lenses so that plot firebreaks were as close as possible to image borders. Accurate photo-interpretation of plots was possible with the high resolution slide images enlarged by projection. Corrections for photo scale distortion resulting from tilt were made by the use of rectified dot grid transparencies mounted in the same frames with color slide plot images. Rectified grids were constructed optically in the lab by photographing tilted dot grids drawn on white paper at a density of four dots per in^2.

For each plot, the total number of dots falling in each of the five RLCT's was counted. That proportion of dots per type to total dots per plot was calculated and used as an estimate for the proportion of area in each plot covered by each cover type. Table 2 presents area estimates for cover types in each of the five treatment areas.

As a check on this method of determining area in cover types from aerial photo interpretations and dot counts, an independent area estimate was made based on a set of 480 ground samples.

Table 1--Dry weight of lifeform components comprising five regeneration layer cover types (RLCT), prior to burning and two growing seasons following Hurricane Hugo.

Plant Lifeform	Regeneration Layer Cover Type				
	Pine	Herb.	Hwd.	Mixed	Shaded
	dry wt. - tons/acre				
Trees	1.97	0.25	1.38	0.72	0.25
Shrubs	0.49	0.07	1.53	0.47	0.39
Woody Vines	0.07	0.04	0.29	0.21	0.08
Graminoids	0.60	1.77	0.25	0.58	0.13
Forbs	0.40	0.13	0.03	0.24	0.04
Ferns/Moss	0.01	0.00	0.01	0.00	0.00
Total	3.54	2.26	3.49	2.22	0.89

Table 2--Area in regeneration layer cover types (RLCT) estimated from aerial photos, summarized by treatment area.

Treatment Area	Regeneration Layer Cover Type					Treatment Total
	Pine	Herb.	Hwd.	Mixed	Shaded	
	acres					
A	1.045	0.832	4.605	5.755	2.762	15
B	1.808	1.075	4.978	4.168	2.972	15
C	1.798	1.315	3.685	5.130	3.072	15
D	0.435	1.682	3.540	4.360	4.982	15
E	1.158	2.158	4.590	4.480	2.615	15
Total	6.242	7.062	21.398	23.892	16.405	75

Thirty-two cover type ground samples (3.3 ft x 9.8 ft) were systematically located in all 15 treatment plots. Each sample was given one of the five RLCT names based on its vegetative makeup. That proportion of ground samples (X/32) in each RLCT was taken as an estimate for the proportion of area in the treatment plot occupied by each RLCT, in the same manner as with the aerial photo procedure.

A simple correlation analysis was performed for the two methods of area estimation. While correlation was expectedly imperfect, the scatter diagram (Fig. 1) and high coefficient of determination ($r^2 = 0.7598$) shows that there is a strong relationship between the estimates of the two methods. Since a statistically significant ($F = 230.95$; $df = 73$) relationship resulted from this analysis, it can be inferred that the two methods yield similar estimates of area in cover types. The aerial technique with its greater sampling intensity (n=2401) is less apt to exclude smaller areas of relatively rare cover types, while the ground method has obvious advantages for correctly identifying vegetative assemblages and assigning cover type names. Aerial photo area estimates were ultimately used to calculate both regeneration layer and forest floor biomass for this project. Overall, regeneration layer biomass averaged 2.3 T/ac across the 75-ac study area (Table 3).

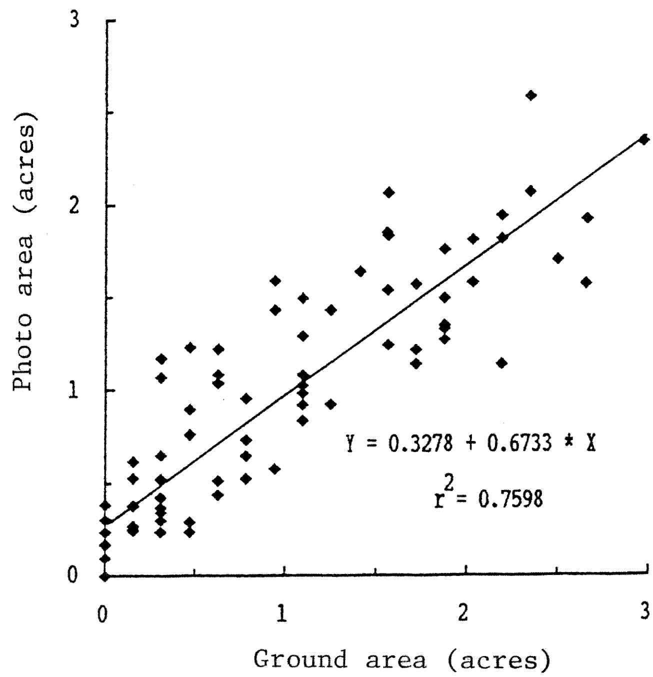

Figure 1--Correlation of photo and ground RLCT area estimates.

Table 3--Pre-burn regeneration layer (RL) biomass distribution, two growing seasons following Hurricane Hugo.

Treatment Area	Regeneration Layer Cover Type					
	Pine	Herb.	Hwd.	Mixed	Shaded	Total
	dry wt. - tons/acre					
A	0.25	0.13	1.07	0.41	0.16	2.02
B	0.42	0.16	1.16	0.62	0.18	2.54
C	0.42	0.20	0.86	0.76	0.18	2.42
D	0.10	0.25	0.82	0.65	0.29	2.12
E	0.27	0.32	1.07	0.66	0.15	2.48
Mean	0.29	0.21	1.00	0.62	0.19	2.32

Forest Floor

Forest floor (FF) biomass was assessed by methods similar to those used in regeneration layer biomass description. High variation in characteristics of the forest floor across the study area were anticipated and assumed to be related in part to vegetation characteristics. To minimize sample sizes while still obtaining representative estimates for forest floor biomass and nutrient content, sampling was stratified by RLCT. One 0.672 ft^2 composite (litter + fermentation layer + humus) sample was collected from one of 48 possible random locations within each of the 40 clipped regeneration layer plots described above. All organic material excluding dead woody material visible on the litter surface was removed, placed in paper bags, labeled, and returned to the lab for drying, processing in a hammer mill, determination of mineral content, and storage for later nutrient content assays. Mineral fraction of samples was determined by the method of Hesse (1974).

Forest floor weight estimates were calculated for each RLCT based on the average of the eight samples per cover type. Area factors for RLCT's already established (Table 2) were used to determine dry weight biomass estimates for the forest floor in each of the 15 treatment plots (Table 4). Overall, forest floor biomass averaged 13.7 T/ac across the 75-ac study area.

Downed Woody Debris

The planar intersect method described by Brown (1974) was employed to estimate pre-burn dry weight of wood and bark contained in down and dead trees and other downed woody material (DWD). Eight sampling planes were established on each 5-ac treatment plot using the permanent measurement points already in place as plane origins. A subset of the 16 points per plot was chosen by

Table 4--Pre-burn forest floor (FF) biomass distribution, two growing seasons following Hugo.

Treatment Area	Regeneration Layer Cover Type					Total Biomass
	Pine	Herb.	Hwd.	Mixed	Shaded	
	dry wt. - tons/acre					
A	0.93	0.31	5.55	4.48	2.70	13.98
B	1.62	0.40	6.00	3.24	2.91	14.17
C	1.61	0.49	4.42	3.99	3.00	13.52
D	0.39	0.63	4.27	3.39	4.87	13.56
E	1.04	0.81	5.53	3.49	2.56	13.42
Mean	1.12	0.53	5.15	3.72	3.21	13.73

random selection of either the even- or odd-numbered stations. Compass bearings for sampling planes were also randomly selected from one of the three remaining cardinal or semi-cardinal directions not already used for plant cover measurement. Thus, eight samples per plot (24/treatment area) were established for downed woody material biomass assessment.

Variable-length sampling planes were utilized to achieve high sampling efficiency. Long planes (50 ft) were used for the larger (3+ in), less-frequently-occurring pieces of DWD, while shorter transects were used for the numerous small pieces. Woody material 0-1 in diameter at the point of plane-intersection was measured on 6-ft planes, while 12-ft planes were used for material 1-3 in diameter. End-points of transects were marked with flagging and aluminum pins placed in the ground to facilitate reestablishment and remeasurement of sample planes after burning.

Table 5 summarizes quantities and variation in DWD distribution, by size class, for the five treatment areas. Given the severity of damage and the large size of trees in these stands prior to Hugo, it is not surprising that DWD represented the largest of the five components of aboveground biomass in the hurricane-impacted forest. Overall, DWD averaged 48.7 T/ac across the 75-ac study area. Variation was moderate, ranging from a low average of 41.8 T/ac for the three plots (15 ac) in treatment C to a high of 56.2 T/ac for treatment B.

Residual Living and Dead Trees

Biomass in living residual trees (LRT) and standing, dead residual trees (DRT) was quantified for each plot using tree measurements of dbh and total height obtained from fixed-radius plot samples. These tree data were used to estimate total aboveground biomass in living and dead residual trees in conjunction with published biomass equations for estimating wood and bark in the total tree (Clark and Taras 1976; Phillips 1981; Saucier and Clark 1985; Taras and Clark 1977). Each treatment plot was "cruised" using sixteen 1/20-ac circular plots with centers at the 240 monumented sampling points previously described. All trees 3.0-in dbh and larger, dead or alive, rooted within these plots were tallied for species, dbh, total height, and condition (vertical, leaning, downed, top-broken, etc.). In addition, 32, 1/200-ac samples per treatment plot (n=480) were established at monuments and at monument mid-points in which the above measurements were taken for trees and large shrubs 1.0 - 2.9-in dbh. Using information from these inventories, woody biomass descriptions were compiled in tabular form for each of the fifteen 5-ac plots.

The majority of trees in the hurricane area had abnormal form, with tops blown out or broken off, limbs removed from crowns to varying degrees, and (with hardwood species) two years of vigorous regrowth in the form of epicormic, limb, and basal sprouts. Equations generally used dbh and total height to predict whole-tree biomass. Trees with crowns completely removed (e.g. the

Table 5--Pre-burn downed woody material (DWM) biomass distribution, two growing seasons following Hugo.

Treatment Area	0-3" size class			3"+ size class		Total Biomass
	0-.25"	.25-1"	1-3"	sound	rotten	
	dry wt. - tons/acre					
A	0.66	1.92	6.22	38.39	2.66	49.85
B	0.59	2.95	6.28	45.57	0.82	56.21
C	0.63	2.52	7.27	31.39	0.03	41.84
D	0.75	2.03	5.64	39.50	2.49	50.41
E	0.47	1.83	4.94	37.10	1.02	45.36
Mean	0.62	2.25	6.07	38.39	1.40	48.73

numerous dead standing pine boles typical of the hurricane-impacted forest area) were measured for total height of that portion of stem remaining, and equations for dbh and merchantable height were used to estimate biomass of wood and bark, on a dry-weight basis.

The many published whole-tree equations are not designed to predict biomass in trees with wind-damaged crowns. Thus, the accuracy of the biomass predictions for the damaged residual forest stand may be in question. However, the alternative to the use of existing equations was to destructively sample many trees of many species, a prohibitively expensive and time-consuming task. Since the quantities of biomass estimated in this study are used primarily as a means for comparing effects of various burning treatments on the redistribution of nutrients, the method is defensible and valid. It is the repeatability of the measurements and estimates that is most important in this application, and not estimate accuracy. Tables 6 and 7, respectively, summarize distribution of LRT and DRT biomass. In Table 7, the term "snags" refers to dead pines whose crowns were completely broken out by strong wind, leaving only the standing boles.

DISTRIBUTION OF BIOMASS

Total aboveground dry biomass across the study area averaged 84.2 T/ac (Table 8). This quantity is similar to estimates from other studies for total forest biomass in natural, 60+-year-old southern pine and mixed pine-hardwood forests (Knight and McClure 1981).

Downed woody debris comprised the largest (57.8%) component, by weight, of biomass in the hurricane-devastated forest. This finding was expected in view of the severity of Hugo's impact and the extensive windthrow and stem breakage of many large trees. The regeneration layer represented the smallest (2.8%) biomass component, but required the most effort for valid quantification because of its variability and the diversity of plant forms comprising it. This effort was considered worthwhile, since RL biomass is high in nutrient content relative to the other more woody biomass components (Van Lear et al. 1988), and because these plants represent the seed sources and root-stocks that will play important roles in the colonization of the sites following burning treatments.

CONCLUSIONS

The biomass quantification phase of this study demonstrated that in the chaotic, complex structure of hurricane-devastated but rapidly regenerating forests, a combination of standard and improvised techniques is necessary for assessing forest attributes. On the Santee Experimental Forest after Hurricane Hugo, downed woody debris was the largest component of total biomass (57.8%), followed by the forest floor, living residual trees, dead residual trees, and the regeneration layer. Baseline data have been collected and summarized which thoroughly describe pre-treatment conditions of stand structure and biomass distribution, allowing for subsequent assessment of nutrient pools. These baselines will enable burning treatment effects to be documented and analyzed in an on-going study of the interactive effects of

Table 6--Pre-burn living residual tree (LRT) biomass distribution, two growing seasons following Hugo.

Treatment Area	Species Group					Total Biomass
	Pine	Oaks	Sweetgum	H-Hwd	S-Hwd	
	dry wt. - tons/acre					
A	4.62	3.49	0.94	0.33	1.73	11.11
B	4.62	6.42	0.45	1.08	0.54	13.11
C	6.20	3.02	0.80	0.57	1.38	11.97
D	7.50	4.40	0.57	2.11	1.20	15.78
E	3.92	4.33	1.32	0.29	1.42	11.28
Mean	5.37	4.33	0.82	0.88	1.25	12.65

Table 7--Pre-burn dead residual tree (DRT) biomass distribution, two growing seasons following Hugo.

Treatment Area	Pine		Hardwood		Total Biomass
	Trees	Snags	Hard	Soft	
	dry wt. - tons/acre				
A	1.52	6.53	0.54	0.02	8.61
B	1.43	3.30	1.04	0.03	5.81
C	0.16	4.79	0.51	0.08	5.54
D	2.56	4.09	1.28	0.04	7.98
E	1.64	4.00	0.27	0.14	6.06
Mean	1.46	4.54	0.73	0.06	6.80

Table 8--Pre-burn aboveground biomass distribution for five treatment areas two growing seasons post-Hugo.

Treatment Area	RL	DWM	FF	LRT	DRT	TOTAL
	dry wt. - tons/acre					
A	2.02	49.85	13.98	11.11	8.61	85.57
B	2.54	56.21	14.17	13.11	5.81	91.84
C	2.42	41.84	13.52	11.97	5.54	75.29
D	2.12	50.41	13.56	15.78	7.98	89.85
E	2.48	45.36	13.42	11.28	6.06	78.60
MEAN	2.32	48.73	13.73	12.65	6.80	84.23
PERCENT	2.8	57.8	16.3	15.0	8.1	100.0

hurricanes and fire on the development of forest plant communities.

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COMPACTION AND RUTTING DURING HARVESTING AFFECT BETTER DRAINED SOILS MORE THAN POORLY DRAINED SOILS ON WET PINE FLATS

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Abstract--Soil compaction and rutting (puddling) are visually distinct types of wet-site harvesting disturbances; however, the way in which they affect soil physical properties and hydrology is not well documented. Three compacted and three rutted sites were evaluated to determine the effects of the disturbances on soil physical and hydrologic properties. For each site, primary skid trails and non-trafficked areas were compared. Both compaction and rutting increased bulk density, and reduced macropore space and saturated hydraulic conductivity. Water tables and reducing conditions were closer to the soil surface within the primary skid trails. For the compacted and rutted skid trails, changes were greatest on sites that initially had better drainage and aeration. Compacted sites may prove easier to mitigate with site preparation than rutted sites due to the shallower nature of the disturbances and drier site conditions that will facilitate mechanical mitigation.

INTRODUCTION

Wet flats comprise a landform on the southern Atlantic Coastal Plain that are characterized by little or no relief, water tables at or near the soil surface for a portion of the year, and soils that are moderately well to very poorly drained. Pine stands on these wet flats are an important source of fiber to the wood products industry; some of the most productive pine plantations are located on these sites (Allen and Campbell 1988). The seasonal high water tables associated with wet pine flats present a dilemma for forestry harvesting operations. Rubber-tired felling equipment and skidders may traffic over 50 percent of a site and may result in soil compaction or rutting, particularly if logging occurs when soils are wet (Aust and others 1993).

Many researchers have concluded that harvesting wet sites can result in soil compaction or rutting (puddling) (Dickerson 1976; Gent and others 1983, 1984; Hatchell and others 1970; Hatchell 1981; Incerti and others 1987; Karr and others 1991; Lockaby and Vidrine 1984; McKee and others 1991; Moehring 1970; Moehring and Rawls 1970; Murphy 1983; Wert and Thomas 1981). However, few forest-harvesting disturbance studies have differentiated between the effects of compaction and rutting on soil properties. Soil compaction and soil puddling occur under different soil moisture conditions and may have different effects. Soil compaction occurs when soil solids in a given soil volume increase relative to

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soil pore space. Soil compaction usually occurs when soils are near field capacity because, compared to drier soils, soils at this moisture level have lower cohesive forces and load-bearing capacities (Akram and Kemper 1979). Therefore, soil moisture levels between field capacity and saturation are most susceptible to compaction, although compaction is also influenced by machinery weight, tire size and pressure, soil moisture, soil texture, and vegetative cover (Greacen and Sands 1980).

Soil rutting (puddling) generally occurs on sites that are harvested under saturated soil conditions (Burger and others 1989). Soil puddling is "the destruction of soil aggregates into ultimate soil particles" (Sharma and DeDatta 1986). Soils at or near saturation experience shear failure when a load is applied, resulting in the formation of a rut. Soil structure is altered by puddling because soils are at the liquid limit and have a liquid response to external forces. Soil aggregates are destroyed and churned into plastic mud (Beacher and Strickland 1955; Ghildyal 1982; Swanson and others 1955).

In the fall of 1989, Hurricane Hugo devastated many wet-flat pine stands in coastal South Carolina and initiated hundreds of salvage-logging operations. Due to an unusually wet fall and winter, salvage-logging was conducted under moist to wet soil conditions. On many sites, logging operations severely rutted or compacted primary skid trails. Site disturbances due to this salvage-logging were similar to those created by many standard clearcut harvesting operations on wet soils. The objective of this study was to evaluate three rutted and three compacted sites in order to contrast compaction and rutting effects on soil physical and hydrologic properties. This information is necessary to determine if different strategies are needed to avoid and mitigate compaction versus rutting disturbances.

METHODS

The study sites were near Charleston, South Carolina, on the Francis Marion National Forest. Six wet pine flats that had been salvage-logged following Hurricane Hugo were selected for study. Dominant soil series in the study included Bethera (poorly drained, clayey, mixed, thermic Typic Paleaquults), Rains (poorly drained, fine-loamy, siliceous, thermic Typic Paleaquults), Lynchburg (somewhat poorly drained, fine-loamy, siliceous, thermic Arenic Paleaquults), and Goldsboro (moderately well drained, fine-loamy, siliceous, thermic, Aquic Paleudults). Topography was nearly level (0-1 slope) and all sites had water tables at or near the soil surface for portions of the year. Soil drainage classes of the sites ranged from moderately well drained to poorly drained. Soil textures included coarser materials in the surface horizon (loamy sands, sandy loams, and loams) overlying finer sub-soil materials (sandy clay loams and clays). Three sites were classified as being rutted (puddled) because soils in primary skid trails had obviously experienced liquid flow and soil had been displaced into berms adjacent to ruts. The other three sites were classified as being compacted, with no berm formation along the primary skid trail.

The compacted and rutted soil studies were conducted as two separate but parallel experiments. Each study consisted of a randomized complete block design (Steele and Torrie 1980) containing three blocks (sites) and two treatments. Treatments consisted of heavily-trafficked primary skid trails and non-trafficked areas adjacent to the primary skid trails (Figure 1). Soils within each site had the same texture and drainage class; therefore, non-trafficked areas were judged to be representative of site conditions prior to salvage operations.

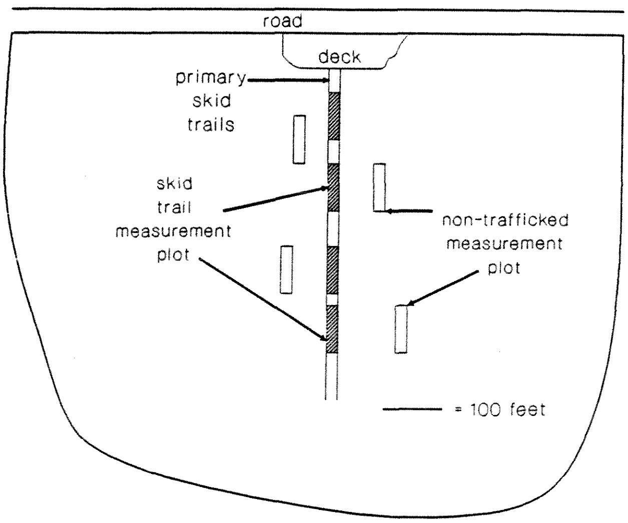

Figure 1--Generalized layout of one salvage-logged block (site) including measurement plots in primary skid trails and non-trafficked areas.

Four measurement plots (25 ft. x 80 ft.) were established within each block (Figure 1) and four sampling transects were randomly located across each measurement plot. At each sampling transect, the following measurements were recorded: soil disturbance class, soil surface profiles, water table depth, soil depth to reducing environment, bulk density, and porosity.

Five soil disturbance classifications (Burger and others 1989) were assigned: non-trafficked, berm (inside and outside), tire-track, and between-tire-track. Non-trafficked subplots contained only non-trafficked cate-gories. Rutted measurement plots contained berms, tire-track and between-tire-track categories. Compacted measurement plots contained tire-track and between-tire-track categories.

Cross-sectional profiles of soil disturbance were measured in the trafficked plots in the following manner: a leveled line was stretched across the skid trail at each sampling transect. Leveled-line height corresponded to the groundline elevation on either side of the skid trail and closely corresponded to the pre-disturbance soil surface elevation. The distance from the leveled line to the post-disturbance soil surface was measured at 0.5-ft. intervals across the sampling transect.

One water table well (Faulkner and others 1989) was established at each sampling transect (4 wells per measurement plot). Wells were located between the tire tracks in the trafficked measurement plots and located randomly in the untrafficked measurement plots. Wells were measured biweekly from April through September, 1991. Elevations of all wells within a block (site) were determined with a transit so that water table values could be corrected for differences in topographic elevation. After topographic differences had been accounted for, the water table levels of the undisturbed areas were used as the baseline comparison value. Water table levels on disturbed plots were recorded relative to the undisturbed areas.

Two iron rods (1/8 in. diameter x 40 in. length) were inserted at each sampling transect to determine the relative depth of reduced conditions that occurred in the different types of treatments (Bridham and others 1991; Carnell and Anderson 1986; Hook and others 1987; McKee 1978). On each sampling transect in the primary skid trail treatment, one iron rod was installed between the tire tracks and another was installed in the tire-track. Two iron rods were randomly located and installed on each sampling transect of all non-trafficked sub-plots. Depth of rust on the iron rods was measured biweekly.

Five soil cores (2 in. diameter x 4 in. length) were collected from the upper four inches of the soil surface on each sampling transect (20 per measurement plot). The soil cores were taken from the tire-track (2), between-tire track (1), and berm (2) soil disturbances classes. Soil cores were subsequently analyzed for bulk density (Blake and Hartge 1986), macropore space (Danielson and Sutherland 1986), and saturated hydraulic conductivity (Klute and Dirksen 1986).

RESULTS

The average depth of ruts in the primary skid trails of the three rutted blocks were 14 inches below the original ground surface, while average rut berm heights were 9 inches above the original soil surface (Figure 2). Average percentages of each disturbance class within the rutted plots were: outside berm (29 percent), tire-track (43 percent), inside berm (24 percent), and between-tire-track (4 percent). Thus, on over 90 percent of the rutted skid trail, characteristically denser and less fertile subsoil horizons were either exposed by tire tracks or deposited as berms over surface horizons.

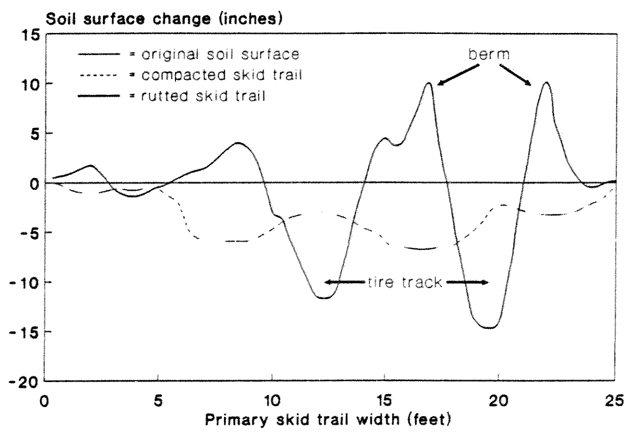

Figure 2--Average change of soil surface profiles in compacted and rutted primary skid trails.

Compacted skid trails had tire-tracks 6 inches below the original soil surface but no berms were formed. Between-tire-track areas also were approximately 3 inches below the original soil surface (Figure 2). The tire-track disturbance class comprised 82 percent of the skid trail area and the between-tire-track class made up 18 percent. No subsoils were exposed; overall the surface profiles of compacted sites were less severely affected than the rutted sites. However, the between-tire-track of the compacted areas were further below the original soil surface than the rutted area, indicating that dragged logs had removed more topsoil in the compacted sites (Figure 2). McKee and Hatchell (1987) concluded that removal of topsoil by dragged-logs could retard tree growth on skid trails.

Rutted skid trails had average bulk density values that were 15 percent higher than non-trafficked areas (Table 1). Bulk densities between the tire tracks and on the berms were not significantly different from bulk densities in the non-trafficked areas. However, soil bulk density values averaged 1.39 Mg m^{-3} within the track, a density level that could limit root growth (Vepraskas 1988) depending on soil moisture levels. This higher bulk density in the track was a function of compaction as well as soil displacement (Figure 2).

Table 1--Average soil bulk density, macropore space, and saturated hydraulic conductivity for primary skid trails and non-trafficked treatments on rutted (puddled) and compacted sites (alpha level = 0.01). (Values represent area-weighted averages of all disturbance classes).

Treatment	Bulk Density	Macro-pore Space	Saturated Hydraulic Conductivity
	(Mg m^{-3})	(%)	(in hr^{-1})
Rutted Study			
Non-trafficked	1.04a	7.8a	3.5a
Skid trail	1.20b	4.7b	0.3b
Compacted Study			
Non-trafficked	0.97a	9.5a	7.4a
Skid trail	1.16b	7.0b	0.9b

Compacted skid trails also had higher average bulk density values relative to the non-trafficked treatment (Table 1). The impact of skidder traffic was more uniformly distributed across compacted trails compared to rutted trails (Figure 2). Tire-track and between-tire-track bulk densities averaged 1.17 and 1.12 Mg m^{-3}, respectively, which were not significantly different. Bulk density values were higher than in the non-trafficked area, but did not exceed levels limiting to root growth.

Macropores are primarily responsible for rapid drainage of free gravitational water from within the soil (Greacen and Sands 1980). Reductions in macropore space caused by trafficking decrease soil drainage and reduce aeration. Rutting reduced soil macropore space to about 60 percent of that on non-trafficked plots, while compaction reduced macropore space to approximately 80 percent of that on non-trafficked plots (Table 1). Similar reductions in soil macropore space due to trafficking have been reported by others (Aust and others 1993; Gent and others 1983; Incerti and others 1987).

Saturated hydraulic conductivity is a measure of the rate that water moves through a saturated soil and is related to macropore space; water flow is proportional to the fourth-power of the pore radius (Baver and others 1972). That is, water moves 16 times faster in a soil pore that is twice the radius of an adjacent pore. Saturated hydraulic conductivity serves as a quantitative index of soil drainage. Rutted primary skid trails had an average hydraulic conductivity of 0.3 in hr^{-1} compared to 3.5 in hr^{-1} on non-trafficked plots (Table 1), a ten-fold decrease in the rate that free water is able to drain from soils puddled by rutting. Compaction resulted in a similar reduction in hydraulic conductivity. The non-trafficked plots averaged 7.4 in hr^{-1} versus 0.9 in hr^{-1} in the compacted skid trails (Table 1). These low hydraulic conductivity rates in compacted and rutted (puddled) sites were similar to those reported by Aust and Lea (1992), Dickerson (1976), and Gent and others (1983) for forest sites that were trafficked under similar conditions.

Low saturated hydraulic conductivity caused by rutting and compaction would suggest poor drainage within primary skid trails. Higher water tables confirmed that drainage was poorer in the somewhat poorly drained to moderately well drained soils. On poorly drained soils water tables were not significantly closer to the soil surface in the skid trails than in the non-trafficked areas (Figures 3.a, 3.b). Two of the rutted sites were poorly drained; so a reduction of saturated hydraulic conductivity in the rutted skid trails did not result in any major hydrologic changes. However, one rutted site was somewhat poorly drained. On this site, the reduction in hydraulic conductivity within the primary skid trails resulted in a water table that was 25 inches higher than in the non-trafficked plots (Figure 3.a).

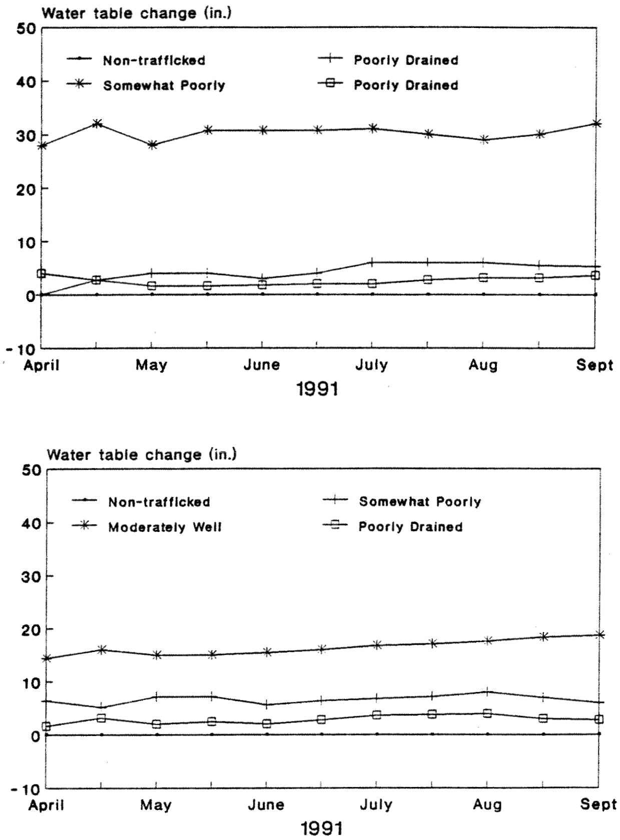

Figure 3--Average disturbance-induced water table change for (a) rutted and (b) compacted primary skid trails by site drainage class. (Water table values are adjusted for topographic differences, so higher water tables indicate change from the non-trafficked condition represented by the zero base line.)

The compacted sites included a moderately well drained, a somewhat poorly drained, and a poorly drained soil. The degree to which soil compaction treatment affected the water table was also related to the initial soil drainage class. Compaction-induced changes in water tables were inversely related to drainage class. The water table increased 17.0 inches in the moderately well drained compacted plots, compared to 6.9 and 3.3 inches, respectively, for the somewhat poorly drained site and poorly drained sites (Figure 3.b).

Higher water tables affected soil aeration, as shown by depth of rust on iron rods. Within the primary skid trails of the rutted (puddled) sites, aerated conditions existed to an average soil depth of 9.6 inches, compared to 12.9 inches within the non-trafficked areas (Figure 4.a). The same pattern existed within the compacted plots: compacted primary skid trails were aerated to a depth of 8.8 inches, and non-trafficked areas were aerated to 9.7 inches (Figure 4.b).

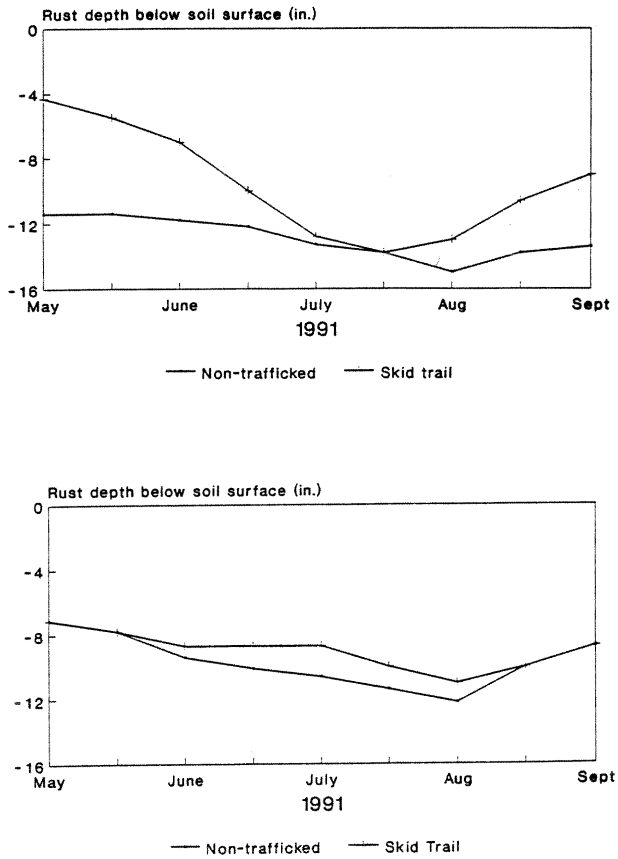

Figure 4--Average soil depth of rust on iron rods for (a) rutted and (b) compacted primary skid trails, where rust indicates depth to reducing environment.

DISCUSSION

Wet pine flats are characterized by seasonally high water tables, many of these sites require bedding for the successful regeneration of pine plantations. Compaction or puddling of soils on these wet sites will probably not result in soil strength increases that would impede root growth. Aust and Lea (1992) compared soil disturbance on a skidder-logged area to a control area in an alluvial floodplain and concluded that skidder-logging did not increase soil strength. Likewise, Burger and others (1989) evaluated soil strengths associated with increasing skidder traffic levels on wet pine flats under saturated and moist conditions and found that soil strengths actually decreased with increasing traffic levels because of a corresponding increase in volumetric water content. Soils in the compacted and rutted blocks usually retain enough water during the growing season so that increases in bulk density do not result in higher soil strengths.

However, both compaction and rutting altered soil drainage and aeration to an extent that could adversely affect root growth. Compaction and puddling decreased macropore space and saturated hydraulic conductivity. Decreases in macropore space and hydraulic conductivity due to wet-site trafficking have been found by numerous researchers (Burger and others 1989, Gent and others 1983, Incerti and others 1987). The compacted and rutted sites drained more slowly, as shown by the higher water tables and more reduced conditions (lower soil oxygen). Drainage and aeration reductions were more pronounced on sites that had better initial drainage and aeration characteristics. The sites having poor drainage and aeration prior to either disturbance were less affected, implying that compaction and rutting can have more severe site productivity impacts on better drained sites. It will be interesting to see if the soil properties observed on the sites affect the development of the stands as evapotranspiration increases. Langdon and Trousdale (1978) showed that the water tables on similar sites were lowered about 1 ft. for each 40 $ft.^2$ of basal area increase.

Both compaction and rutting can have deleterious impacts on soil physical properties. However, the compacted sites were on better drained areas that are easier to mitigate. Rutted sites were wetter and may have relatively narrower windows of operation when a mechanical mitigation treatment could be applied. Additionally, the rutted areas had deeper disturbance profiles and successful mitigation of these disturbances will probably require mechanical operations that operate to deeper soil depths. Bedding may successfully fill in the rutted areas, but may have little impact on soil physical properties (Gent and others 1983, 1984). Disking may prove to be a successful mitigation treatment on shallow disturbances of the compacted sites. However, Hatchell (1981) observed that bedding improved early growth of loblolly pine on a similar poorly drained site, but disking was not effective for mitigation of skid trails. The interaction of site drainage and different methods of mitigation may change with time.

Three mechanical (disking, bedding, disking and bedding) and one fertilization treatment were applied to these rutted and compacted treatment plots. Results of these mitigation treatments on soil properties and tree growth will be reported at a later time.

ACKNOWLEDGMENTS

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SOIL PHYSICAL AND HYDROLOGICAL CHANGES ASSOCIATED WITH LOGGING A WET PINE FLAT WITH WIDE-TIRED SKIDDERS

W. M. Aust, T. W. Reisinger, J. A. Burger[1], and B. J. Stokes[2]

Abstract--A wet pine flat in the coastal plain of South Carolina was harvested with a rubber-tired skidder equipped with 68-in.-wide tires. Soil physical properties were measured immediately before and after a salvage harvest to document changes associated with traffic disturbance. Paired t-tests indicate that the wide-tired operation significantly increased soil volumetric water content, bulk density, and soil strength, and decreased saturated hydraulic conductivity, soil porosity, and depth to the water table. Changes were greatest for the more disturbed areas, and rutting that occurred in the skid trails apparently interrupted subsurface drainage.

INTRODUCTION

Technological modifications in harvesting equipment, such as the use of wide, high-flotation skidder tires, have made it possible to operate on soft, wet sites. However, there is continued concern over the site impacts associated with wet site operations. Most postharvest evaluations of site impacts reported in the literature have concentrated on soil damage due to trafficking of relatively well-drained soils (Reisinger and others 1988).

When a poorly drained soil is trafficked, its soil strength may actually decrease due to an increase in volumetric water content (Burger and others 1989). For many wet sites, assuming few periods of soil drying, the soil strength may never approach levels that will actually limit root or seedling growth (Burger and others 1991). The most critical changes associated with wet-site harvesting operations are those that are related to the movement of air and water within the soil profile. Any decreases of soil aeration and drainage on already poorly drained soils have the potential to reduce overall site productivity and further limit management opportunities. The objectives of this study were to evaluate the impacts of a wide-tired grapple skidder on soil physical and hydrological properties of a wet forest site.

METHODS

Site Description

The study site is located on the Francis Marion National Forest in the Coastal Plain of South Carolina (Berkeley County), where Hurricane Hugo devastated the forests during the fall of 1989. The 4.0-ha study site had a slight slope (1-2 percent) from west to east (Figure 1). The soil was classified as a Bethera loam, clayey, mixed, thermic Typic Paleaquult (USDA Soil Conservation Service 1980). This soil series typically has a loamy surface layer about 10.2 to 17.8 cm thick over a clay layer. Drainage is poor, and the soil is commonly saturated from early winter through spring. A 60-year-old natural loblolly pine (*Pinus taeda*) stand covered the entire site prior to Hurricane Hugo. After the hurricane, over 50 percent of the trees in the stand were bent, uprooted, or broken due to the high winds. This

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damage prompted a tremendous effort to salvage downed timber on the Francis Marion National Forest and within the region.

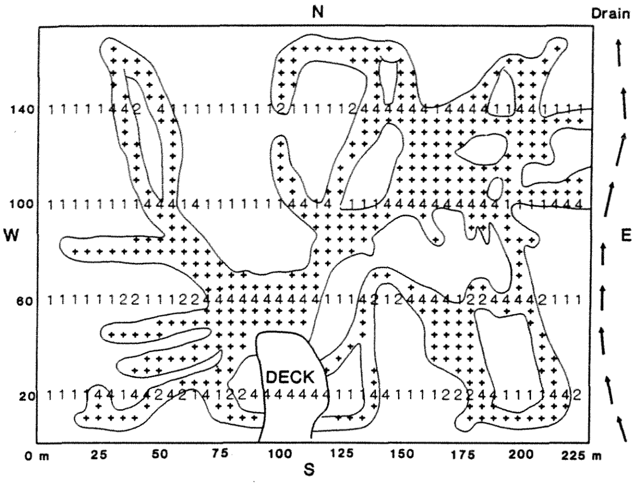

Figure 1--Map of transect lines used to delineate skid trails and soil disturbance classes: + = skid trails; 1 = undisturbed; 2 = slightly disturbed; 4 = rutted.

Salvage Operations

The salvage operation consisted of chainsaw felling of large-diameter standing snags and bucking merchantable sawlogs from windthrown trees; only dead trees were removed during this operation. After the sawtimber had been felled and bucked, the logs were grapple-skidded to a landing located next to a graveled road. All skidding was done over a 2-day period (in May 1990) with a John Deere 648 grapple skidder equipped with 68 X 68 x 25 in. Ardco tires.

Study Design

An assessment of site disturbance was made immediately prior to and immediately after the salvage harvest. Four transect lines, spaced 40 m apart, were installed to locate sampling stations perpendicular to the expected skid trail pattern. Each transect line measured 225 m in length, as determined by salvage sale boundaries (illustrated in Figure 1).

Soil disturbance classes were determined and assigned continually along each transect line and were similar to the disturbance classification system developed by Miller and Sirois (1987). The classes were:

Class 1--Undisturbed
Class 2--Slightly disturbed
- a. litter still in place
- b. litter removed and mineral soil exposed
- c. mineral soil and litter mixed
- d. mineral soil deposited on top of litter

Class 3--Deeply disturbed, surface soil removed and subsoil exposed
Class 4--Rutted, compacted
- a. 0-15.2 cm
- b. 15.2-30.5 cm
- c. > 30.5 cm

Class 5--Depression deposit, soil deposited in low spots
Class 6--Covered by slash to depth that will hamper regeneration
Class 7--Nonsoil, streambed, stump, etc.

Along each transect line, on a 5 m spacing, cone penetrometer (Bradford 1986) samples were taken in 2.54 cm intervals to a soil depth of 15.2 cm (at 184 stations). A standard U.S. Army Corps of Engineers penetrometer (ASAE Standards 1990), equipped with a 30° 1.27-cm^2 cone was used. Soil bulk density (Blake and Hartge 1986) core samples (5.1 x 5.1 cm cylinders) were taken from the soil surface every 12.5 m along the transect lines (at 76 stations). Every other bulk density sample (40 stations) was kept in its cylinder and later analyzed to determine total pore, micropore, and macropore space (Danielson and Sutherland 1986), and saturated hydraulic conductivity (Klute and Dirksen 1986). Water table wells were augered on a 40 m spacing (40 stations) to determine depth to the water table (Reeve 1986). All stations were marked with flagged stakes so that before- and after-harvest samples could be taken within 15 cm of the same point. Sampling the before-and-after periods from the same stations allowed the data to be analyzed by paired t-tests (Steele and Torrie 1980). All preharvest stations were classified as undisturbed, but the tests paired stations based on the postharvest classification.

RESULTS

Visual inspection of the study area indicated no machine disturbance prior to salvage harvest. Immediately after harvest, the area was reclassified, and only three classes of site disturbance were detected. The undisturbed (Class 1), slightly disturbed (Class 2a), and rutted (Class 4a), covered 52, 14, and 34 percent of the site, respectively, following the harvest (Figure 1). In general, Class 2a represented areas that had received 1 or 2 skidder passes, while Class 4a represented an area that had been repeatedly trafficked (i.e., primary or secondary skid trails).

The area was harvested under conditions of relatively high soil moisture (Table 1), as necessitated by the time constraints of the salvage effort. Volumetric water contents increased as the level of disturbance increased. Volumetric water content is influenced by bulk density; because bulk density increased on Classes 2 and 4, the volumetric water content also increased compared to the preharvest level.

Postharvest bulk density values were higher than preharvest values and increased as the level of disturbance increased (Table 1). Although the increase in bulk density was significantly higher for the slightly disturbed and rutted classes, average bulk densities were still relatively low, being less than 1.0 Mg/m^3.

Hydraulic conductivity, an index of soil drainage, is proportionally related to macropore space. Soil drainage is primarily a function of macropore space under saturated soil conditions. Saturated hydraulic conductivity values decreased as traffic intensity increased, with a twofold reduction for slightly disturbed areas and an almost complete interruption of water movement for the rutted areas (Table 1).

Harvesting operations caused a significant decrease in total porosity in disturbed areas (Table 1). No change in micropore space occurred; however, macropore space decreased significantly. Notable was the significant difference in macropore space, even for the undisturbed Class 1. Areas visually classified as undisturbed may have received some level of undetected traffic, or the impact of felled trees may also have had an effect.

Mechanical resistance values for the postharvest treatment were higher than for the pretreatment values (Table 1). Mechanical resistance tends to decrease as volumetric water content increases; however, volumetric water contents did not vary greatly (i.e., 30.9-35.2%). Mechanical resistance, like bulk density, increased more on the more highly trafficked areas, down to the 15 cm depth.

Preharvest well measurements indicated that the water table depth was fairly constant across the entire site (i.e., 50-56 cm). Postharvest measurements (from the same wells) revealed that water tables were nearer the soil surface (i.e., 32-37 cm) than before harvest. The water table was also significantly closer to the surface in the slightly disturbed areas (33 cm) and primary skid trails (32 cm) than in the undisturbed areas (37 cm) (Table 1).

Table 1--Mean values of soil physical and hydrological properties for the pre- and postharvest sampling period separated by postharvest site disturbance class following a salvage harvest on the Francis Marion National Forest.

	Volumetric water (%)	Bulk density (Mg/cm^3)	Saturated hydraulic conductivity (cm/hr)	Total (%)	Porosity micro (%)	Macro (%)	Mechanical resistance (0-15.2 cm) (kPa)	Depth of water table (cm)
Preharvest								
undisturbed	33.8#a	0.71a	57.8a	74.3a	53.7a	20.6a	433a	51a
slightly disturbed†	32.2a	0.70a	66.7a	75.1a	54.2a	20.9a	359a	50a
rutted†	30.9a	0.72a	64.2a	71.4a	54.1a	17.3b	525b	56a
Postharvest								
undisturbed	33.5a	0.75a	44.6a	72.0a	53.9a	18.1*a	425a	37*a
slightly disturbed	35.2b	0.89*b	20.5*b	64.6*b	52.4a	12.2*b	450*a	33*b
rutted	34.4b	0.96*c	0.2*c	65.6*b	53.2a	11.4*b	625*b	32*b

* Significant difference between before and after values (alpha = 0.05).
# Different letters denote significant difference between site disturbance classes within each period (alpha = 0.05).
† No preharvest areas were disturbed or rutted; the classification refers to the pairing of stations following harvest.

DISCUSSION

Wide-tired skidders are the most commonly used machine adaptation for logging on wet sites. However, the use of wide tires does not necessarily reduce site disturbance. On this study area, the wide tires provided operators the necessary mobility to harvest the area, often operating on ground too wet to support a conventionally equipped skidder. In this case, the wide-tired skidder trafficked 48 percent of the total site during the harvest.

The impact on soil physical properties on the untrafficked area was negligible. Mechanical resistance was the only soil property for which a preharvest difference was found. It is not coincidental that the skid trails occurred in areas with the highest soil strength. Equipment operators quickly find, via trial and error, the areas that best support the machine. On the trafficked areas, soil strength and bulk density were well within the acceptable ranges for normal plant growth (< 1.4 Mg/m^3 and < 2500 Kpa, respectively), even for the most highly disturbed classes (Reisinger and others 1988).

However, the hydrology of the area was significantly influenced by the network of skid trails (Figure 1, Table 1). No rainfall occurred on the site between pre- and postharvest measurements, and no live trees were harvested during the salvage operation. Thus, the increase in water tables was not a function of precipitation or reduced evapotranspiration; rather, the difference was a result of decreased subsurface water movement. The rutted areas, where total porosity and saturated hydraulic conductivity were drastically reduced, impede the lateral flow of water through the porous surface soil horizons above the clay layer.

The study site has a slight slope from the western side of the site towards the small drain on the eastern side. The skid trails intersected and blocked this natural flow pattern, resulting in a larger change in water table elevations on the western side of the study area (Figure 2). The clay subsoil on this site has an inherently low hydraulic conductivity, so the interruption of lateral subsurface flow within the surface horizon resulted in a higher water table. This higher water table will result in a less well-aerated condition on an already poorly drained site and may ultimately reduce site productivity. A previous study within the same general area indicated that the amelioration of similar sites through natural soil processes may require as long as 18 years (Hatchell and others 1970). An 18-year period of less than optimal growing conditions represents a significant proportion of a pine stand's rotation and thus may affect future volume yields.

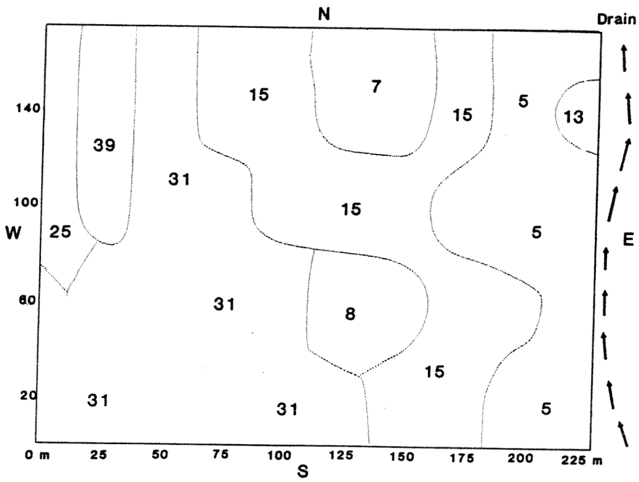

Figure 2--Decrease in depth (i.e., cm of change) to water table following the logging operation.

Skidders equipped with wide tires can effectively reduce site impacts when used on sites that are marginally possible to log with a conventionally tired skidder. When wide tires are used as a mechanism of gaining access to sites normally inoperable with narrow-tired skidders, negative soil and site impacts can occur.

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CHANGES IN BALD CYPRESS-SWAMP TUPELO WETLAND SOIL CHEMISTRY CAUSED BY HURRICANE HUGO INDUCED SALTWATER INUNDATION[1]

Charles A. Gresham[2]

Abstract--Several soil chemical characteristics were measured in three bald cypress (*Taxodium distichum* L. Rich. var *distichum*) - swamp tupelo (*Nyssa sylvatica* var *biflora* (Walt.) Sarg.) swamps that were either not inundated, or inundated to various depths by the storm surge associated with Hurricane Hugo. Soil chloride concentrations were high 2.5 years after the storm and were the only soil change directly attributable to saltwater inundation. Many other parameters including soil organic matter, nitrogen and phosphorus were indirectly associated with saltwater inundation via canopy tree mortality.

Introduction

Hurricanes frequently disturb coastal forests in the southeastern United States (Purvis 1973) with both short-term and long-term effects. Short-term damage is seen as saltburn (Gresham 1981) or wind damage (Gresham and others 1991) and the degree of damage is a function of proximity to the hurricane's eye and species. Forest recovery from short-term damage is rapid because pre-existing regeneration will be released or residual stems will sprout. For example, heavily damaged stands on the Francis Marion National Forest were revegetated by loblolly pine (*Pinus taeda*) and sweetgum (*Liquidambar styraciflua*) by the second growing season after the hurricane. Long-term hurricane damage to a forest results from saltwater inundation causing tree mortality and soil chemistry changes. This type of site alteration not only changes what is present in the short-term, but could also influence how fast an inundated area is revegetated and what species re-occupy the forest during recovery. Along the Atlantic Coastal Plain, bald cypress (*Taxodium distichum* L. Rich. var *distichum*) - swamp tupelo (*Nyssa sylvatica* var *biflora* (Walt.) Sarg.) wetlands are the most vulnerable forest type to saltwater inundation because of their hydrologic connection to marshes and estuaries. Salinity tolerence of bald cypress has been investigated (Pezeshki and others 1988) but little is known about the effects of saltwater inundation on wetland soil chemistry despite several hypothesized effects.

Overstory mortality resulting from saltwater inundation will allow more direct sunlight on the wetland floor, thus increasing soil temperatures and possibly nitrogen mineralization. This mortality will also add coarse woody debris to the wetland and will decrease annual leaf fall. Chloride ions could extract ammonium and nitrate ions from the soil thus increasing the potential to lose nitrogen from the wetland. Soil microorganism metabolism could be reduced in the presence of saltwater, thus affecting the oxidation/reduction status of the soil. Saltwater inundation should not directly affect soil phosphorus concentrations. Ammonium nitrogen mobilization by saltwater

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inundation has been reported in pine forest soil solutions (Blood and others 1990, 1991) and freshwater and marine sediments (Gardner and others 1991). Ion pairing of ammonium with saltwater anions and saltwater cations occupying soil cation exchange sites would increase ammonium loss. Alterations of several soil chemical characteristics due to flooding are driven by microorganism oxygen consumption (Gambrell and Patrick 1978, Ponnamperuma 1984, Patrick and others 1985). Since the activity of microorganisms is affected by soil salinity (McClung and Frankenberger 1985, Roseberg and others 1986), several wetland soil physical and chemical characteristics could be altered by saltwater inundation, as compared to freshwater inundation. The intrusion of North Inlet estuarine saltwater into adjacent cypress wetlands associated with Hurricane Hugo on Hobcaw Barony (Hook and others 1991) created an opportunity to monitor the effects of saltwater inundation on cypress-tupelo wetland soil chemistry. Similar wetlands that were not either inundated or less deeply inundated were also available for comparison. Specific objectives were to monitor (1) wetland hydrology, (2) selected soil chemical characteristics, and (3) canopy woody and foliage litterfall patterns.

Methods

Three bald cypress-swamp tupelo wetlands on Hobcaw Forest, 3 mi east of Georgetown, South Carolina were chosen for study. The most severely impacted stand, referred to as Marsh Road, is a linear inter-dune swamp approximately 750 ft from North Inlet estuary which was inundated to a depth of approximately 9 ft during Hurricane Hugo's landfall on September 21, 1989. The soil is a Hobcaw soil (fine-loamy, siliceous, thermic, Typic, Umbraquult; Stuckey 1982). There was no evidence of saltwater intrusion since the hurricane. The least impacted stand was an isolated bald cypress-swamp tupelo-ash (*Fraxinus* (L.)) swamp approximately 1 mi from North Inlet estuary. This stand, called Crabhaul suffered only light wind damage and is also on a Hobcaw soil. The third stand, referred to as Boardwalk, is a bald cypress-swamp tupelo headwater swamp that drains into a brackish marsh and was flushed with saltwater during the hurricane. Soil types are Rutledge sand (sandy siliceous thermic Typic Humaquept) on the brackish marsh side and Johnston loam (coarse loamy, siliceous, acid, thermic, Cumulic Humaquept) on the inland side.

Five 0.12-ac plots were installed in each stand in the spring of 1990, and two 10.7 ft^2 wooden littertraps were placed in each plot in February, 1991. A soil sampling station and a shallow observation well was installed in each plot in May, 1991. At each sampling station, type K thermocouples and platinum redox probes (Letey and Stolzy 1964) were buried at approximately 3 in, 7 in, and 12 in (Crabhaul and Boardwalk) or 12 in and 16 in (Marsh Road) below the top of the litter layer. A recording rain gauge was installed within a mile of each site and one observation well in each stand had a water level recorder installed.

Soil samples were taken twenty times from April 1991 to April 1992 by extracting two 3 in by 18 in soil cores with a sharpened pipe from each plot in each stand. The soil cores were divided into upper and lower 6-in sections and samples taken by depth. Equal volumes of soil from both depths of the first core and DDW were mixed in the field and pH was measured with glass electrodes. Thermocouples were read with a hand-held meter and redox probes were read with a hand-held millivolt meter and a calomel reference electrode in a KCl-agar salt bridge. Littertraps were emptied monthly and the water table depth in non-recording observation wells was measured weekly.

Results and Discussion

Water table dynamics of the three study areas is presented in Figure 1. In the Crabhaul stand, the water table drops rapidly due to leaf emergence, rises with frequent rains and drops again when the rainfall decreases. This stand dries out the most because of the high basal area and floods the deepest because of its pond-like topography. Similar, though less pronounced patterns were noticed in the Marsh Road stand which had the most tree mortality. In contrast, the water table level in the Boardwalk stand rarely dropped below ground level nor flooded deeper than 4 in. Since we noticed that part of the Boardwalk stand water table behaved differently from the other, two recording wells were installed and this difference is seen in Figure 1 as deeper flooding of the inland plots. The hydrologic

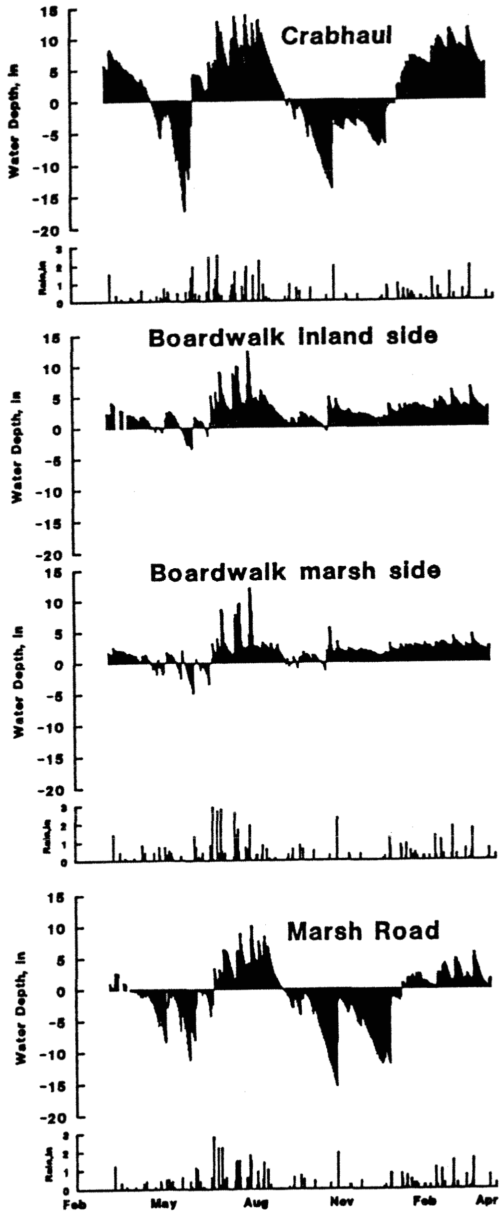

Figure 1--Water level depths and rainfall for three bald cypress-swamp tupelo stands in coastal South Carolina that were severely impacted (Marsh Road), moderately impacted (Boardwalk), and not impacted (Crabhaul) by Hurricane Hugo's tidal surge.

connection between the Boardwalk stand and brackish marsh is probably responsible for both the lack of flooding (rainfall quickly flows from the swamp to the marsh) and the lack of drying (water flowing from the marsh to the swamp if the swamp water table level is low). This hydrologic connection is supported by the presence of short periods of high water levels not closely associated with rainfall. These "spikes" are explained by lunar tides pushing marsh water into the swamp. The two saltwater impacted stands had similar soil and water temperatures, and both were warmer than the control Crabhaul stand. These temperature trends indicate that saltwater inundation indirectly affected soil temperature by reducing canopy shading of the swamp floor. The seasonal range of temperatures, within stand variation of temperatures, and yearly average temperature decreased along the progression of; air, water, upper soil, and deeper soil. During most of the study period all soils were reduced (+100 to -100 mv) to highly reduced (-100 to -300 mv) at both depths. However, the upper layers were less reduced than the lower layers. Reduced conditions indicate that the microbial populations were active in the impacted stands. Crabhaul soils did not oxidize when the water table dropped below the soil surface, as would be expected in a drained soil. Soils of impacted stands were less acid than the control stand. Two factors probably contribute to this: more decomposing litterfall in the control stand contributing more organic acids and the displacement and loss of hydrogen ions by saltwater cations in the impacted stands (Blood and others 1991). Foliage and woody litterfall rates reflected saltwater-induced tree mortality in opposite ways. The unaffected control stand had a foliage litterfall rate of 5900 kg ha-1 yr-1 as opposed to 2800 kg ha-1 yr-1 for Boardwalk and 1110 kg ha-1 yr-1 for Marsh Road. Woody litterfall was highest for Boardwalk (10,900 kg ha-1 yr-1) less for Marsh Road (2500 kg ha-1 yr-1) and far less (600 kg ha-1 yr-1) for the Crabhaul, the control stand. Therefore, saltwater inundation reduced foliage litterfall and increased woody litterfall. Soil organic matter was highest in Crabhaul swamp, lowest in Marsh Road, with Boardwalk having slightly more than Marsh Road. Long-term heavy litterfall and cooler temperatures of Crabhaul swamp probably contributed to soil organic matter buildup, while low litterfall rates and warmer soil temperatures probably reduced Marsh Road's soil organic matter. Boardwalk's intermediate soil organic matter may have resulted from different soil types and less tree mortality than Marsh Road. Upper soil layer organic matter content was higher than the lower layer in all three stands. The stand with the highest saltwater mortality, Marsh Road, had soil chloride concentrations of approximately 400 ppm and Crabhaul stand had far less. Boardwalk soil chloride levels were 5-10 times that of Marsh Road. This can be explained by repeated brackish water inundation from the marsh into Boardwalk over many years. Tidal "spikes" were noticed in water table level recordings indicating that marsh water entered Boardwalk during high lunar tides. Because this has probably been happening for decades the stand has apparently accumulated chloride. Soil ammonium nitrogen levels were highest in Marsh Road, which may have resulted from mineralization of the high biomass input following tree mortality. Lower soil ammonium concentrations in Crabhaul may reflect tree uptake removing nitrogen about as fast as litterfall and mineralization replaces it. Similarly Boardwalk has less litterfall input and less basal area to remove ammonium from the soil. Also the high chloride levels may indicate that ion paring may be making ammonium more mobile.

Soil nitrate levels were low in all three stands which is expected in reduced soils where microorganisms reduce nitrate nitrogen to ammonium nitrogen. Among the low values, Crabhaul stand had the highest nitrate levels indicating that this stand had the least reduced soil. The water level in Crabhaul did drop below the soil twice during the study to deeper levels than in the other stands. Soil phosphorus concentration patterns were similar to soil ammonium concentration patterns; highest in Marsh Road, lowest in Crabhaul. Like ammonium nitrogen, high phosphorus levels in Marsh Road are likely the result of mineralization of mortality related biomass input to the swamp floor. Lower phosphorus in Crabhaul may indicate a balance between litterfall mineralization and tree uptake.

Overall Saltwater Inundation Effects

Soil chloride was the only soil chemical parameter directly affected by saltwater inundation. Perhaps soil pH differences were influenced by hydrogen ion displacement due to saltwater anions, but the data could not verify this. Most of the other soil chemical parameters measured were indirectly affected by saltwater inundation via tree mortality. Marsh Road, the stand with the highest tree mortality, had higher soil temperatures, less leaf litterfall, more woody litterfall, lower soil organic matter, and higher ammonium nitrogen and phosphorus. These same soil chemical changes would be expected if similar mortality were caused by another agent such as herbicide or insect infestation.

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SALT WATER MOVEMENT WITHIN THE WATER TABLE AQUIFER FOLLOWING HURRICANE HUGO[1]

Thomas M. Williams[2]

Abstract--Hurricane Hugo generated a tidal surge approximately twenty feet high which inundated a strip of coastal forest from Charleston to just south of Myrtle Beach. On the Hobcaw Forest, east of Georgetown, the surge was about 10 feet above sea level and inundated a strip about 3500 feet wide. Salt water infiltrated directly into the forest soil and water table aquifer during the surge and from ponded areas for a period after the storm. Early auger hole measures of water table aquifer salinity reflected the deposition of salt within the aquifer throughout the surge area. Later multi-level sampling indicated that salt concentrations have remained high (2000 mg Cl/l) through 1992. Higher concentrations have persisted deep (12 ft) in the aquifer but groundwater flow has also carried high concentrations into hardwood drainages. Forest mortality was more closely related to salinity determinations in multi-level samplers than earlier auger hole data.

INTRODUCTION

Southern coastal forested wetlands are subject to hurricanes sometime during the lifetime of most of the tree vegetation (Conner In press). Tidal surges are associated with most hurricanes and affect coastal wetlands with the same frequency. The extent of flooding associated with a tidal surge depends on the tidal stage when the hurricane approaches the coast and the slope of the upland adjacent to the coast. Since much of the coastal landscape has very small relief a tidal surge occurring near high tide may cause flooding miles landward from the coast. Salt water carried into the forest will infiltrate into the soil and potentially move within the water table aquifer. Trees may be killed if water conductivity exceeds 5 millimhos/cm (approximately 3000 mg Cl/l) around their roots (Franscois 1980). The fate of salt water within the water table aquifer will determine both mortality and the rate of forest recovery.

Hurricane Hugo struck the coast of South Carolina on September 21, 1989, approximately 2 hours before the astronomical high tide (Brennen 1991). The eye of the storm crossed the coast just north of Charleston, S.C. The tidal surge extended northeast of the storm center with a maximum height of twenty feet above sea level near McClellanville, S.C., about thirty miles northeast of the center of the eye (Coch and Wolff 1991). Elevated tidal stages extended to Garden City about 75 miles northeast of the center of the eye.

The Hobcaw Forest is located approximately 50 miles northeast of the storm center. The forest is located directly behind a barrier beach and salt marsh. Tidal surge at this location was between 9.5 and 10.5 feet above sea level (7.5 feet above mean high tide) and extended into the forest up to 3500 feet landward of the salt marsh edge (Gardner and others 1991). Salinity

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measured in auger holes in this zone immediately after the storm ranged from >100 to 4000 mg Na/l. The maximum was equivalent to 40% of the Na concentration in sea water.

INITIAL DAMAGE

Wind damage from Hurricane Hugo was moderate on Hobcaw Forest. The most severely damaged tall oaks experienced less than 30% mortality while the more resistant trees had less than 10% mortality (Gresham and others 1991). Initial damage due to salt stress was noted in November of 1989. By February 1990 many pines were showing severe stress with yellowing foliage and defoliation throughout the portion of the forest with elevations below 10 feet above sea level. Defoliation continued throughout the spring of 1990. By late spring pines with yellowing crowns were also heavily infested with southern pine beetle (*Dendroctonus frontalis* Zimmerman) and engraver beetles (*Ips* spp.) and the role of salt stress became ambiguous. Many deciduous trees within the same zone failed to produce foliage in the spring of 1990. Except for a few cypress (*Taxodium distichum* (L.) Rich.) that produced new sprouts in late 1990 and early 1991 these trees subsequently died. Aerial photographs taken in early February 1991 revealed the pattern of initial mortality within the zone of tidal surge flooding (Figure 1).

Figure 1--Distribution of living (gray) and dead timber (black) on Hobcaw Forest (February 1991) as a result of soil salinity.

The pattern of survivors in 1990 was not predictable from the auger hole salinity measures taken by Gardner and others (1991). Salinity in auger holes was highest near the edge of the marsh and generally higher on pine ridges. Most surviving trees were on ridges and there was a fringe of living trees along much of the marsh edge. The distribution of mortality suggested that salt had moved from the highest and best drained areas and accumulated in lower topographic positions. This suggested that a large portion of the tidal surge waters had moved within the water table aquifer.

Salt water within the water table aquifer poses a threat to the present survivors and to regeneration, either natural or planted. This study had the objective of determining three aspects of salt distribution in the aquifer: (1) What was the present distribution of salt in the aquifer? (2) What were the rates and direction of water movement and was salt moving with the groundwater flow? (3) What was the rate of salt removal from the system and when would salt no longer threaten forest health?

METHODS

The premise of this research was that sea salt movement would be most easily characterized by piezometric potential and distribution of chloride ion. Piezometric potential measures allow determination of flow directions. Chloride is a major constituent of sea salt and most closely approximates a conservative tracer.

The study was conducted within a small watershed in conjunction with Gresham (this volume) and Conner (this volume). The watershed is located adjacent to the North Inlet salt marsh and is labeled marsh road in each paper. It is oriented from southwest to northeast with an outlet to the marsh northeast of the study site. A small stream draining the watershed to the northeast flows within a stand of cypress (*Taxodium distichum* (L.) Rich.) and swamp tupelo (*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.). Elevations within the stream wetland vary from 4.5 to 6 feet above sea level. The bottom of the best-defined channel slopes from 4.8 to 4.5 feet above sea level within the study area. The wetland is separated from the marsh by a ridge on the eastern side that ranges from 7 to 8 feet above sea level. A ridge along the western side separates the watershed from another stream to the west. The western ridge also ranges from 7 to 8 feet above sea level.

Groundwater was sampled from five transects along the stream section (Figure 2). A piezometer station was placed in the center of each vegetation plot established by Conner (this volume). Four more piezometer stations were established on a line perpendicular to the stream forming five transects from the top of the eastern ridge to the top of the western ridge each with five piezometer stations. Each piezometer station followed a design which had accurately measured water chemistry and piezometric potential in a layered sandy aquifer near the study area (Williams and McCarthy 1990). At each station, piezometric potential was measured at depths of 5, 7.5, 10, and 15 feet below the surface in capped 3/4 in piezometers screened with #10 well screen for an interval of 4 in at the appropriate depth. Water chemistry samples were collected from 1/2 in x 4 in samplers screened with #10 well screen and connected to the surface by 1/4 in polyethylene tubing. Water chemistry samplers were at 4, 6, 8, 10, and 12 feet below the soil surface.

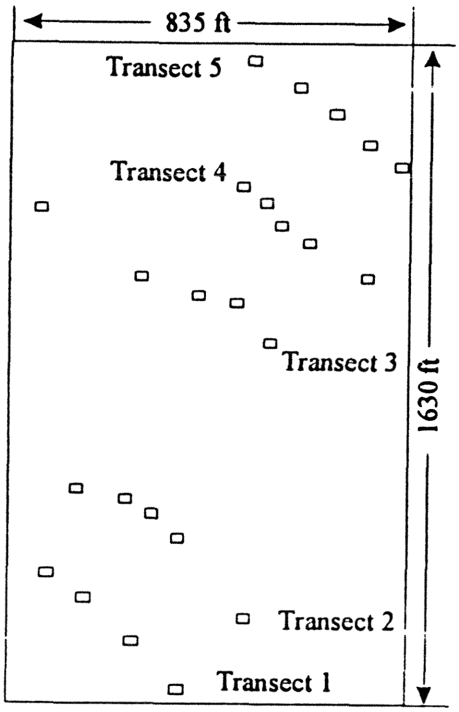

Figure 2--Distribution of sampling piezometers.

Piezometric potential was measured weekly from April 1, 1991 through March 31, 1992. Piezometer top elevations were surveyed from a nearby benchmark. Water levels in each piezometer were measured with an electrical resistance probe.

Water chemistry samples were withdrawn from the soil on a monthly basis during the same time period. Samples were withdrawn from the samplers with a peristaltic pump. Water was pumped from each sampler and discarded until three to five sampler plus tubing volumes were removed. Then a 60 ml sample was taken in a NHCl washed polyethylene sample bottle which had been rinsed with distilled water to remove all traces of NHCl. Samples were returned to the laboratory and refrigerated until analysis. Chloride analysis was performed on a Technicon II auto analyzer using the ferri-cyanide method (American Public Health Association).

RESULTS

Twenty-four sampling stations were actually installed. The western ridge was indistinct on transect 1 and a station was not installed. Piezometric potentials were collected for 52 weeks from April 1, 1991 until March 31, 1992. Potentials varied with weekly changes in rainfall and potential evapotranspiration. Large weekly variability is normal for shallow water tables (Lipscomb and Williams 1989). During high rainfall periods piezometric potentials within the wetland were relatively uniform and equal to the height of water standing on the surface.

Groundwater chloride concentrations showed spatial as well as temporal variability. Individual measures varied from less than 50 mg/l to over 3000 mg/l during the year. Highest values were found during drier summer months while lowest values were found during high water in April, 1991. However, any inverse relation of groundwater chloride concentration to antecedent rainfall was weak and obscured by spatial variability.

Chloride distribution and groundwater flow directions can be summarized as annual averages. The study site can be circumscribed by a 1630 feet by 835 feet by 20 feet thick block. Figure 2 shows the position and orientation of the five piezometer transects within this block. Figure 3a shows five cross-sections of the block at each of the transects. Figure 3b represents horizontal maps of the block at each of the five sampling depths. Figures 3a and 3b each depict three aspects of the experiment. The maps represent a contouring of the mean chloride concentrations. At each actual sample point a small rectangle is shaded to indicate the 95% confidence interval of the mean value at that point. Arrows on each

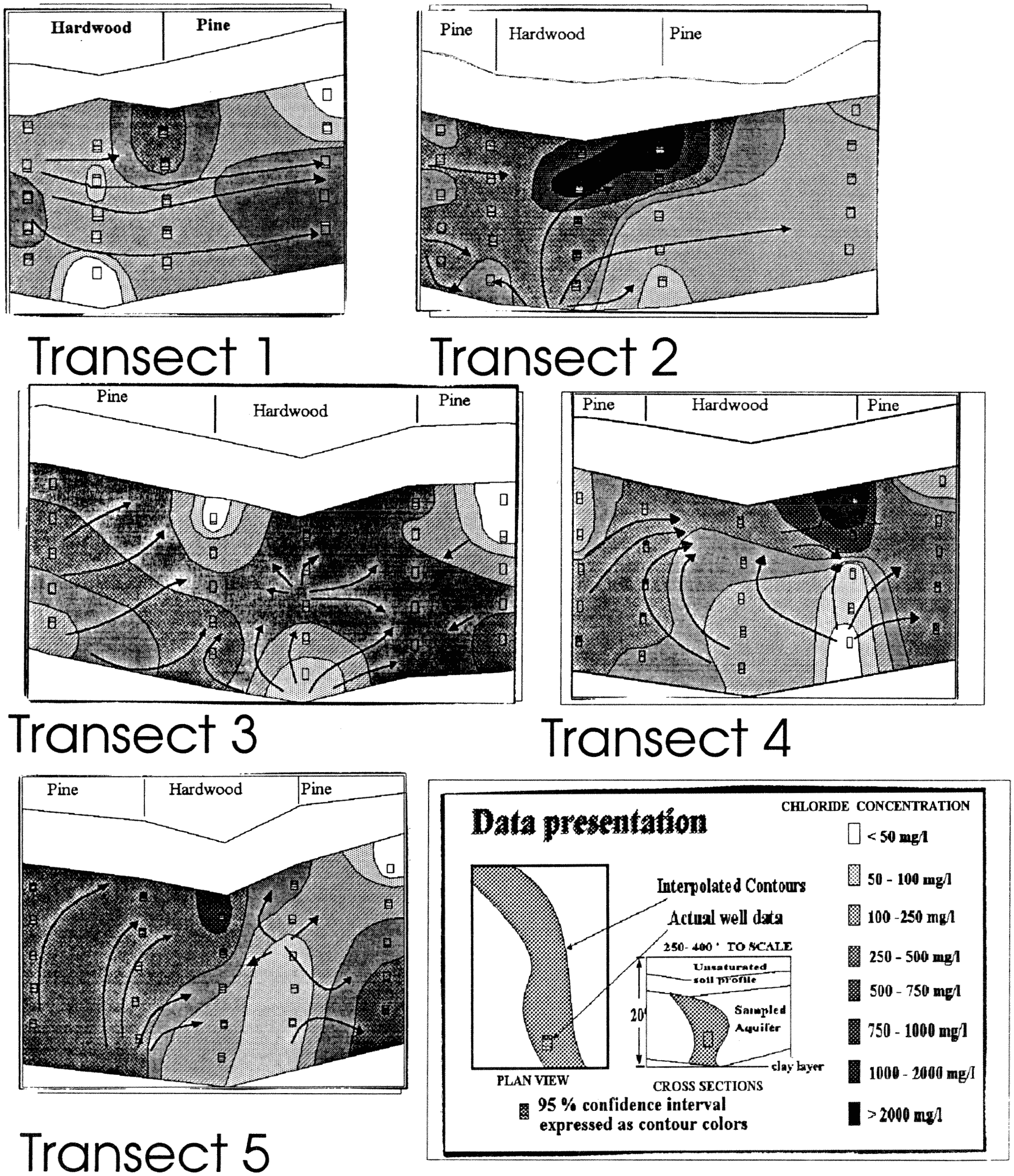

Figure 3a--Cross sections of each transect showing mean chloride concentrations (contoured gray scales), 95% confidence limits on mean values for each sampling site (small rectangles with gray scales) and mean direction of groundwater flow (arrows).

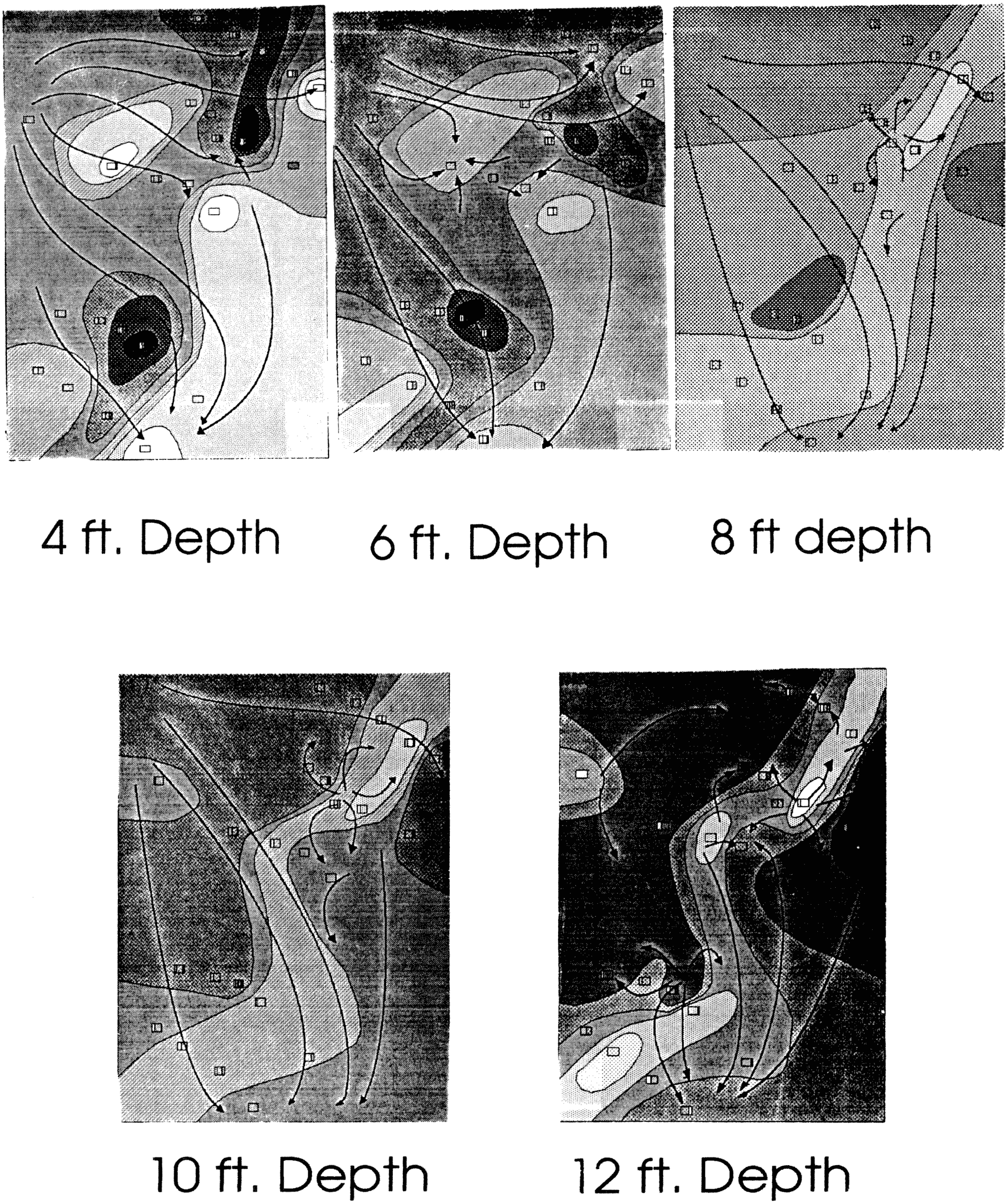

Figure 3b--Horizontal cross sections of sampled area at each chloride sampling depth. Chloride concentration contours and 95% confidence rectangles use the same scale as Figure 3a. Groundwater flow lines are for piezometer level just below sampling level.

map are a two-dimensional representation of groundwater flow direction determined from average piezometric potential gradients which were significantly (95%) different from zero. There were only four piezometers per station and they were at depths intermediate between chloride samplers. The arrows on Figure 3b are representations of the flow at depths just below the samplers. The 10-foot depth is the exception with flow directions of the 10-foot piezometers (same as the 8-foot depth).

In Figure 4 the mean concentration at the upper level (4 foot) is compared to forest mortality determined from February 1991 color infrared aerial photography. Photography was digitized and rectified to the Hobcaw Forest GIS system base map (Lipscomb and Williams 1990). The base map in its present configuration has an error from true ground position of 7.5 to 10 feet. The digitized photography has a pixel size of 10 feet and a mean error of registration of 1.5 pixels or 15 feet. In the photography living vegetation has a bright red or pink appearance while dead material is dark blue or black. In the gray scale rendition the darker the gray the less living vegetation in the pixel.

DISCUSSION

Spatial Distribution of Salt in the Aquifer

The contours in Figure 3 clearly indicate heterogeneity in all three dimensions. High concentrations (> 1000 mg/l) are found near the surface in the centers of transects 2, 4, and 5. These high values show greater temporal variability resulting in 95% confidence intervals from 100 to 2000 mg Cl/l. Slightly lower concentrations were found at lower depths under both the east and west ridges. Values over 750 mg/l were found beneath the east ridge at transect 5. An extensive area with concentrations over 500 mg/l was present under the western ridge from transect 2 north all the way to transect 5. High concentrations in these locations were consistent throughout the study and 95% confidence limits were often less than 100 mg/l wide. Concentrations below 50 mg/l were found at the surface under the eastern ridge at transects 1, 3, and 5, and at the surface under the border of the western ridge at transect 4. Values below 100 mg/l were found at the aquifer bottom near the centers of all five transects.

Figure 4--Comparison of photographic mortality (right) estimates and 4-foot depth salinity estimates (left). Salinity map is the same as Figure 3b and uses same gray scale. Mortality is gray scale of digitized February color infrared photograph. White box and markers are study area and well locations. Larger gray squares are 10 x 10 ft pixels with gray level indicating extent of live vegetation. Darker tones indicate greater mortality.

Groundwater Flow Direction and Salinity

Groundwater flow direction combined with the chloride concentration distribution shows a relatively clear explanation of the data collected in this study. The bulk of the high salinity water is located under the west ridge, primarily beneath transects four and five. The bulk of the movement is to the southeast at most depths (Figure 3b). In addition, at transects 2 - 5, there is a strong upward movement from beneath the western ridge. The eastern ridges do not show much movement and the fresh water beneath them is most likely an accumulation of rainfall since the surge. The low salinity areas at the bottom of the aquifer in transects 3, 4, and 5 are all consistent with artesian flow from an aquifer below the clay layer. At the eastern side of transect 4, a very strong gradient is moving fresh water in all directions and blocking the flow from the west. The saline water from the west is turned toward the south and the surface resulting in very high salinity at the surface in transects 4 and 5. Saline water also flows towards transect 2. In transect 2, the same upward movement of saline waters from the west and northwest seems to be caused by a very small upwelling. In this case, relatively little water seems to be entering the aquifer; but a high pressure area caused the waters from the west to rise.

In all cases, high salinity occurred at the surface where upwelling of water from the lower aquifer forced the normal flow in the water table aquifer to the surface. At each of these points, salinity rose rapidly during periods of little rainfall and high evaporation. In some cases the upwelling fresh water moved laterally and vertically. In transect 3, there is a small fresh area that may have resulted from upwelling water in transect 4 moving upward and outward at depths below 6 feet. Such a flow may have forced saline water to both the south and north at the edge of the lowland in transect 3.

Measured Salt Concentrations and Mortality

The similarity of spatial pattern of salt concentration in this study to that of tree mortality (Figure 4) is quite apparent. Those portions of the site where mean chloride concentrations were found to average over 500 mg Cl/l also generally had dead trees. Likewise, the portions where concentrations were less than 100 mg Cl/l were mostly undamaged. Since the salt study was not begun until seven months after overstory death had occurred the measured salinity was not the cause of death. The measured salinity is more a record of groundwater flow patterns that may have also occurred during the period of overstory mortality. Also the mean chloride concentration of all samplers in March 1992 was only 5 mg/l less than that measured in April 1991 indicating relatively little change in overall salinity over the entire year.

CONCLUSIONS

High concentrations of salinity were found up to 30 months after a tidal surge covered a coastal pine and wetland area. Yearly averaged chloride concentrations at the top of the aquifer were found to be above 500 mg/l in most of the study area which experienced overstory mortality during 1990.

Chloride concentrations varied over two orders of magnitude in all three physical dimensions as well as through time. The spatial variability was consistent with measured flow paths and salinity patterns. With elaborate three-dimensional sampling the pattern of overstory mortality was explained post priori.

A consistent finding in this study was that highest salinity and overstory death were found in areas where groundwater flow moved deeper groundwater toward the surface. One might expect that in coastal systems highest salt induced mortality would be along wetland borders where one would normally find perennial wet spots.

ACKNOWLEDGMENTS

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THE EFFECT OF HURRICANE HUGO ON FOREST PRACTICE COSTS[1]

Allan P. Marsinko, Thomas J. Straka, and Jeffrey L. Baumann[2]

Abstract--Comparisons were made of forest practice costs on Hurricane Hugo damaged sites and on undamaged sites. In general, mechanical site preparation costs were higher on damaged than on undamaged sites. Chemical site preparation costs tended to be the same or lower on damaged sites, probably due, in part, to economies of scale. Timber stand improvement costs tended to be about the same on damaged and undamaged sites.

INTRODUCTION

On September 21-22, 1989, Hurricane Hugo, a class 4 hurricane, struck South Carolina causing severe damage to midland and coastal plain forests. Of immediate concern to forest managers was salvage. Later, programs to encourage reforestation and timber stand improvement became primary considerations. The severity of the damage resulted in inordinate amounts of residual vegetation which presented operational and economic problems to site preparation operations. Because site preparation costs occur at the beginning of a rotation and must bear the effect of compound interest throughout the rotation, small increases in these costs can have a large effect on net revenue. Thus, these costs will have a large impact on the long-term timber supply in the region. This paper addresses the effect of the hurricane on site preparation costs and timber stand improvement costs.

METHODOLOGY

The objective of this research was to determine the effect of Hurricane Hugo on site preparation costs based on site preparation method and amount of residual vegetation, and timber stand improvement and chemical costs based on intensity of practice.

Conventional site costs were obtained for South Carolina through the South Carolina Forestry Commission. Because of the relatively small amount of data available when broken down by category, these conventional cost estimates were averaged with Southwide cost data from the Forest Farmer Manual 1990 and 1992 cost of forest practices surveys. Post-hurricane costs were obtained from the South Carolina Forestry Commission based on data collected through reforestation programs they administered after the hurricane. Both sets of data were summarized and analyzed by category.

RESULTS

As expected, site preparation costs were generally higher on damaged sites than an conventional sites (Table 1). They ranged from 6% higher for shear, rake and pile to 59% higher for the shear and disk operation. In one case, the post hurricane cost was lower than the cost on a conventional site.

This is probably partly due to the way Table 1 is constructed. Costs on conventional sites are based on the site preparation method only. Cost figures relating method to residual vegetation are not available for conventional sites. Thus the cost of $165.68 is listed twice, for the same site preparation method and different amounts of residual vegetation. This figure can be viewed as an average site preparation cost for all levels of residual vegetation. The post-hurricane costs are broken down by the amount of residual vegetation. These costs are

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Table 1--Site preparation costs for reforestation on Hurricane Hugo-damaged forest land in South Carolina, 1990-1992

Amount of Residue Vegetation	Site Preparation Practice	Cost on Conventional Forest Site[1]	Cost on Hurricane Damaged Forest Site
Light vegetation present	single disk or chop	$ 42.84	$ 50.60
Medium vegetation present	shear and disk	88.00	139.94
Medium-heavy vegetation present	shear, rake, and pile	124.41	131.66
Heavy vegetation present	shear, rake, pile, and bed or disk	165.68	144.41
Heavy vegetation present with blowdowns and tree breakage	shear, rake, pile, and bed or disk	165.68	182.23
Heavy vegetation present with blowdowns and tree breakage	V-bladed strips with medium herbicides	62.00	98.86

[1] Conventional cost is the average cost on sites not damaged by Hurricane Hugo in South Carolina, averaged with Southwide cost of forest practices data from the 1990 and 1992 Forest Farmer Manual surveys (Dubois et al. 1991 and Belli et al. 1993). This column is based on the site preparation practice only (previous column). It is not related to residual vegetation.

lower ($144.41) when there is less residual vegetation and higher ($182.23) when there is more residual vegetation.

The post-hurricane costs behave as expected. They increase as the site preparation method becomes more complex and as the site becomes more difficult to work. Other differences between pre- and post-hurricane costs are likely due to variability in the post hurricane data which was due to the relatively small number of observations and to differences in criteria (from the standpoint of residual vegetation) used to select site preparation methods. Because of the extent of damage, foresters from all over the state assisted with determining damage levels and site preparation practices. Because many of these foresters were not familiar with local damage criteria, it is likely that damage levels were overstated in some cases. This is supported to some extent by the fact that the "heavy" vegetation category consisted of 140 tracts (5,746 acres) and the "medium heavy" category consisted of only 30 tracts (1,711 acres).

The final entry in Table 1, V-bladed strips with medium herbicides, was a method devised as a result of Hurricane Hugo. All cost data for this method were supplied by the S.C. Forestry Commission. This is an atypical site preparation method devised specifically for the hurricane salvage area. Both the conventional and post hurricane data for this method were supplied by the S.C. Forestry Commission.

The first five entries in Table 1 increase in difficulty and, in general, in cost. These were used along with the number of acres per tract in an attempt to define an explanatory equation relating these variables to site preparation cost per acre. The resulting regression equation is:

$$\text{Site prep. cost per acre} = \$78.12 - \underset{(3.5)}{\$.15}\ \text{Acres} + \underset{(9.0)}{\$24.80}\ \text{Practice Level} \qquad R^2 = .30$$

where

Acres = number of acres on site being prepared.
Practice level = difficulty level of practice (1-5, from Table 1).

The model behaves as expected. Costs increase as the practice level increases and they decrease as larger tracts undergo site preparation. The regression coefficient R^2 was .30 which is reasonable for this type of data. The equation says that costs per acre will be reduced by $.15 for each additional acre in the tract due to economies of scale and will increase by $24.80 for each increase in complexity (difficulty) of the site preparation practices. Because the cost decreases as the number of acres increase, this equation gives feasible results only within a limited range of acres. At practice level 1, for example, the equation becomes negative if acres increases beyond 686.13. The data analyzed for this regression includes several tracts in the 300-400 acre range and one tract in excess of 500 acres. The equation cannot be used with reliability over about 350 acres. Likewise, practice levels must be in the range 1-5 as they have no meaning beyond this range. The value of this equation is explanatory, not predictive. It does explain the quantitative nature of the relationship.

There is little difference in chemical site preparation costs between damaged and conventional sites (Table 2). This is to be expected as helicopters were used for this method and the application costs should not vary much on different sites. The quantity of chemicals used would be expected to be greater on hurricane damaged sites and this could be why costs on the light and medium sites (Table 2) were higher on the damaged areas. However, the large number of tracts being treated helped contain the costs on these sites. On the "Heavy" sites, the costs on damaged lands were lower than on conventional sites. This is likely due to the fact that a large number of tracts were set up for this practice in Sumter and Clarendon counties, thus permitting a contractor to complete many sites in a concentrated area. This would be expected to result in significant economies of scale.

Timber stand improvement costs on hurricane damaged sites were nearly the same as costs on conventional sites for medium and heavy levels of timber stand improvement (Table 3). The cost was higher on damaged sites for light levels of timber stand improvement. However, this cost resulted from treatment of only one tract. Therefore, no general conclusions can be made.

Table 2--Chemical control costs for reforestation on Hurricane Hugo-damaged forest land in South Carolina, 1990-1992

Level of Site Preparation	Cost on Conventional Site	Cost on Hurricane-damaged Site
Light	$ 58.00	$ 64.75
Medium	88.00	91.53
Heavy	128.00	106.27

Table 3--Timber stand improvement costs for reforestation on Hurricane Hugo-damaged forest land in South Carolina, 1990-1992

Level of Timber Stand Improvement	Cost on Conventional Site	Cost on Hurricane-damaged Site
Light	$30.00	$41.52[1]
Medium	66.00	70.37
Heavy	90.00	88.02

[1] This cost is for one tract of land. Generalizations should not be made based on this figure.

SUMMARY

In general, mechanical site preparation costs were higher on Hurricane Hugo-damaged lands and they increased with increasing levels of residual vegetation. This is to be expected because the residual vegetation affects the site preparation activity through direct contact with the site preparation equipment, resulting in slowing the activity and increasing equipment wear and the propensity for equipment malfunction.

Chemical site preparation costs tended to be the same or lower on Hurricane Hugo-damaged lands although these costs also increased with increasing levels of residual vegetation. Chemical application was by helicopter so the effect of residual vegetation was primarily to slow application somewhat as greater quantities of chemicals were applied. Costs reflect the effect of residual vegetation but economies of scale probably counteracted the effect of the hurricane.

Timber stand improvement costs did not appear to be affected much by the hurricane. This was probably due largely to the fact that the less-damaged stands underwent timber stand improvement.

Finally, local market conditions would be expected to influence these costs. The demand for these services increased. If the increase was sufficient to create a shortage of services, prices (in this case costs on hurricane damaged sites) would be expected to increase. The exact magnitude of the change that is due to this market situation cannot be determined. However, some effect should be expected as a result of a disaster of this magnitude.

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A FINANCIAL ASSESSMENT OF CAPITAL-EXTENSIVE MANAGEMENT ALTERNATIVES FOR STORM-DAMAGED TIMBER[1]

Thomas J. Straka and James B. Baker[2]

Abstract--An analysis of the investment costs of three management alternatives for storm-damaged pine stands is presented: (1) selection management, with 25-30% initial stocking, (2) natural even-aged management resulting from chemical release of suppressed pine seedlings, and (3) a standard pine plantation, with and without increased site preparation costs due to storm damage. Selection management and natural even-aged management were shown to provide a low-capital alternative with reasonable rates of return for stand rehabilitation. The landowner's management objective and treatment of land cost will determine the optimal alternative.

INTRODUCTION

Catastrophic loss of timber is not common in forestry investments. Wildfire or beetles may cause an occasional sudden loss, but the risk is minimal. The average southern forested acre also has little chance of being damaged by a hurricane. However, averages mean little to a forest landowner after a hurricane has passed over his personal forested tract. In September 1989, Hurricane Hugo damaged over one-third of South Carolina's total timberland base. Damaged timber volume exceeded three times the normal annual timber harvest in the state.

Storm-damaged timber, especially for disasters of this magnitude, means a "timber glut" and short-term depressed timber prices. It can also mean a shortage of loggers, timber harvesting equipment, tree planting equipment, seedlings, and contractors to plant the seedlings. The only way to produce an "economical" timber sale may be to allow both down and standing green timber to be jointly harvested. This poses a dilemma for the timberland owners. Some landowners can get just the damaged timber harvested. But for those who can't, is it better to sell both the damaged and standing timber at "current" depressed prices, or to forego salvage to sell the standing timber at later higher prices. Will the unsalvaged down timber affect the cost of regenerating the tract? Can natural regeneration methods be used, and, if so, how important is it to retain the standing timber for seed trees or growing stock?

This article (1) discusses management alternatives available to forest landowners after such a disaster as Hurricane Hugo, particularly alternatives that require minimal capital outlays by the forest owner and (2) addresses the financial efficiency of the management alternatives for storm-damaged timber. Several methods that require low levels of initial capital investment are described. The importance of the residual stand to management alternatives is stressed. When capital, loggers and contractors are limited, the residual stand may provide the basis for economically

[1] This article is based on "Financial Assessment of Management Alternatives for Storm-Damaged Timber" presented at the Management Alternatives for Storm-Damaged Timber Workshop, February 8-10, 1990, Sumter, SC.

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regenerating a damaged stand. The many small-acreage nonindustrial private forest landowners with limited capital resources may find these management alternatives to be more cost-effective than the more traditional site preparation and plant alternative.

METHODS

This discussion is based on yield tables developed from case studies conducted on or near the Crossett Experimental Forest in southeastern Arkansas. These results apply to loblolly pine (*Pinus taeda* L.), but the economic comparison can be applied to any tree species.

Three alternatives were evaluated for a 50-year management period: (1) selection management, starting with an understocked residual stand (30% stocking and 10 ft^2 of basal area/ac), (2) natural even-aged management, resulting from a chemical release of suppressed pine seedlings, and (3), a standard pine plantation, requiring site preparation and planting. Average cost data are primarily from Straka and others 1989 and Baker 1987. All alternatives incur a $3/ac annual management cost.

The selection management alternative assumes a stand that was initially 30% stocked, on site index 90 (base age 50) land, and a 7-year cutting cycle beginning at year 18. Competing hardwoods were controlled initially with herbicide at a cost of $45/ac. A supplemental management cost of $13/ac (for inventory and marking) was incurred every 7 years prior to the harvest cut. Timber stand improvement was done every 10 years at a cost of $45/ac.

The natural even-aged management alternative incurred an initial cost of $45/ac to chemically release a stand originating from natural reproduction (at least 100% stocked) using herbicide. Timber stand improvement was done at age 5 at a cost of $45/ac. Prescribed burning was done every 5 years, beginning at age 15, at a cost of $5/ac. A supplemental management cost of $13/ac (for inventory and marking) was incurred every 5 years prior to harvest.

Plantation management normally may require an initial outlay of $150/ac for site preparation and planting. After storm damage approximating Hurricane Hugo this initial outlay may be $250 or higher. Both of these initial costs were considered. Thus, the plantation management alternative has two "subalternatives": a normal site preparation/planting cost of $150/ac and a post-storm-damaged site preparation/planting cost of $250/ac. Pine release was done at age 5 at a cost of $45/ac. Prescribed burning was done every 5 years, beginning at age 15, at a cost of $5/ac. A supplemental management cost of $12/ac (for inventory and marking) was incurred every 5 years prior to harvest.

Pulpwood stumpage was valued at $15/cord and sawtimber stumpage at $150/mbf (Doyle). These were treated as real prices (i.e., net of inflation), and no price appreciation is assumed. The analysis was on a before-tax basis. Also, cost-sharing was not considered. Tax savings and cost-sharing would improve the economic performance of these alternatives. However, different owners may have vastly different tax treatments (e.g., many nonindustrial landowners may amortize their investment over 7 years and take an investment tax credit, while industrial owners effectively will not have this option or access to cost-sharing).

All the alternatives were considered with and without a $400/ac land cost. Land cost is an opportunity cost. Almost all forest landowners have the option of selling the forestland and investing the proceeds elsewhere. But not all forest landowners actually feel they can exercise this option. Perhaps the land is an integral part of a farming operation, or the land has been in the family a number of years, or the land is held in a trust that does not allow its sale. If the option to sell the land does not exist, then land cost need not be included (many small acreage nonindustrial private forest tracts may fall into this category). Industrial forest owners would need to include land cost, as they do have the opportunity to sell the land.

Stand characteristics, harvests, and timber production data for the three alternatives are presented in Tables 1 to 3. The yield data used to describe the recovery and development of understocked loblolly-shortleaf pine stands are from Baker (1990). Data for the even-aged natural stand and plantation are from Baker (1987). All three alternatives were evaluated over a

Table 1--Growth, yield, and harvest cuts over a 50-year management period for an uneven-aged loblolly pine stand that was initially 30% stocked (site index 90, base age 50).

	Year	Basal area (ft^2/ac)	Merchantable cubic foot volume (per acre)	Sawlog volume (Doyle) (per acre)
	0	10	200	274
	5	24	538	1,010
	10	43	1,111	2,772
Before harvest	18	66	1,807	5,708
Harvest		11	301	1,184
After harvest		55	1,507	4,524
Before harvest	25	76	2,105	7,184
Harvest		21	598	2,660
After harvest		55	1,507	4,524
Before harvest	32	76	2,105	7,184
Harvest		21	598	2,660
After harvest		55	1,507	4,524
Before harvest	39	76	2,105	7,184
Harvest		21	598	2,660
After harvest		55	1,507	4,524
Before harvest	46	76	2,105	7,184
Harvest		21	598	2,660
After harvest		55	1,507	4,524
Before harvest	50	67	1,849	6,044
Harvest		67	1,849	6,044
After harvest		--	--	--
Total production		152	4,542	17,594

Table 2--Growth, yield, and harvest cuts over a 50-year management period for an even-aged natural loblolly pine stand after chemical release over a 50-year management period (site index 90, base age 50).

	Year	Basal area (ft^2/ac)	Merchantable cubic foot volume (per acre)	Sawlog volume (Doyle) (per acre)
Before harvest	20	147	1,800	460
Harvest		62	652	---
After harvest		85	1,148	460
Before harvest	25	115	2,173	2,291
Harvest		30	535	---
After harvest		85	1,638	2,291
Before harvest	30	117	2,466	2,887
Harvest		31	508	1,022
After harvest		86	1,958	1,865
Before harvest	35	111	3,178	7,050
Harvest		26	710	1,593
After harvest		85	2,468	5,457
Before harvest	40	106	3,561	9,593
Harvest		21	684	1,210
After harvest		85	2,877	8,383
Before harvest	45	96	3,310	9,300
Harvest		11	1,093	927
After harvest		85	2,217	8,373
Before harvest	50	100	3,625	11,662
Harvest		100	3,625	11,662
After harvest		---	---	---
Total production		281	7,807	16,414

Table 3--Growth, yield, and harvest cuts over a 50-year management period for a loblolly pine plantation (site index 90, base age 50).

	Year	Basal area (ft^2/ac)	Merchantable cubic foot volume (per acre)	Sawlog volume (Doyle) (per acre)
Before harvest	15	120	2,071	---
Harvest		35	400	---
After harvest		85	1,671	---
Before harvest	20	125	2,521	1,520
Harvest		40	576	---
After harvest		85	1,945	1,520
Before harvest	25	125	2,794	3,910
Harvest		40	728	
After harvest		85	2,066	3,910
Before harvest	30	110	2,916	5,980
Harvest		25	96	1,124
After harvest		85	2,820	4,856
Before harvest	35	103	3,670	8,100
Harvest		18	1,392	1,314
After harvest		85	2,278	6,786
Before harvest	40	105	3,270	10,390
Harvest		20	1,152	3,262
After harvest		85	2,118	7,128
Before harvest	45	100	2,843	11,238
Harvest		15	688	2,438
After harvest		85	2,155	8,800
Before harvest	50	100	3,456	12,818
Harvest		100	3,456	12,818
After harvest		---	---	---
Total production		293	8,488	20,956

Table 4--Net present values and internal rates of return of timberland investment alternatives, with and without land cost, on a per acre basis.

Alternative	Net present value 4%	7%	10%	Internal rate of return (%)
Without Land Cost				
Selection management	$397.86	$ 96.71	-$ 2.16	9.9
Chemical release	442.00	71.96	-33.04	8.6
Plantation (est. cost $150)	488.89	26.26	-111.14	7.4
Plantation (est. cost $250)	388.89	-73.74	-211.14	6.2
With Land Cost				
Selection management	$ 54.15	-$289.71	-$398.75	4.1
Chemical release	98.29	-314.46	-429.63	4.4
Plantation (est. cost $150)	145.18	-360.16	-507.73	4.5
Plantation (est. cost $250)	45.18	-460.16	-607.73	4.2

50-year management period. This may bias the results slightly toward the selection management system. Timberland investors utilizing the more capital-intensive alternatives often would use much shorter rotation lengths. For example, land owned by a pulp mill might be on a 25-year rotation. However, the advantage of comparing equal length investments, all managed for high quality sawtimber, outweighs this potential bias.

FINANCIAL RESULTS

All three alternatives were analyzed in terms of net present value at 4, 7, and 10% and in terms of internal rate of return. Recall this analysis is before-tax and in real terms (interest rates are net of inflation). This accounts for the seemingly low internal rates of return. If one assumes an inflation rate of 4%, for example, a 4.5% real rate of return equates to a current interest rate (like on a certificate of deposit) of 8.68%. Analysis results are presented in Table 4.

When land cost is not considered, the low capital alternatives produce the highest rates of return. Since land is "free," it makes sense that modest timber output, coupled with low initial costs, will produce high rates of return. At the low discount rates that are most likely appropriate for nonindustrial private forest landowners, the selection management also is "competitive." With no land cost, selection management produces a higher net present value than site preparation and planting a storm-damaged site (at the $250/ac cost) at all interest rates. Indeed, at a 5% interest rate the net present values of the first three alternatives (i.e., selection management, even-aged natural stand management, and the plantation having the $150 establishment cost) are within $10.75 of one another. This suggests nonindustrial private forest landowners with limited capital and no land cost could rehabilitate storm-damaged loblolly-shortleaf pine stands with at least 30% initial stocking and earn rates of return competitive with large industrial site prepared and planted stands.

However, land is not "free" for many landowners. Over 50 years the net present value of holding $400/ac land is significant. At the three interest rates discussed above, the net present values of land cost would be

Interest rate (%)	Net present value of land cost
4	$343.71
7	386.42
10	396.59

The results in Table 4 show lower net present values and internal rates of return when land cost is considered. The alternatives are ranked identically with the "no land cost" analysis. Even when land cost is considered, rates of return are attractive on a real interest rate basis.

WHY GROW PLANTATION WOOD AT ALL?

One may ask, why grow plantation wood at all? Pine plantations have an economic advantage over selection management when land cost is considered. But the advantage hardly seems great enough to justify the large establishment cost. The advantage of pine plantations over natural regeneration is based on the fixed cost of land being spread among many more units of volume in the pine plantation (Holley 1976). While land represents an opportunity cost to many forest landowners, especially forest industry, pine plantations produce an opportunity return for industrial forest landowners.

Consider the three management alternatives. Each produces a different total cubic foot output over 50 years:

Management alternative	Cubic foot output
Selection management	4,542
Even-aged natural stand management	7,807
Plantation management	8,488

Plantation management produces 87% more cubic feet of wood (primarily pulpwood) than the selection system. The nonindustrial private forest landowner, concerned only with overall rate of return, would not have a need for the extra wood. For the industrial forest landowner, however, site preparation and regeneration can be "traded" for a smaller required land base (Straka and Hotvedt 1984). A pulp and paper company requiring 32 million ft^2 of pulpwood annually from company-owned timberlands would be required to own 352,268 acres using selection management (a management system that concentrates tree growth on sawlog rather than pulpwood production) and 188,501 ac under plantation management. If land is worth $400/ac, the extra 163,767 ac required under selection management represents $65,506,800 of capital. At a 5% interest rate this is an annual opportunity cost of $3,275,340.

Thus, it makes perfect sense for the industrial landowner to invest in high establishment costs; just as it makes perfect sense for nonindustrial private forest landowners to use a selection system to maximize rate of return. The simple example above does not consider the higher valued products that longer rotations and selection management produce; but it does illustrate the effects of land cost on pulpwood oriented industries.

Porterfield and others (1979) described other reasons the extra investment in plantation management might be acceptable to a timber company. Plantations produce uniformity. This can translate to lower harvesting costs or lower sorting and manufacturing costs.

Thus, delivered cost of wood to a mill or rail concentration point could be reduced. Plantations produce higher yields and increase timber availability near a mill. The extra wood might be costly to the timber company, but marginal wood purchased on the open market would not have to be "bid up" because of the extra availability. This serves to keep the overall cost of timber lower. Plantations also offer the chance to reap the benefits from growing genetically improved trees.

The advantage of pine plantations is that they produce more wood in a shorter rotation. The disadvantage is that they cost more. Whether natural stand management or plantation management is preferrable depends on the landowner's objectives and financial expectations.

CONCLUSION

Selection management and natural even-aged management provide a low-capital investment alternative for nonindustrial private forest landowners to regenerate storm-damaged forest stands. If land cost is not considered, these alternatives can produce higher rates of return than plantation management. For forest landowners facing large-scale catastrophic storm damage, such as the 4.4 million ac of timberland damaged by Hurricane Hugo, the low-capital requirements of selection management may make it the best available means of rehabilitating a damaged stand.

Not all stands are suitable for this selection system. Baker (1989) suggests that a manageable and biologically and economically feasible stocking threshold is in the range of 15 to 25%, or 5 to 10 ft^2, of basal area/ac. If the trees are uniformly distributed, of good form, and vigorous, then the stand could probably be rehabilitated and managed at a lower cost than starting over with a pine plantation. Foresters should make nonindustrial private landowners with storm-damaged timber aware of this management alternative.

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SITE PREPARATION AND TREE PLANTING COSTS ON HURRICANE-DAMAGED LANDS IN SOUTH CAROLINA

Thomas J. Straka, Allan P. Marsinko, Jeffrey L. Baumann, and Robert G. Haight[1]

Hurricane Hugo damaged 4.5 million acres of South Carolina forest land in 1989; 1.2 million of these acres required reforestation. Much of this acreage required site preparation. This article presents the major types of site preparation utilized after a natural disaster like Hurricane Hugo and contrasts the costs of these operations with those on conventional sites.

Standard site preparation techniques were used on the hurricane-damaged sites. The amount of residual vegetation was rated as light, medium, medium-heavy, and heavy with blowdowns and tree breakage. Site preparation techniques varied from a single disk or chop for light damage to shear, rake, pile, and bed or disk for heavy blowdowns and tree breakage (Table 1). A cheaper alternative used in areas with heavy vegetation present with blowdowns and tree breakage was to push V-bladed strips through the debris, plant in the strips, and use an application of herbicide to control vegetation.

As expected, site preparation costs were generally higher on damaged sites than on conventional sites (Table 1). They ranged from 6 percent higher for shear, rake, pile and bed or disk to 54 percent higher for the shear and disk operation. In one case, the post-hurricane cost was lower than the cost on a conventional site. This is probably partly due to the way Table 1 is constructed. Costs on conventional sites are based on the site preparation method only. Cost figures relating method to residual vegetation are not available for conventional sites. Thus the cost of $165.68 is listed twice, for the same site preparation method and different amounts of residual vegetation. This figure can be viewed as an average site preparation cost for all levels of residual vegetation. The post-hurricane costs are broken down by the amount of residual vegetation. These costs are lower ($162.75) when there is less residual vegetation and higher ($176.33) when there is more residual vegetation.

The post-hurricane costs behave as expected. They increase as the site preparation method becomes more complex and as the site becomes more difficult to work. Other differences between pre- and post-hurricane costs are likely due to variability in the post-hurricane data which was due to the relatively small number of observations and to differences in criteria (from the standpoint of residual vegetation) used to select site preparation methods. Because of the extent of damage, foresters from all over the state assisted with determining damage levels and site preparation practices. As many of these foresters were not familiar with local damage criteria, it is likely that damage levels were overstated in some cases. This is supported to some extent by the fact that the "heavy" vegetation category consisted of 140 tracts (5,746 acres) and the "medium heavy" category consisted of only 30 tracts (1,711 acres).

The final entry in Table 1, V-bladed strips with medium herbicides, was a method devised as a result of Hurricane Hugo. V-bladed strips were placed every 25 to 40 feet within the forest stand, using a D-8 equivalent-sized tractor. Seedlings were planted using a 5 foot by 8 foot spacing within the

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Table 1--Site preparation and tree planting costs per acre for reforestation on undamaged and Hurricane Hugo-damaged forest land in South Carolina, 1990-1992.

Amount of Residue Vegetation	Site Preparation Practice	Cost Per Acre on Conventional Forest Site	Cost Per Acre on Hurricane Damaged Forest Site	Percentage Difference	Cost Per Acre for Tree Planting with Loblolly Pine
Light vegetation present	single disk or chop	$ 42.84	$ 51.60	+ 20.4%	$31.10
Medium vegetation present	shear and disk	88.00	135.47	+ 53.9%	61.36
Medium-heavy vegetation present	shear, rake, and pile	124.41	133.99	+ 7.7%	50.35
Heavy vegetation present	shear, rake, pile, and bed or disk	165.68	162.75	- 1.8%	49.68
Heavy vegetation present with blowdowns and tree breakage	shear, rake, pile, and bed or disk	165.68	176.33	+ 6.4%	51.44
Heavy vegetation present with blowdowns and tree breakage	V-bladed strips with medium herbicides	62.00	93.65	+ 51.0%	21.15

strips. All cost data for this method were supplied by the S.C. Forestry Commission. This is an atypical site preparation method devised specifically for the Hurricane salvage area.

Tree planting costs per acre on the site prepared stands are also presented in Table 1. No consistent pattern is evident as amount of residue vegetation and intensity of site preparation practice seem to interact to create different quality levels of planting sites. All practices, except the V-bladed strips, required 350 well-spaced seedlings per acre after the first growing season as minimum acceptable seedling survival. The V-bladed strips required 250 seedlings per acre. Average tree planting cost per acre was $50.13 for loblolly pine. Ten tracts were planted with longleaf pine at an average cost of $79.89 per acre.

Five representative photographs of site preparation activities on hurricane-damaged lands appear at the end of this paper.

SUMMARY

In general, mechanical site preparation costs were higher on Hurricane Hugo-damaged lands and they increased with increasing levels of residual vegetation. This is to be expected because the residual vegetation affects the site preparation activity through direct contact with the site preparation equipment, resulting in slowing the activity and increasing equipment wear and the propensity for equipment malfunction.

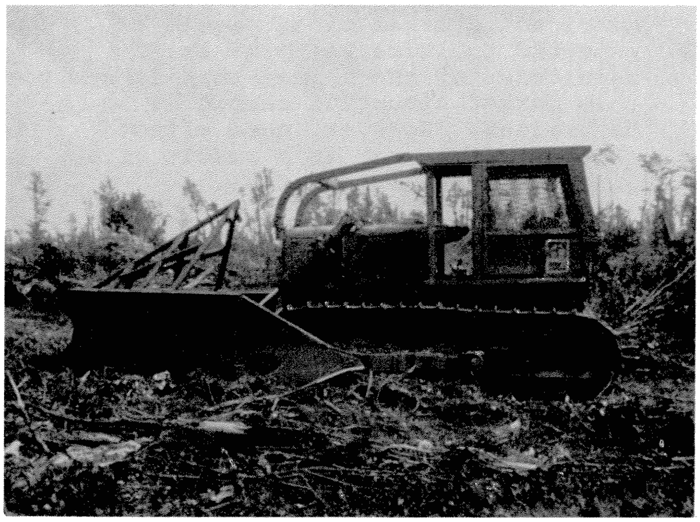
Chemical site preparation costs tended to be the same or lower on Hurricane Hugo-damaged lands although these costs also increased with increasing levels of residual vegetation. Chemical application was by helicopter so the effect of residual vegetation was primarily to slow application somewhat as greater quantities of chemicals were applied. Costs reflect the effect of residual vegetation but economies of scale probably counteracted the effect of the hurricane.

Timber stand improvement costs did not appear to be affected much by the hurricane. This was probably due largely to the fact that the less-damaged stands underwent timber stand improvement.

Finally, local market conditions would be expected to influence these costs. The demand for these services increased. If the increase was sufficient to create a shortage of services, prices (in this case costs on hurricane damaged sites) would be expected to increase. The exact magnitude of the change that is due to this market situation cannot be determined. However, some effect should be expected as a result of a disaster of this magnitude.

1. Example of moderate damage.

2. Single chop site preparation on light damage.



3. A tractor equipped with a V-blade in a site preparation area.

4. A tractor operating in a site preparation area.

5. Tractor pushing windrows.

THE ECONOMICS OF LOBLOLLY PINE PLANTATIONS UNDER RISK OF HURRICANE DAMAGE

Robert G. Haight, William D. Smith, and Thomas J. Straka[1]

Abstract--Hurricanes have the potential to instantly destroy or damage loblolly pine plantations in the southern United States, and the risk of hurricane damage substantially reduces the expected economic yield. With a 6 percent annual probability of hurri-cane damage, which is the same as the historical frequency of hurricanes reaching the coastal plain of South Carolina, the expected present value of intensive plantation management is less than zero using 1992 prices and costs and a 4-percent discount rate. If trees are salvagable and young stands are less vulnerable, expected present value is positive but still much less than the economic yield computed with no risk. Government assistance with planting cost results in a moderate improvement. The economic effect of tree damage depends on the type of damage. Stem sweep causes negligible reductions in the expected present value; tree mortality results in substantial reduc-tions. These results should caution decision makers to make a thorough economic accounting of the risk of hurricane damage.

INTRODUCTION

Hurricane Hugo, which passed over South Carolina in September 1989, demonstrated the destructive potential of intense hurricanes. Hugo instantly damaged or destroyed 4.5 million acres of pine and hardwood forest (Sheffield and Thompson 1992). Although several authors document the economics of loblolly pine (*Pinus taeda* L.) management (Arthaud and Klemperer 1988, Broderick and others 1982, Roise and others 1988), none account for the risk of hurricane damage possibly because intense hurricanes have been relatively infrequent during the last two decades. During the period of 1970 to 1987, only one Saffir-Simpson category 3 hurricane (maximum sustained wind speed of greater than 110 miles per hour) made landfall along the U.S. east coast. In constrast, during the period of 1947 to 1969, 13 category 3 or greater hurricanes made landfall (Gray 1990). A review of data linking the occurrence of intense hurricanes with weather patterns in western Africa suggests that hurricane landfall will be more frequent in the 1990s and 2000s (Gray 1990).

The damage caused by Hurricane Hugo and the prediction of increased hurricane frequency raise two immediate ques-tions: (i) What is the effect of the risk of hurricane damage on the long term economic yield of forestry? (ii) What is the effect of hurricane-induced tree damage on the economic yield of an existing stand? We address these ques-tions using case studies for loblolly pine plantations located in the coastal plain of South Carolina. Yields are predicted with a version of the North Carolina State University Plantation Management Simulator (Hafley and Buford

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1985, Smith and Hafley 1986) that includes the effects of tree damage in the form of stem sweep (Smith 1988). Stand value is computed using 1992 prices and costs. These parameters are included in formulas for the expected present values of income streams under hurricane risk for two management situations: (i) the land expectation value (LEV) of an infinite series of plantations starting with bare ground, and (ii) the expected present value (EPV) of a damaged stand that may be regenerated in the future. In each case, the effect of hurricane risk is determined by varying its level within the range of historical hurricane frequency.

Most work on the economics of stand damage addresses the effect of the risk of catastrophe on the long term economic yield of plantation management (see Caulfield 1988 for review). In a pioneering study, Reed (1984) shows that expected LEV can be determined with a simple modification of the Faustmann formula rather than with more complicated stochastic optimization methods. For the case of fire risk, Reed (1984) assumes that fires occur in a time-independent Poisson process and result in total destruction, and he extends the formulas to include salvagable yield following fire and fire risk that depends on stand age. Because the assumptions about stochastic fire damage apply reasonably well to the case of hurricane damage, we use Reed's (1984) formulas to estimate the effect of the risk of hurricane damage on the economics of loblolly pine plantation management.

There is evidence that even moderate levels of risk quickly dissipate expected LEV. Using data for white spruce (*Picea glauca* (Moench) Voss) in the northern interior region of British Columbia, Reed and Errico (1985) show that expected LEV is negative for all possible rotation ages when the risk of fire damage is, on average, 1 fire per 100 years. Based on this evidence, we hypothesize that the level of risk associated with the historical rate of hurricane occurrence substantially reduces the expected LEV associated with loblolly pine management.

Two studies analyze the effects of risk on the economics of loblolly pine plantation management for risk-averse decision makers who account for both expected economic yield and its variation (Caulfield 1988, Taylor and Fortson 1991). We limit the formulation to risk-neutral decision makers who maximize expected present value and leave the problem of risk aversion for future work.

There is one study on the economics of managing storm-damaged loblolly pine stands. Straka and Baker (1991) evaluate alternative reforestation systems for damaged stands that have either abundant natural regeneration or enough vigorous seed trees. They find that low-cost treatments that utilize natural regeneration have present values close to or greater than those of high-cost planting alternatives.

In our analysis of storm-damaged stands, we focus on management alternatives for young plantations less than 20 years old. Storm damage consists of stem sweep in live trees and mortality. Because young stands have growth potential even with damage, we hypothesize that higher economic yield is obtained by postponing regeneration. Yield predictions explicitly account for the effects of stem sweep on product value. Further, the formula for EPV accounts for the risk of further hurricane damage. Because the growth model is developed to predict plantation yield, we limit the reforestation option to planting.

METHODS

Predicting Plantation Yield and Value

The Plantation Management Simulator includes growth models that predict a frequency distribution of trees by stem diameter and sweep class in one-year intervals. Predictions are based on parameters describing the initial stand: site index, age, density, and sweep distribution. The predicted tree distribution is the basis for computing the value of the yield from a thinning or final harvest.

The value of stand yield on the stump (dollars per acre) is computed with a residual value approach (e.g., Hotvedt and Straka 1987). The first step is to compute the value of the yield at the mill. Each tree is utilized as sawtimber or pulpwood depending on value. Sawtimber value is computed using a bucking program (Faaland and Briggs 1984) that splits the tree into sawlogs based on stem size and sweep and on lumber value (from *Random Lengths*) and milling cost (Deal 1986). Sawlogs are cut with a minimum 4-inch top. Pulpwood value is the product of tree volume and pulpwood price. Volume is computed using the stem dimensions (Smith 1988). From *Timber Mart-South*, pulpwood price (at the mill) is $50 per cord.

The second step is to compute the value of the yield on the stump by subtracting logging and transportation costs from the mill value. Logging and transportation costs are a function of the diameter distribution of tree-length logs (Deal 1986). The transportation cost assumes a 50-mile haul distance.

The residual value approach allows us to account for the effect of stem sweep on tree value. Stem sweep affects log length. Because the bucking program attempts to produce straight logs, as sweep increases, log length decreases. Because shorter logs have lower values (per unit volume), trees with stem sweep have lower values than straight trees (Smith 1988).

The residual value approach results in stumpage values that increase with stand age. For stands without stem sweep, sawtimber values (Scribner) increase from $111 per thousand board feet (Mbf) for a 20-year-old plantation to $232 per Mbf for a 45-year-old plantation. Pulpwood values increase from $23 per cord to $37 per cord. For comparison, quarterly 1992 southern pine sawtimber and pulpwood stumpage prices in *Timber Mart-South* vary around $180 per Mbf and $22 per cord, respectively.

Determining Land Expectation Value Under Risk of Storm Damage

The Faustmann equation for LEV is used to measure the economic impact of the risk of storm damage. According to the Faustmann equation, LEV is the present value of an infinite series of plantations starting with bare land and using a fixed reforestation strategy and rotation age. Let c_1 be the cost of reforestation and T be the rotation age. Associated with the reforestation strategy is a value function $V(T)$ representing the value of the plantation (dollars per acre) at rotation age. Letting r be the instantaneous, risk-free discount rate, LEV (represented by the term $L(T)$) is

$$L(T)=\frac{[V(T)-c_1]e^{-rT}}{1-e^{-rT}}-c_1. \qquad (1)$$

The instantaneous discount rate r is related to the annual discount rate i by the formula $e^r=1+i$. LEVs are computed with an annual discount rate of 4 percent ($r=0.03922$). With some manipulation, equation 1 is equivalent to the more familiar LEV formula:

$$L(T)=\frac{V(T)-c_1e^{-rT}}{e^{-rT}-1}.$$

We assume that management takes place on site index 70 (ft in 25 years) land in the lower coastal plain of South Carolina. The planting spacing is 8x8 (680 trees per acre) with 90 percent survival. Stand value is predicted assuming no sweep for rotation ages between 15 and 45 years in annual intervals. In the formulas for LEV, the impacts of storms are determined by accounting for the probability of storm damage.

We start with three assumptions about storm occurrence and damage: (*i*) Storms occur independently of one another and randomly in time with some average annual probability. (*ii*) The probability of storm damage is independent of stand age. (*iii*) A storm totally destroys the stand. Under these assumptions, storm damage is a time-independent Poisson process. If the management policy is to cut when the stand reaches age T and to reforest immediately following harvest or storm, then the management regime involves a sequence of plantations that may or may not reach rotation age depending on when storms occur. Because storms occur in random intervals, LEV is a random variable with an expected value. Let c_1 and c_2 be costs of reforestation following harvest and storm, respectively, and let h be the hazard rate (mean annual probability of a damaging storm). The risk-adjusted Faustmann equation for the expected LEV is (Reed 1984)

$$L(T)=\frac{[h+r][V(T)-c_1]e^{-(h+r)T}}{r[1-e^{-(h+r)T}]}-\frac{h}{r}c_2-c_1. \qquad (2)$$

Note that, apart from constant terms, equation 2 is the same as equation 1 with a risk premium h added to the discount rate r. Thus, the impact of storm risk on the optimal rotation age can be determined simply by adding a premium to the discount rate in the marginal conditions for the optimal rotation age (Reed 1984). The effect of adding a premium to the discount rate is to decrease the optimal rotation age and expected LEV.

Reforestation cost depends on storm damage. Because of unusable debris, the cost of reforestation following a damaging storm is greater than the cost of regenerating an undamaged stand. Based on average reforestation costs recorded in the South in 1992, the cost of regenerating an undamaged stand is $200 per acre (Belli and others 1993). Based on a finding that the costs of mechanical site preparation in storm-damaged stands are up to 54 percent greater than site-preparation costs in undamaged stands (Straka and others 1993), the total cost of reforestation following storm damage is $250 per acre.

To set the hazard rate for a locale, it is useful to look at both the historical frequency of hurricanes and the results of hurricane prediction models. We use the Francis Marion National Forest (FMNF) located in the coastal plain of South Carolina as an example. Hooper and others (1990) estimate that 18 hurricanes have affected the FMNF over the last three centuries. With this frequency, the average return time is 16 years and the hazard rate is 6 percent. Using a hurricane prediction model developed at the National Hurricane Center in Florida, Hooper and McAdie (In press) estimate that the average return time for hurricane-induced winds (exceeding 75 miles per hour) that strike the FMNF is 14 years producing a hazard rate of 7 percent. Because of its location near the Atlantic coast, the FMNF is more likely to receive hurricane winds than inland forests which have lower hazard rates. To determine the impact of the hazard rate on LEV, we compute LEVs using hazard rates of 0 percent, 3 percent, and 6 percent.

The next formula for LEV relaxes the assumption that a storm totally destroys the stand. Instead, immediately following a damaging storm, some of the timber may be salvaged prior to reforestation. In the area affected by Hurricane Hugo, about 25 percent of the damaged softwood timber was salvaged (Marsinko and others 1993). In most damaged stands, only a portion of the timber was salvaged because of stem breakage and limited accessability. Further, the value of harvested timber was reduced because of higher logging costs. To account for salvage, the risk-adjusted Faustmann equation (2) is modified to include an age-dependent salvage rate $s(t)$ representing the proportion of the undamaged value of a stand age t that is salvaged immediately following a storm. We assume that 25 percent of the value of stands aged 15 and older is salvagable:

$$s(t) = \begin{cases} 0 & \text{if } t < 15 \\ 0.25 & \text{if } t \geq 15. \end{cases} \qquad (3)$$

The formula for the expected LEV of a plantation regime with rotation age T and salvage following storm damage is (Reed 1984)

$$L(T)= \frac{[h+r]\{[v(T)-c_1]e^{-(h+r)T}+\varnothing(T)\}}{r[1-e^{-(h+r)T}]} - \frac{h}{r}c_2-c_1, \qquad (4)$$

where

$$\varnothing(T)= \int_0^T hs(t)v(t)e^{-(h+r)t}dt.$$

Equation 4 includes the term $\varnothing(T)$ representing the cummulative discounted salvage value weighted by the hazard rate. The integral for $\varnothing(T)$ is approximated using a finite summation over annual intervals. In equation 4, the risk of storm damage with salvage not only adds a premium to the discount rate but also increases the effective stumpage value (Reed 1984). Storm salvage increases the expected LEV, but its effect on the optimal rotation age depends on the form of the salvage function. A salvage rate that increases with stand age (e.g., equation 3) increases the optimal rotation age. To determine the economic effect of the salvage function defined by equation 3, we compute the relationship between LEV and rotation age with a hazard rate of 6 percent.

The final formula for LEV relaxes the assumption that the risk of storm damage is independent of stand age. Instead, the hazard rate is age dependent. In the area affected by Hurricane Hugo, stands less than 20 years old sustained much less damage than older stands (Gresham and others 1991, Hooper and McAdie 1993, Hooper and others 1990, Sheffield and Thompson 1992). Further, as we find later, even if storm damage in the form of stem sweep is widespread in a young stand, the damage does not greatly reduce the expected economic yield. Thus, we assume that young stands (<10 years old) are not subject to risk of storm damage and teenage stands (10 to 20 years old) are subject to half the risk affecting older stands. Letting $h(t)$ be the risk of storm damage in a stand of age t, the piecewise hazard function is:

$$h(t) = \begin{cases} 0.00 \text{ if } t < 10 \\ 0.03 \text{ if } 10 \leq t < 20 \\ 0.06 \text{ if } t \geq 20. \end{cases} \quad (5)$$

Following Reed (1984), we modify equation 4 for the expected LEV with salvage to incorporate the hazard function $h(t)$. Letting $m(T)= \int_0^T h(t)dt$ be the cummulative hazard rate for a plantation with rotation age T, the expected LEV of the plantation regime with salvage following storm damage and age-dependent damage risk is

$$L(T)= \frac{[v(T)-c_1]e^{-[m(T)+rT]}+\varnothing(T)-c_2[1-e^{-m(T)+rT}]}{r\int_0^T e^{-[m(t)+rt]}dt} +c_2-c_1 \quad (6)$$

where

$$\varnothing(T)= \int_0^T h(t)s(t)v(t)e^{-[m(t)+rt]}dt.$$

The integrals are approximated using finite summations over annual intervals.

In equation 6, the effect of the risk of storm damage is more complicated than changing the effective discount rate and value function as in equations 2 and 4 (Reed 1984). The optimal rotation age depends on c_2, the cost of reforestation after storm damage. With an age-dependent hazard rate, the rotation age affects the probability of storm damage and thus the frequency of more costly reforestation efforts.

The reforestation cost is an important variable in the computation of expected LEV because, as the hazard rate increases, the number of reforestation occurrences is likely to increase. If the reforestation cost is high, the economic impact of an increase in the hazard rate is greater than if the reforestation cost is low. Government assistance can reduce reforestation cost following a damaging storm. For example, the Federally funded Hugo Incentive Program (over 6 million dollars) paid about 75 percent of the total reforestation cost to over 900 qualified applicants (Straka and others 1993). To determine the impact of assistance with reforestation cost on expected LEV, we compute LEVs using equation 6 with reforestation costs for damaged stands ranging between $0 and $250 per acre.

Evaluating Management Regimes for Damaged Stands

Sheffield and Thompson (1992) estimate that 62 percent of the area of pine plantations within a 23-county area of South Carolina sustained some form of damage. The storm left broken, dead trees and live trees with damaged crowns, boles, or roots. The degree of plantation damage increased with stand age. More than 80 percent of the young plantations (<10 years old) sustained little or no damage, and damage was limited to crown reduction and stem sweep. In contrast, about 40 percent of the teenage plantations suffered moderate to heavy damage in which stocking was substantially reduced because of tree mortality.

The presence of damaged trees affects the economic yield. Trees with stem sweep in young plantations have lower value at rotation age because logs are bucked into shorter lengths and some logs are merchandized as pulpwood rather than more valuable sawtimber. Trees with stem sweep in teenage plantations have even less value at rotation age because the degree of sweep limits their use to pulpwood.

The presence of damaged trees raises the question of the best management strategy. When should the damaged stand be clearcut and replanted? Should the stand be thinned to remove crooked trees? We address these questions for a set of representative stands (Table 1). The stand descriptions are based on plot information collected following Hurricane Hugo (Sheffield and Thompson 1992). The first two stands are 5 years old. Stand 1 has no damage. Fifty percent of the trees in stand 2 are leaning more than 30 percent from vertical and will develop significant stem sweep. Stands 3 and 4 are 15 years old. Stand 3 has no damage. Forty percent of the trees in stand 4 are leaning more than 30 percent from vertical. To simulate hurricane-induced mortality, the yields in stand 4 are multiplied by a percent representing stand stocking. Stocking percentages range between 100 percent and 10 percent in intervals of 5 percent.

The management variables for each stand are the timing and intensity of a commercial thinning and the rotation

Table 1. Initial conditions for representative loblolly pine stands

Stand number	Age (years)	Density (trees/ acre)	Density (ft^2/ acre)	Percent trees by lean class (0-30 pct)	Percent trees by lean class (>30 pct)
1	5	725	16	100	0
2	5	725	16	50	50
3	15	521	92	100	0
4	15	521	92	60	40

age. The rotation age varies between 15 and 45 years in 5-year intervals. The thinning age varies between 15 and 39 years in 2-year intervals. The percent of the trees thinned may be 20, 40, or 60 percent. Damaged trees are cut first.

Expected present value is the criterion for determining the best management strategy for each stand. The EPV is computed assuming that damaging storms may occur in the future. For simplicity, future storm damage is modeled as a time-independent Poisson process using the three basic assumptions in the LEV analysis. Although the assumptions that a storm totally destroys the stand and that the probability of storm damage is independent of stand age over-state the potential economic impact of storm damage, these impacts are reduced by lowering the hazard rate.

Following Reed (1984), we let X be a random variable representing the time until either the first destructive storm or the rotation age T. By definition of the Poisson process, the distribution function for X is

$$pr(X \le t) = \begin{cases} 1-e^{-ht} & \text{if } t < T \\ 1 & \text{if } t \ge T. \end{cases} \qquad (7)$$

The economic yield Y associated with X depends on whether the stand is destroyed. If so, the economic yield at the time of destruction is the LEV (represented by the term L) minus the cost of clearing c. For simplicity, we assume that the value of the thinning is lost if the stand is destroyed. Although this assumption is unrealistic if a storm occurs between thinning and rotation age, the effect on EPV is probably small because thinning values are small. If the stand reaches rotation age, the economic yield is the sum of two components: the compounded value of the thinning and the value of the trees present at rotation age ($v(T)$) and the LEV. Thus,

$$Y = \begin{cases} L-c & \text{if } X < T \\ v(T)+L & \text{if } X = T. \end{cases}$$

The pair of random variables (X,Y) is used to determine EPV (represented by J) where $J=E(e^{-rX}Y)$. Using the distribution function for X (equation 7),

$$J= \int_0^T [L-c]e^{-rT}he^{-hT}dt+e^{-rT}[v(T)+L]e^{-hT}.$$

The first term represents the expected yield if the stand is destroyed; the second term is the expected yield if the stand reaches rotation age. After integrating and combining terms, the formula for EPV is:

$$J=[v(T)+L]e^{-(h+r)T}+ \frac{h[L-c][1-e^{-(h+r)T}]}{h+r}. \qquad (8)$$

Management regimes for damaged stands are evaluated using hazard rates of 0 percent, 3 percent, and 6 percent. The annual discount rate is 4 percent. The cost of clearing the land after a storm and prior to site preparation and planting is $50 per acre.

RESULTS

Effects of Risk on Land Expectation Value

To begin the assessment of the economic impact of the risk of storm damage, we use equation 2 for expected LEV assuming that the hazard rate is independent of plantation age and each storm destroys the plantation. The relationships between expected LEV and rotation age are plotted in figure 1 for hazard rates of 0 percent, 3 percent, and 6 percent. The outstanding feature of Figure 1 is how rapidly the expected LEVs decrease with increasing hazard rate. With no risk of storm damage, the maximum LEV is $1,076 per acre with a 31-year rotation. With a 3 percent hazard rate, the maximum expected LEV ($343 per acre) is 68 percent less than the maximum LEV with no risk of storm damage. With a 6 percent hazard rate, which is equivalent to the historical average annual probability of a damaging storm reaching the Francis Marion National Forest, the maximum expected LEV is $-153 per acre. In fact, for hazard rates greater than about 5 percent, this plantation investment earns less than the annual discount rate of 4 percent. As expected, the optimal rotation age decreases with increasing hazard rate.

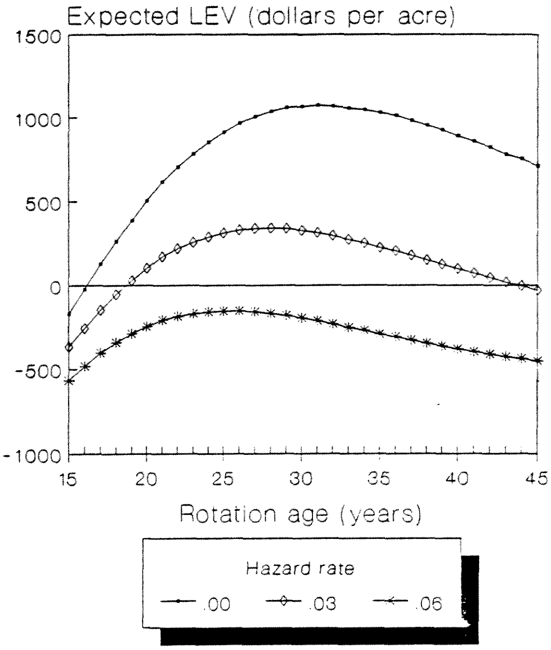

Figure 1--Expected LEV versus rotation age for loblolly pine plantations under alternative levels of hurricane risk.

The next step in the assessment of the economic impact of the risk of storm damage is the computation of an expected LEV that includes an age-dependent salvage rate (equation 4). Compared to the relationship between expected LEV and rotation age for the case with a 6 percent hazard rate and no salvage, including a 25 percent salvage rate for stands greater than 15 years old (equation 3) produces a minor increase in expected LEV (Figure 1). The maximum expected LEV ($-86 per acre) provides a $67 per acre increase over the maximum expected LEV in the case with no salvage. The optimal rotation age (27 years) is slightly longer than the case with no salvage (26 years) because salvage increases the stand's expected value growth rate.

Finally, the economic impact of the risk of storm damage is assessed using the formula for expected LEV that includes an age-dependent hazard rate in addition to an age-dependent salvage rate (equation 6). When the hazard is less than 6 percent for stands less than 20 years old (equation 5), the expected LEVs are substantially greater than the expected LEVs of plantation regimes computed with a 6 percent hazard rate that is independent of stand age (Figure 2).

In the case with an age-dependent hazard rate, the maximum expected LEV ($461 per acre) is 57 percent less than the maximum LEV with no risk.

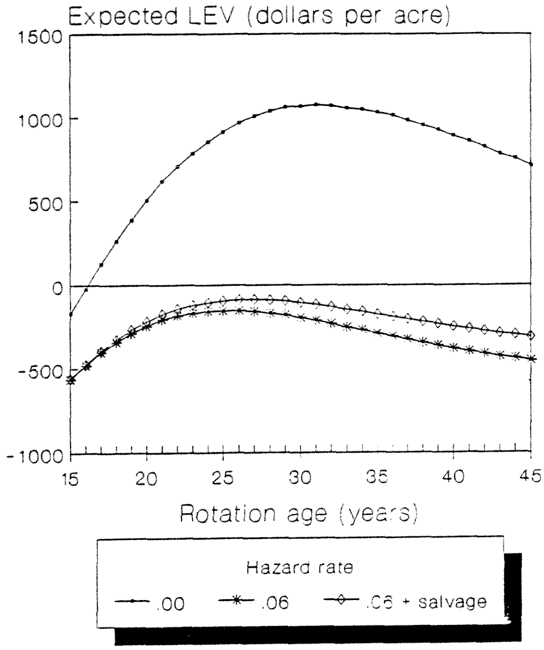

Figure 2--The effect of an age-dependent salvage rate on the relationship between expected LEV and rotation age for loblolly pine plantations under a 6% annual risk of hurricane damage.

In Figure 3, we find that, for hazard rates greater than about 5 percent, plantation management has a negative expected LEV. One way to mitigate the negative effect of the storm hazard is to reduce the cost of regenerating a damaged stand (e.g., government cost-sharing). Figure 4 shows maximum expected LEVs for alternative costs of regenerating damaged stands. The LEVs are computed using equation (6) with an age-dependent hazard rate and salvage. For comparison, the horizontal line represents the LEV of plantation management without hazard ($1,076 per acre). Although the expected LEV with hazard increases with reduced cost, a full cost subsidy produces a maximum expected LEV ($574 per acre) that is still 46 percent less than the maximum LEV without risk. This expected loss in value emphasizes the economic importance of hurricane damage that reduces and postpones harvest revenue.

The Economics of Managing Damaged Stands

Management regimes for damaged stands are evaluated according to their EPV (equation 8) under alternative hazard rates. From the analysis above, the expected LEV (L in equation 8) is $461 per acre, which is the maximum LEV obtained using equation (6) with a 25 percent salvage rate in stands greater than 15 years old (equation 3) and with the age-dependent hazard rates (equation 5).

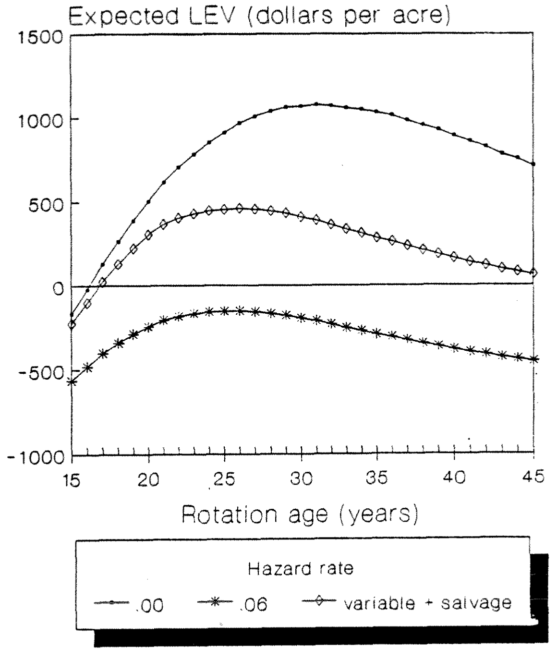

Figure 3--The effect of an age-dependent salvage rate and an age-dependent risk of hurricane damage on the relationship between expected LEV and rotation age for loblolly pine plantations.

In the first case, we compare EPVs and optimal management strategies for young plantations (5 years old) with and without damage. The damaged stand includes stem sweep in 50 percent of the trees. The relationships between EPV and rotation age for 3 percent and 6 percent hazard rates are presented in Figure 5. The outstanding feature is the negligible impact of stem sweep on the EPV of the young plantation. For the 3 percent hazard rate, the maximum EPV of the undamaged stand ($585 per acre) is only 7 percent greater than the maximum EPV of the damaged stand ($544 per acre). For a 6 percent hazard rate, the difference between maximum EPVs is even less. In addition, the presence of stem sweep has only a slight effect on the optimal management strategy. Damage does not affect the optimal rotation age (30 years for a 3 percent hazard

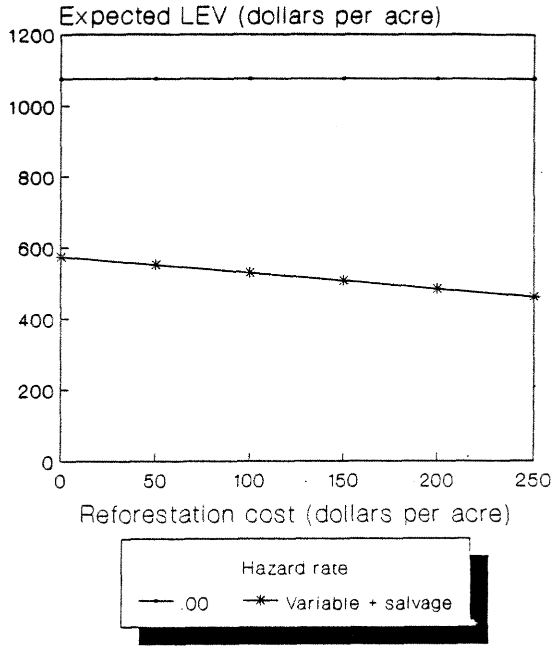

Figure 4--The effect of reducing reforestation cost following hurricane damage on the maximum expected LEV of loblolly pine plantations. LEVs are computed with age-dependent salvage and hazard rates.

rate and 25 years for a 6 percent hazard rate); however, damage does call for an earlier commercial thinning. For example, for a 3 percent hazard rate, 40 percent of the trees should be removed from the damaged stand in year 21 compared to year 23 for an undamaged stand.

We attribute the small economic effect of hurricane-induced stem sweep to the relationship between log size and value. Price premiums are given to long logs that are sawn into wide boards. However, for rotation ages less than 35 years, which provide the highest present values in the above cases, few premium logs are produced even in stands without stem sweep. There is no premium for long logs that are sawn into small dimension lumber. Thus, although stands with stem sweep produce shorter logs, the value reduction is not great.

We have assumed that lumber cut from trees with stem sweep does not affect lumber grade. However, the compression wood found in logs with sweep can cause lumber to warp, which in turn reduces lumber grade and value (Smith 1988). Because we do not know the

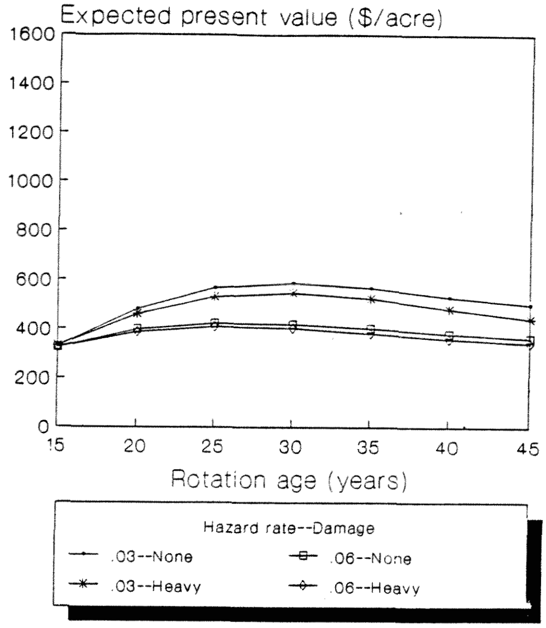

Figure 5--Expected present value versus rotation age for a 5-year-old loblolly pine plantation with alternative levels of stem sweep under 3% and 6% hazard rates.

degree of this problem, we may underestimate the effects of stem sweep on the EPVs of damaged stands.

In contrast to the small effect of stem sweep on EPV, increasing the hazard rate substantially reduces the EPVs of young stands. The maximum present value of an undamaged stand under no hazard ($1,051 per acre) is 44 percent and 60 percent greater than the maximum EPVs of the same stand under 3 percent and 6 percent hazard rates ($585 per acre and $421 per acre, respectively). Similar results are obtained for damaged stands. These expected reductions in present value result from the assumption that another storm totally destroys the stand regardless of its age. This assumption is reasonable for older stands (>$20 years old), but younger stands are less susceptible to damage. Although an age-dependent hazard rate similar to equation 5 would give a more accurate estimate of the effect of storm hazard on EPV, using an average hazard rate across all age classes (e.g., 3 percent) is a reasonable approximation.

In the second case, we compare EPVs and optimal management strategies for teen-age plantations (15 years old) with and without damage. In the damaged stand, about 40 percent of the trees have severe stem sweep and must be utilized entirely as pulpwood. The relationships between EPV and rotation age for 3 percent and 6 percent hazard rates appear in Figure 6. Stem sweep in a teenage stand reduces EPV slightly more than does stem sweep in a young stand. The maximum EPVs of the undamaged stand are up to 11 percent greater than the maximum EPVs of the damaged stand for hazard rates between 3 percent and 6 percent. Compared to the optimal strategy for an undamaged stand, the optimal thinning age and rotation age for a damaged stand are up to 5 years earlier.

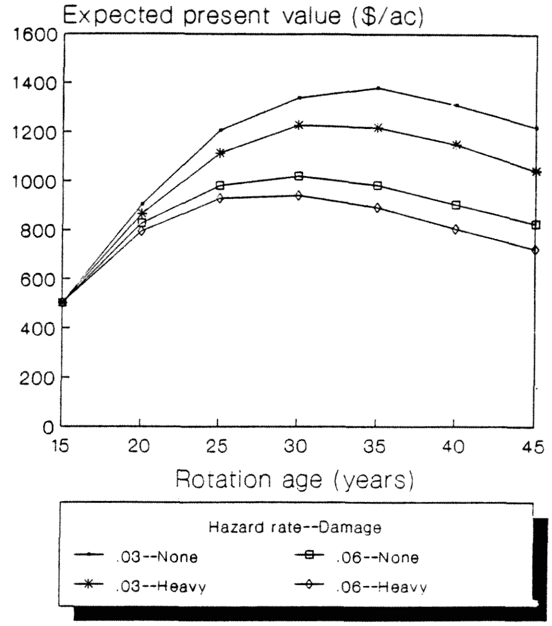

Figure 6--Expected present value versus rotation age for a 15-year-old loblolly pine plantation with alternative levels of stem sweep under 3% and 6% hazard rates.

Stem sweep has a greater economic impact in teenage stands because we assume that teenage trees with stem sweep cannot be cut into merchantable sawlogs. Instead, damaged trees must be utilized entirely as pulpwood. Nevertheless, the economic impacts are mitigated by removing damaged trees during commercial thinning. By concentrating growth on undamaged sawtimber, the effects of storm damage are reduced.

Increasing the hazard rate substantially reduces EPVs of both damaged and undamaged teenage stands. The maximum present values of an undamaged teenage stand under no hazard ($2,161 per acre) are 36 percent and 53 percent greater than the maximum EPVs of the same stand under 3 percent and 6 percent hazard rates ($1,380 per acre and $1,141 per acre, respectively). Similar results are obtained for damaged stands.

Hurricane-induced stocking reduction affects EPV much more than stem sweep. The relationships between EPV and rotation age for damaged teenage stands with alternative stocking levels are shown in Figure 7. The hazard rate is 3 percent. Each 25 percent reduction in stand stocking reduces the maximum EPV by $240 per acre. As stocking drops below 25 percent, the maximum EPV approaches the expected LEV associated with immediate reforestation.

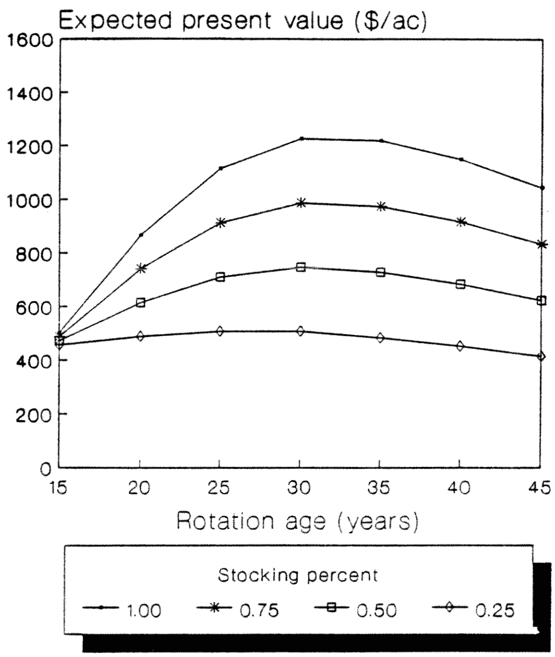

Figure 7--Expected present value versus rotation age for a 15-year-old loblolly pine plantation with stem sweep and alternative levels of mortality (expressed as stand stocking) under a 3% hazard rate.

Moderate reductions in stand stocking do not affect the optimal management strategy. For stocking levels above 50 percent, the optimal thinning age (21 years) and rotation age (30 years) are unchanged. The surprising result is that a stand with as little as 25 percent stocking should be allowed to grow for 10 years before clearcut. The EPV of this strategy ($508 per acre) is 10 percent greater than the EPV of immediately clearcutting and replanting ($476 per acre).

DISCUSSION

The outstanding result is the negative effect of the risk of hurricane damage on the expected economic yield of plantation management. With a 6 percent hazard rate, which is consistent with the historical frequency of hurricanes affecting a locale in the coastal plain of South Carolina, intensive plantation management is not profitable using 1992 prices and a 4 percent real discount rate. Assuming that young stands are immune to damage and that a small portion of damaged stands may be salvagable makes plantation management profitable, but the expected economic yield is substantially less than the yield computed with no risk. These results should caution decision makers to adjust their estimates of the economic yields from forestry taking into account the risk of hurricane damage.

There are ways to mitigate the economic effect of hurricane risk. Our results show that government payment of regeneration cost following storm damage moderately increases expected economic yield. Using low-cost management options would have a similar effect. Indeed, Straka and Baker (1991) show that low-cost reforestation methods for damaged stands with adequate sources of natural regeneration can have present values that are superior to those of more intensive reforestation methods. The potential economic benefits of practicing low-cost forestry in areas subject to high hurricane risk are an incentive to investigate the efficacy of these practices.

The results in this paper apply to risk-neutral decision makers who want to maximize the EPV of the stream of future stand yields. The best harvest policy and EPV may change for risk-averse decision makers (Caulfield 1988, Taylor and Fortson 1991). Because the actual yield stream depends on the particular sequence of destructive storms, actual present value may be above or below the EPV. Taking into account the variability in EPV, a risk-averse decision maker may not want a management policy that maximizes EPV. Instead the manager may want to minimize the probability of obtaining a low total discounted yield or to maximize the minimum periodic yield. These problems are left for further work.

The LEV results are based on a single-stand model that can be extended to a whole forest only under restrictive assumptions. The expected LEV of a single plantation can be viewed as the average LEV obtainable from many similar sites that are managed independently under similar, although independent, hazard rates (Reed and Errico 1985). These assumptions are not realistic when the decision maker imposes harvest flow constraints and when stands are grouped geographically so that hazard rates are not independent. A whole-forest model similar to those developed by Reed and Errico (1986) and Gassmann (1989) is needed to address the harvest scheduling problem under hurricane risk.

ACKNOWLEDGMENT

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THE IMPACT OF HURRICANE HUGO ON SOUTH CAROLINA'S TIMBER SUPPLY[1]

Robert Abt, John Burch, and Gerardo Pacheco[2]

ABSTRACT--The immediate impact of Hurricane Hugo on timber inventory has been documented by the Forest Inventory and Analysis (FIA) unit of the Forest Service's Southeastern Forest Experiment Station. The impact on South Carolina's timber economy, however, will be felt long after the salvage operation is over. The approach in this research project is to model the impact of Hugo on inventory, supply, and price over the next thirty years. This will be accomplished by building three inventory models that correspond to the FIA categories of heavy, light, and undamaged regions. Yield models will be used to model the growth response of the damaged stands. These inventory models are being built using the Forest Service's ATLAS modeling system that has been configured to include five management-types (plantation, natural pine, mixed-pine, upland hardwood, lowland hardwood) and two ownerships (industry, non-industrial private). These models will be linked by a stumpage market model (SRTS) which will project aggregate stumpage price changes and allow harvest to shift among damage regions and ownerships in response to inventory levels. The economic model allows simulation of different harvest projections and sensitivity analysis to economic assumptions. The model will also be used to evaluate the welfare effects by estimating consumer and producer surplus implicit in each projection. The basis for the comparison will be a "without Hugo" projection based on historical trends. Employment impacts will be modeled by linking harvest simulations to IMPLAN input-output multipliers for the forest products sector. If you are interested in receiving a copy of our final report, please send your request to Bob Abt, Department of Forestry, North Carolina State University, Box 8008, Raleigh, NC 27695-8008. The report should be available by July 1, 1993.

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[1] A paper presented at the 72nd Annual Meeting of the Appalachian Society of American Foresters held at Greenville, S.C., on January 20-22, 1993.

[2] Robert Abt, John Burch, and Gerardo Pacheco, North Carolina State University, Raleigh, NC 27695-8008.

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HURRICANE HUGO: TIMBER INVENTORY, PRICE AND WELFARE EFFECTS FOR SOUTH CAROLINA

John R. Burch, Robert C. Abt, Gerardo Pacheco, T. Barton Lander, and Raymond M. Sheffield[1]

Abstract--Economic implications of decreased timber supply in South Carolina due to hurricane Hugo are examined using estimates of changes in consumer and producer surplus. The approach used is a "with" and "without" Hugo comparison. The baseline, "without" scenario, simulates South Carolina inventory without the occurrence of Hugo. This is compared to a projection based on the Forest Service's Hugo survey. Timber inventory is projected using the ATLAS model. Regional supply and demand shifts are estimated using the Sub-Regional Timber Supply (SRTS) model. Together they produce compatible inventory and stumpage price projections. Comparison of producer and consumer surplus are made and aggregate welfare impacts are estimated. Note that these results are preliminary and subject to revision. The focus in this paper is on the modeling approach, not the price or inventory levels.

INTRODUCTION

Hurricane Hugo swept through the coastal plain and piedmont of South Carolina on September 21, 1989 damaging over one-third of the state's timberland. The inventory reduction was estimated to be 1.3 billion cubic feet of which one billion was in softwood management types. The immediate destruction wrought by Hurricane Hugo will have long-run impacts on the future of South Carolina's timber economy. The objective of this study is to estimate long-run inventory, price, and welfare impacts which result from the loss of private timber inventory.

In this study we project statewide inventory using two different scenarios. The baseline projection estimates state inventory levels that would have been likely if Hurricane Hugo had not occurred. The second, with-Hugo, projection models inventory trends based on what was left after the Hurricane.

The long-run difference in inventory projections is a result of the different starting inventories, the resulting change in age-class distribution, and the price and harvest consequences of the shift in supply. It is doubtful that South Carolina's demand for growing stock will be unaffected by Hugo. In this paper, however, we model the inventory effect given the same demand scenario.

The change in welfare for producers and consumers was calculated by integrating the appropriate areas of the estimated supply and demand relationships resulting from the economic analysis.

MODELING APPROACH

The period of analysis for this study is from the year 1990 to 2025. This will allow for at least one rotation of inventory recovery. For the purpose of this study South Carolina is considered to be an autonomous trade region. The

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ameliorating effect of stumpage flows between South Carolina and the coastal plain of Georgia or North Carolina are ignored. Within the state of South Carolina, the inventory is subdivided into damage regions which reflect the various degrees of damage sustained from the hurricane. The damage regions are heavy, light, and no damage as defined by the USDA Forest Service. Private and industrial ownerships are modeled separately within each category. The exclusion of publicly owned forest inventory was due to the small number of FIA plots available to support an extensive modeling effort (3 damage classes x 3 management types x age class) and its uncertain prospects for contributing to future timber supply.

Within ownerships, inventory is divided into three types, 1) planted pine, 2) natural pine/oak-pine, and 3) bottomland/upland hardwood management types.

Data

These models are currently structured to allow for the projection of only a single product (growing stock) and a single market price. SRTS models price as an index. In this case, initial price was calculated as an average of the pulpwood and sawtimber prices weighted by their proportion of total state removals as reported in the industry summary of 1988 (Davenport and Tansey 1990). The starting price for the baseline projection is calculated from third quarter 1989 Timber Mart-South data (Timber Mart South 1989). The third quarter of 1989 was the last data period prior to Hurricane Hugo. The weighted price for the with-Hugo simulation is calculated using the fourth quarter 1990 data. It is assumed that the interim fifteen months gives a more stable starting point for the price series.

Starting inventory information was provided by the Forest Inventory and Analysis (FIA) survey. The 1977 (Snyder 1978; Craver 1979; Sheffield and Hutchison 1979) and 1986 (Tansey 1986, 1987, 1987a) South Carolina state FIA surveys are used to establish accurate growth and yield information. The 1986 survey inventory level was used as the baseline starting inventory. It was adjusted, using average annual rates of change, to represent 1985 levels primarily for reporting purposes and the five-year increment used in the model. An additional special FIA survey of post-Hugo inventory was completed in 1990 and provided the starting inventory for the with-Hugo projection (Sheffield and Thompson 1992).

The Economic Model: SRTS

The SubRegional Timber Supply (SRTS) market model is used to model the economic effect of the inventory changes through time. SRTS models demand as function of price and an unspecified shifter. It models supply as a function of price and beginning of period inventory assuming a constant elasticity (logarithmic) functional form. SRTS uses projected harvest and aggregate supply to determine price and reallocate harvests between region-owner units (Abt and others 1993).

It is assumed that demand increases as projected in the South's Fourth Forest study (USDA Forest Service 1988). The harvest trend was used in the baseline case to determine the implicit demand shift through time (Abt and others 1993). These period-specific demand shifts were then applied to the post-Hugo projection.

Table 1 shows the demand and supply elasticities used for the results reported here. These correspond generally to the elasticities for the Southeast in Haynes and Adams(1985).

Table 1--Elasticities assumptions.

Elasticity	Owner	Estimate
Inventory-Supply	Owner	Estimate
Supply-Price	FI	.47
	NIP	.30
Demand-Price	ALL	.15
Inventory-Supply	ALL	1.0

The Inventory Model: ATLAS

The Forest Service model ATLAS (Aggregate TimberLand Assessment System; Mills and Kincaid 1991) was used to project timber inventories for the two scenarios. ATLAS is an age-class based model that moves acres through time based on user specified management assumptions and yields. Timber inventory was modeled by damage region, ownership, and management type (3 damage regions x 2 ownerships x 3 management types). Each was projected separately to determine aggregate inventory. Table 2 illustrates the ATLAS configuration that is specific to the Hurricane Hugo study.

Table 2--ATLAS configuration for Hugo study.

Damage Region	Ownership	Management Type
None	Industrial Private	Planted Pine
Light	Non-Industrial Private	Natural Pine/ Oak Pine Mix
Heavy		Hardwood

The acreage shifts, or conversion rates, used in the inventory projection are consistent with published trends for South Carolina (Alig 1985). We assumed that acreage allocation among management types and initial age classes was not shifted by the hurricane though it is possible that some rapid one time conversion will take place. The only accelerated conversion accounted for in this projection is that which occurred after Hurricane Hugo but before the completion of the 1990 FIA post-Hurricane Hugo survey. Some consequences of these assumptions are discussed later.

The yield tables are constructed differently for the baseline and with-Hugo scenarios. For the baseline projection, "growth" yield tables are developed using the FIA survey data. It assumed that cumulative average growth by age class most accurately describes stand yield in each five-year age class.

For the with-Hugo scenario, yield tables for damaged stands were constructed using a planted pine growth model and a natural pine model to reflect changes in growth and yield patterns due to tree loss at different ages. Damaged hardwood yield tables are constructed from estimated growth reductions. The yield tables for undamaged stands are the same in both scenarios.

Market-Inventory Model Linkage

ATLAS projects individual inventories for the region-owner-type units for a five-year period. This inventory is passed to the SRTS market model. The percentage change in aggregate inventory is used as a shifter for the aggregate supply curve. Supply curve shifts and assumed harvest level determines a new price. The new price is applied to the supply curves of the six individual region-owner units to determine the new harvest allocation for each region-owner. The allocation of harvest across management types within a region-owner unit is not modeled economically. It is determined by a combination of initial harvest proportions, current inventory proportions, and/or current growth proportions.

The harvest request for the next period is then passed back to ATLAS, and the sequence is repeated for the next five-year period to the end of the projection horizon. Figure 1 shows the conceptual relationships between the inventory model and the economic model.

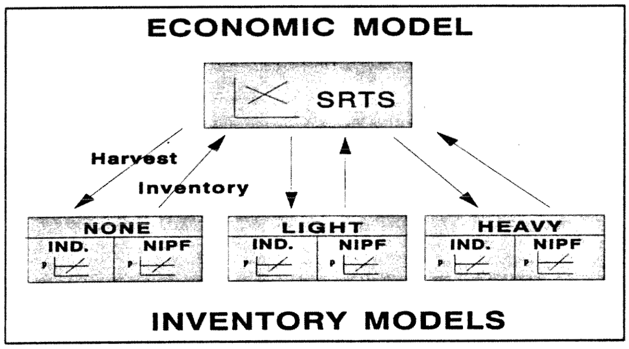

Figure 1--Relationship between inventory and economic model.

The sequencing of this link is different in the baseline projection and the with-Hugo projection. The difference is due to the need to hold demand rather than harvest constant between the two projections. The baseline simulation is projected first using the harvest trends from the South's Fourth Forest. Along with supply shifts due to inventory, SRTS uses these harvest levels to determine price and the implicit demand shift for the period. The with-Hugo run takes the more traditional economic approach to use demand (as estimated above) and supply to determine harvest. Though the demand curve is assumed to be the same, harvest declines due to the decrease in supply.

Figure 2 illustrates the modeling approach. The line labeled "Baseline" is the baseline supply curve for any period and the "With Hugo" is the corresponding supply curve for the with-Hugo run. In the base run, harvest level for each period is known and the supply curve is determined as inventory is passed from ATLAS. The price is determined at the point where the supply curve and harvest levels intersect and the demand curve is implied through this point. In the with-Hugo run, the inventory is passed to SRTS as before and the aggregate supply curve "With Hugo" is determined. Since the demand curve is the same as in the baseline projection, the resulting equilibrium harvest level and price can be determined.

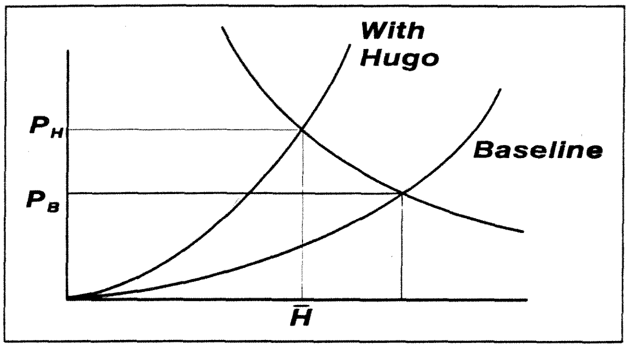

Figure 2--Modeling approach.

WELFARE MEASUREMENT

Welfare effects were measured as changes in consumer and producer surplus. Producer surplus is the area left-bounded by the y axis, upper-bounded by the price line and lower-bounded by the supply curve. Similarly, consumer surplus is that area left-bounded by the y axis, lower-bounded by the price line and upper-bounded by the demand curve. For this study the welfare estimates are calculated as changes rather than as absolutes.

In the stumpage market, producers are the forest landowners, and consumers are users of stumpage or primary owners of processing facilities. The producers of stumpage lose potential income associated with volume loss. Those who have a residual forest after the hurricane, however, will realize gains from the higher prices. The consumers who face more competition for reduced supply lose due to both reduced production and higher input prices. In this project no attempt was made to separate welfare effects for fully integrated industries that operate as both producers and consumers in this market.

Figures 3 and 4 illustrate changes in consumer and producer surplus from a shift in supply. Figure 3 shows in area ***a*** the loss in consumer surplus from an increase in price and a decrease in quantity. In Figure 4 area ***a*** represents gains to producers due to the increased price. Area ***b*** represents the loss to producers from decreased harvest. The difference between area ***a*** and ***b*** is the net gain to producers.

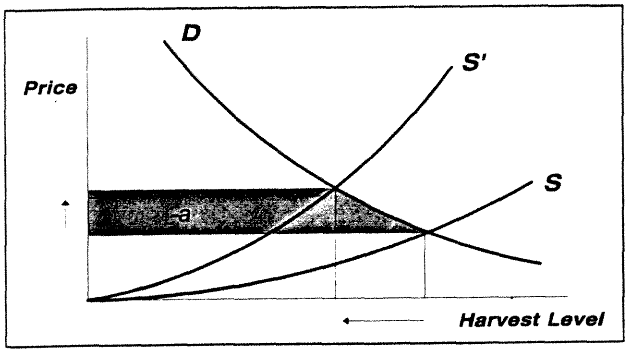

Figure 3--Consumer surplus change.

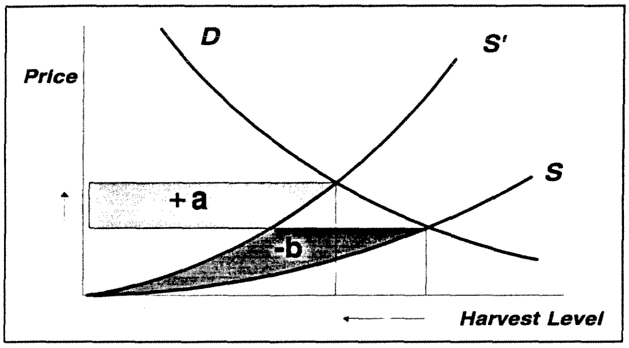

Figure 4--Producer surplus change.

RESULTS

Inventory

Initial inventory reduction in softwood for the ownerships in this model was about 700 million cubic feet or about 8 percent of aggregate volume. About 6 percent of aggregate hardwood inventory was destroyed by Hugo or roughly 300 million cubic feet. The impact of this initial reduction in aggregate inventory levels is evident in the with-Hugo projections of both management types.

Initial reductions in softwood inventory seem to be the basis for the gap between baseline and with-Hugo softwood projection (Figure 5). The baseline projection for softwoods shows an increase from 8 billion cubic feet to

12 billion cubic feet. The Hugo scenario projected slightly less than 11 billion cubic feet. The with-Hugo projection flattens after 2020 as a result of relatively higher demand pressure on younger age classes. In 2030 the aggregate inventory differences are approximately 13 percent for softwoods.

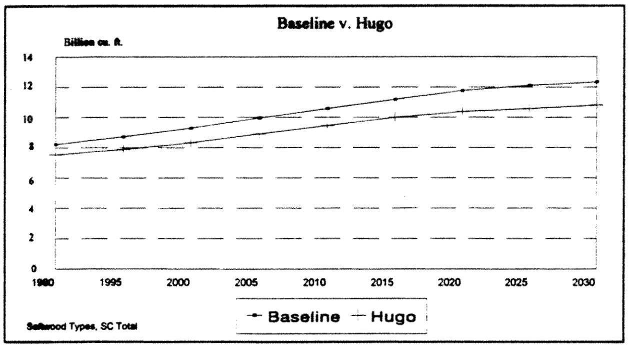

Figure 5--Softwood inventory projection.

The initial inventory reduction in hardwood types seems to be a large factor in the projected inventory differences as well (Figure 6). However, the growth/drain ratio also plays an important role in determining the future hardwood inventory. From 1995 to 2005 in baseline run the inventory increases indicating balanced growth and removals. After this period, removals surpass growth and inventory flattens and then declines to the end of the projection. The first 10 years of the with-Hugo simulation indicates the initial effect of the hurricane on the growth/removals balance. An increasing trend up to 2010 indicates some recovery of the growth/removal

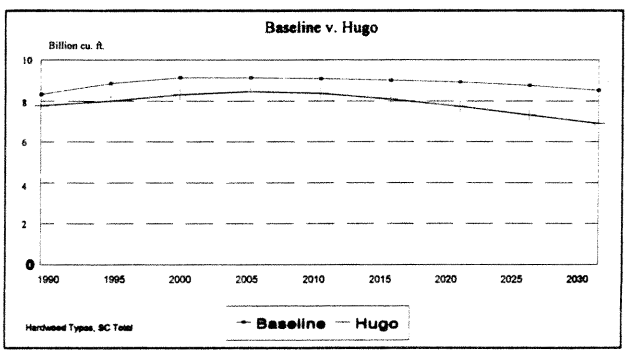

Figure 6--Hardwood inventory projection.

ratio. However, the inability of inventory to recover fully in the with-Hugo projection ultimately results in suppressed growth and an approximate 20 percent lower inventory at the end of the projection period.

If a more elastic demand curve were used to reflect substitution of wood in neighboring states, the harvest would decrease more and the with-Hugo inventory projection would likely show better aggregate inventory recovery.

Price

Since supply and demand are inelastic, the decrease in inventory leads to a relatively small decrease in harvest, but relatively a greater increase in price. Price trends follow similar paths but the effect of timber supply reduction is to magnify the price effects (Figures 7 and 8). For example, increasing price trends in the baseline are also increasing trends in the with-Hugo but at a faster rate. When the price decreases for softwoods, the trends decrease more slowly than in the baseline.

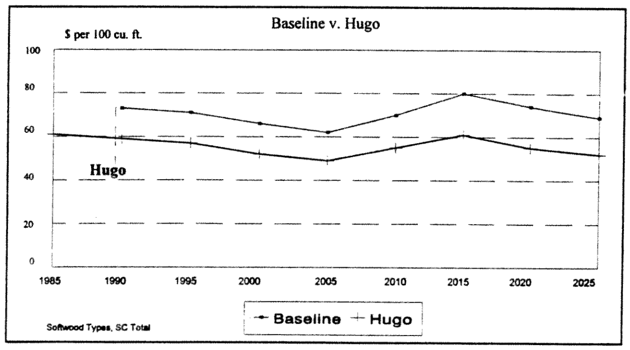

Figure 7--Softwood price projection.

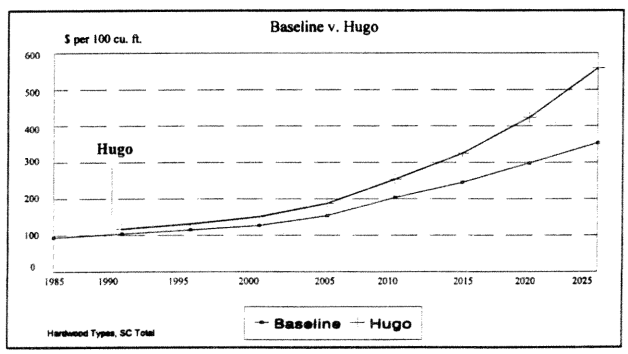

Figure 8--Hardwood price projection.

Welfare

The welfare results indicate that as producers wait until the price effects peak, they can maximize welfare gains by realizing the highest prices. The consumers will realize maximum losses when forced to compete for less wood offered at the price peaks. Stumpage consumers will be relatively worse off until sufficient inventory recovery restores the market to pre-hurricane conditions.

Consumers are expected to have increasingly negative welfare effects throughout the projected period. Conversely, producers are estimated to have positive welfare effects. Furthermore, the projected losses to consumers will exceed the gains to producers over the 35 years. The relative distribution of gains and losses over time for producers and consumers is shown in Tables 3 and 4. The net value of producer surplus and consumer surplus or total social welfare loss for all markets is displayed in Table 5. The present value of net welfare loss to the timber economy is discounted at several rates to indicate relative severity in 1990 dollars.

The welfare effects reported in this paper are aggregate impacts and could be different for producers and consumers under alternative assumptions or model specifications. The following section discusses some conditions that could alter the results.

Table 3--Softwood Consumer and Producer Surplus Change and Net Welfare.

Period	PS Change	CS Change	Net Welfare Impact
1990			
	134,261,042	-220,346,709	-86,085,667
1995			
	164,914,885	-267,410,600	-102,495,715
2000			
	186,109,058	-298,749,162	-112,640,104
2005			
	185,133,236	-294,791,097	-109,657,861
2010			
	182,970,643	-290,350,430	-107,379,788
2015			
	228,230,493	-360,872,070	-132,641,577
2020			
	315,292,103	-498,579,305	-183,287,202
2025			
	308,766,171	-489,329,670	-180,563,499
2030			
Total	1,705,677,657	-2,720,429,043	-1,014,751,386

Table 4--Hardwood Consumer and Producer Surplus Change and Net Welfare.

Period	CS Change	PS Change	Net Welfare Impact
1990			
	99,864,119	-167,231,329	-67,367,210
1995			
	136,833,814	-232,474,459	-95,640,645
2000			
	220,610,930	-369,559,277	-148,948,347
2005			
	329,140,690	-548,110,713	-218,970,022
2010			
	534,344,735	-862,897,251	-328,552,515
2015			
	845,051,195	-1,378,763,763	-533,712,568
2020			
	1,332,330,328	-2,188,895,667	-856,565,338
2025			
	2,181,141,587	-3,616,743,567	-1,435,601,979
2030			
Total	5,679,317,398	-9,364,676,026	-3,685,358,628

Table 5--Net Present Value of Welfare Effects.

Discount Rate	Net Present Value
4%	-1,854,583,439
6%	-1,267,212,230
8%	-916,538,951
10%	-699,407,165

DISCUSSION

These projections are sensitive to some of the input parameters and economic assumptions. Alternative assumption on several parameters would likely create different inventory and economic results. Sensitivity should be conducted on ATLAS, SRTS and the link between the two models for the following components: acreage assumptions, stocking adjustment coefficients, harvest trend (i.e., demand assumptions), regional definition and product differentiation. A discussion of sensitivity on several of these variables is presented for TRIM by Alexander (1991).

Acreage Shifts

In ATLAS, acreage by age class is an important determinant of aggregate inventory so projections are sensitive to these specifications. Acreage trends reflecting alternative conversion rates in response to Hugo may alter the results. It is likely that stand conversion to planted pine or younger age classes of natural pine will proceed more rapidly than anticipated in the Alig study as a result of Hurricane Hugo. Data from the 1992 statewide remeasurement indeed show that replanting may be minimal but natural regeneration has increased significantly. This one-time rapid conversion could have a significant impact on the long-run inventory recovery and therefore on the resulting price trends and welfare effects. Potential consequences will be explored in future models.

Stocking Adjustment

The density change (approach-to-normal) coefficients in ATLAS are used to adjust stocking ratios through time to what would be considered "normal" stocking. The process to estimate the density change coefficients involves regressing current stocking on previous period stocking (Mills 1989). It was found that small changes in coefficient specification may lead to large changes in inventory projections. It should be noted that this is primarily an accepted theory at the stand level but evidence that regional inventories exhibit this behavior has not been documented empirically.

Harvest Assumptions

Harvest requests have important implications for supply shifts and price projections for the baseline projection. The assignment of regional starting harvests was based on historic regional harvesting activity. Basing initial harvests on historical information caused some regions with little inventory after the hurricane to be over harvested because they had the highest requests due to heavier historic cutting. The resource in some of the regions was being cut out before the economic model could shift harvests to other regions. The problem was solved by moving harvests to regions with higher inventories for the first period. This assumes that regional harvests are better predicted by current inventory than past harvest levels.

Related to harvest assumptions is the implied increasing derived demand for stumpage. The reduction of inventory by Hugo will likely affect the demand in both the end use and stumpage markets. The harvests may remain constant or even decline in response to supply shifts and market pressure. To capture this effect, demand should be allowed to change in the with-Hugo simulation or at least shift to outside regions (i.e., North Carolina and/or Georgia).

Regional Definition

Restricting stumpage trade between South Carolina and Georgia or North Carolina imposes unrealistic restrictions on the stumpage market. It furthermore elevates the estimated price and welfare effects by not allowing some capacity to shift out of the state. The mitigating effects of allowing trade between these regions should be investigated to obtain more realistic impact assessment. One method of accommodating other regions is to define additional management units for bordering regions. Another method may be to adjust elasticities to reflect more quantity harvest adjustments in response to price movements.

Product Differentiation

Product differentiation is not accommodated in this research. If welfare impacts could be distributed among consumers by products, the producers and consumers would likely have very different results. For example, the welfare impacts to the consumers of pulpwood would be different from those experienced by sawmills since degrade may create an overabundance of pulpwood.

CONCLUSION

Hurricane Hugo affected the short- and long-run timber economy of South Carolina. Though the net social welfare loss was substantial, the distribution of the loss is also important. These welfare impacts show the potential size of the impact and its distribution among consumers and producers of timber.

Only the long-term welfare effects were estimated by this research. The short-term welfare impacts were very different from the long run. Producers had short-term losses from depressed market prices and unsalvaged timber. Consumers however had gains from salvage wood and the ability to stock salvaged timber. From a broader perspective, some of the losses to the timber sector may have been offset by gains in other parts of the state economy, e.g., home construction.

ACKNOWLEDGMENTS

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THE EFFECT OF HURRICANE HUGO ON TIMBER SUPPLY

Allan P. Marsinko, Thomas J. Straka, and Robert G. Haight[1]

INTRODUCTION

Timber damage caused by Hurricane Hugo was over $1 billion. Many trees were downed and many others suffered in terms of quality. A total of 10.3 billion board feet of sawtimber and 13.2 million cords of pulpwood were damaged, representing a tremendous impact on the state's timber supply. This article examines the short-term effects of this large scale natural disaster on the timber supply in the state.

TYPES OF SUPPLY

Supply is the amounts of a product that will be offered to the market at various prices. It is the entire curve, S, shown in Figure 1. Quantity supplied is a specific quantity offered to the market at a specific price (e.g., Point A, B or C in Figure 1). The quantity supplied would be expected to change as a result of a change in price. For example, it might move from point A to point B. A change in the quantity supplied by moving along the curve (from A to B) is not a change in supply. Because supply is the entire curve S, a change in supply is a change in the entire curve, such as a shift in location from S to S'. The term "supply response" refers to a change in the quantity supplied. This can occur as a movement along a supply curve (e.g., from A to B in Figure 1), or it can occur along with a shift of the supply curve (e.g., from A to C in Figure 1).

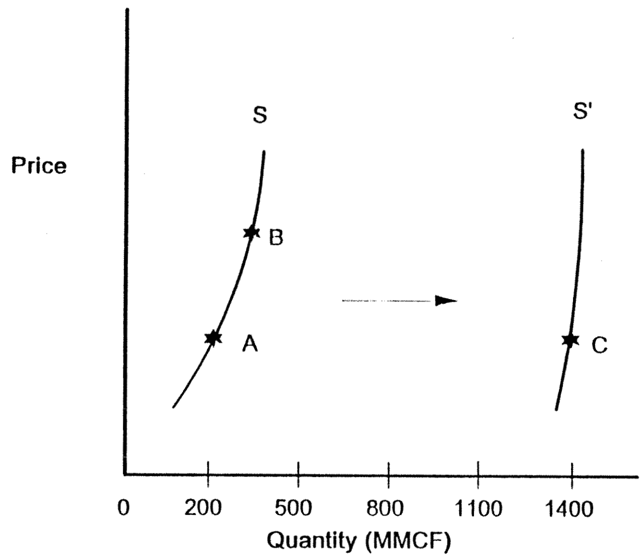

Figure 1--Hypothetical pre- and post-hurricane supply curves for pine timber.

Three types of supply are usually identified. The first goes by several names that imply a brief time span: e.g. very short run (Nicholson 1972), momentary run (Samuelson 1989), market (Worrell 1959), or stock supply (Duerr 1993). It consists of the supply of stocks on hand, available for more or less immediate offering to the market. It is the amount of stock in a warehouse or, as in this case, the timber ready for market. The second is short run supply. This is based on the rate of output going into stocks, the rate controlled by changing the variable inputs in the short run (e.g. increasing the intensity of management). In the short run, factory size and technology do not vary. Last is long run supply. It is based on changing the rate of output by changing most or all inputs. In this case, factories, technology, and the number of producers can change. This paper focuses on the very short run supply, the effects of which are now apparent. This paper has been extracted and condensed from a detailed discussion of the three types of supply which has been submitted to a journal.

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Hurricane Hugo's Effect on the Very Short Run Supply of South Carolina Timber

Although there are some indications that Hurricane Hugo caused a situation which illustrates "textbook economics," there are several factors which do not fit the standard models. Generally, a perfect market is assumed in which buyers and sellers have complete knowledge of the market. But, after a disaster such as this, knowledge of the pre-disaster market is no longer valid and confusion reigns. In a perfect market, market price adjusts instantaneously. Immediately after Hurricane Hugo, it was hoped that prices would remain near their pre-hurricane levels, and, in the days immediately following the hurricane some landowners received higher prices for their wood than did those who sold later. A few others, however, panicked and gave their timber to loggers in order to get their land cleared. Both buyers and sellers found themselves in a unique situation, never before having witnessed this type of loss. Uncertainty was heightened by conflicting reports about the time available to salvage the wood, which has the effect of temporarily dividing the market into relatively small local entities, each with its own set of "knowledge."

Supply responses are generally considered to be the results of decisions made by producers based on their predictions of future market conditions. A producer will make a positive supply response (offer more standing timber to the market) if he believes that he can get a higher price now than in the not-too-distant future. He acts in such a way as to take advantage of what he believes to be temporarily higher prices. This type of supply decision is usually a decision of whether or not to cut. The decision is tempered by longer term market perceptions because it takes a long time to replenish the stock of standing timber. In this case, Hurricane Hugo made the decision or, at least, changed the decision framework. By virtue of damaging the timber and making it potentially worthless in the future, Hurricane Hugo increased the timber available to the market at all prices. The result is a positive supply response; not the type that moves from A to B in Figure 1; but the type that moves from B to C. It shifted the supply curve to the right.[2] The quantity of pine timber normally available to the market from the hurricane damaged area was 216,339,000 cubic feet (Tansey 1987). After Hurricane Hugo, the quantity available was increased to about 1.4 billion cubic feet, 6.5 times the normal harvest in the affected counties. Figure 1 approximates the magnitude of the supply response for pine. The pre-hurricane curve is shown by S and the post-hurricane curve is shown by S'. Although the actual shapes and slopes of the supply curves are not known, the post-hurricane curve is probably less responsive to price (less elastic) and is drawn to reflect this assumption.

When the supply curve shifts to the right as has occurred here and the shift is not accompanied by a corresponding shift of the demand curve (an increase in demand), prices can be expected to fall. This is what happened after Hurricane Hugo. Prices were higher just after the hurricane than later probably because of the lack of knowledge in the market. The market did adjust prices, however, to post-hurricane averages 20 to 50 percent of their pre-hurricane levels. Although the exact shape and slope of the demand curve is not known, it is probably reasonably close to the curve (D) shown in Figure 2. It is possible that demand decreased which means the demand curve also shifted (to the left in this case). However, most mills were back in operation soon after the hurricane. If the demand curve did shift, then the true demand curve is not as steep as the one drawn in Figure 2.

The preceding example grouped pine pulpwood and sawtimber into a single product, pine timber. Table I breaks down the sawtimber and pulpwood and compares average annual removals to quantities damaged by Hurricane Hugo. Although it would be better to analyze the supply of pulpwood or sawtimber individually, the nature of the damage precludes this. Table I indicates that

[2] An argument can be made that Hurricane Hugo changed the product from standing timber to cut timber. However, since the very short run supply decision is whether or not to cut, the analysis should still be valid. The difference is that, under normal circumstances, the decision maker can rescind if the market becomes unfavorable; in this case, he can't.

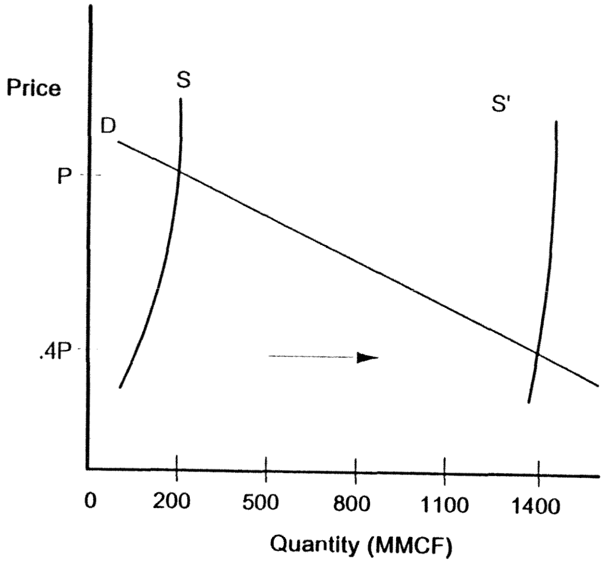

Figure 2--Hypothetical pre- and post-hurricane stock supply curves for pine with demand curve.

Table I--Comparison of average annual removals in the hurricane damaged area to hurricane damaged volumes of pine sawtimber and pulpwood.

	Average Annual Removals[1]	Hurricane Damaged[2]	Change [(Damaged / Removals)]
Sawtimber (MBF)	842,215	6,318,892	7.5
Pulpwood (MCF)	90,635	459,796	5.1

[1] Based on forest survey (Tansey 1987) and S.C. Forestry Commission conversion factor of 6.7 BF international rule/cubic foot.
[2] Classified before Hurricane Hugo. After Hurricane Hugo, much sawtimber was not usable as sawtimber.

6,318,892 MBF or 7.5 times the normal annual removals of sawtimber was damaged. This timber was sawtimber before the hurricane struck. After the hurricane, much of this wood could not be used as sawtimber. Instead, it became pulpwood. Exactly how much was no longer sawtimber is not known. Therefore, all that can be said is that a supply response occurred and the quantity of pine sawtimber available to the market increased by a factor less than 7.5 and that the quantity of pine pulpwood available to the market increased by a factor greater than 5.1. The exact magnitudes of these supply responses are not known.

Stumpage prices before and shortly after the hurricane are shown in Table II. These prices are taken from Timber Mart South (1989) and reflect normal fluctuations, prices for undamaged timber, and prices for hurricane damaged timber. Therefore, the post-hurricane prices shown are probably high for damaged timber. They are near the upper end of the 20 to 50 percent range discussed earlier. Stumpage prices also reflect increased logging costs. Delivered product prices after the hurricane were over 80 percent of pre-hurricane prices.

TABLE II--Comparison of average pine stumpage prices in the hurricane damaged area before and after Hurricane Hugo.[1]

	Average Price Before Hurricane	Average Price After Hurricane[1]	Change [(After / Before)]
Sawtimber ($/MBF)	$175.00	$89.00	.51
Pulpwood ($/Cord)	21.50	11.00	.51

[1]Source: Timber Mart South, South Carolina, Area 3.

This "almost textbook" example shows that the very short run supply curve shifted, the market was flooded, and the price fell. Pressure to sell before the wood deteriorated lowered reservation prices and made the post-hurricane supply curve relatively unresponsive to price. Not all of the wood was salvaged because logging and mill capacity were not sufficient and because most loggers were forced to take a technological step backward to chain saws in order to harvest fallen trees.

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THE TIMBER SITUATION IN SOUTH CAROLINA'S NORTHERN COASTAL PLAIN THREE YEARS AFTER HUGO[1]

Herbert A. Knight and Stephen K. Nodine[2]

Abstract--A new forest survey of the Northern Coastal Plain (Forest Survey Unit 2) of South Carolina, conducted in 1992, measured a 27-percent reduction in pine growing stock, a 16-percent reduction in cypress, and a 13-percent reduction in hardwood. Most of these reductions are attributed to Hurricane Hugo, which demolished much of the Region's forests on the night of September 21, 1989. A more significant dimension of the inventory reductions was the loss of large trees, particularly pine sawtimber. Inventory of pine sawtimber was down by 1/3. There is evidence a recovery is underway. The new survey measured more than 1.0 million acres of pine stands 10 years and younger. Many of these young pine stands had already been established prior to the storm, through the Conservation Reserve Program and other regeneration efforts. These young pine stands were not seriously affected by Hugo. They will provide thinning opportunities for pulpwood within the next 10 to 15 years, but it will be 30 years or longer before they can replace the pine sawtimber stands destroyed. In the meantime, mills producing solid-wood products will be drawing supplies from a greatly diminished resource.

INTRODUCTION

Today, we meet to assess the timber situation in the Northern Coastal Plain (Forest Survey Unit 2) of South Carolina. This assessment is based on statistics developed in a new forest survey conducted in 1992, about three years after Hurricane Hugo demolished much of the Region's forests on the night of September 21, 1989. This storm was perhaps the greatest forest disaster in South Carolina's history (Sheffield and Thompson 1992).

While our attention will focus on damage to the forests and evidence of their recovery, we should not forget the loss of life and property associated with this storm outside the forests. Overall losses and damages were severe and extended well beyond the area we are going to be looking at in this meeting.

The greatest destruction of forests did occur in this Unit, where the storm damaged more than 90 percent of the timberland in some counties. The new survey measured a 27-percent reduction in pine growing stock, a 16-percent reduction in cypress and a 13-percent reduction in hardwood. Most of these reductions are attributed to Hugo.

[1] Presented at a forestry conference in Columbia, South Carolina on April 28, 1993. This conference was jointly sponsored by the South Carolina Forestry Commission and the U.S. Forest Service's Southeastern Forest Experiment Station.
[2] Herbert A. Knight, formerly the principal forest resource analyst in the Southeast with the USDA, Forest Service, is a forestry consultant in Asheville, N.C., specializing in timber resource analysis. He wrote and presented this paper. Stephen K. Nodine is Instructor and Extension Forester, Clemson University Department of Forest Resources, Clemson, S.C. He edited the text and figures for this publication.

A more significant dimension of the inventory reductions was the loss of large trees, particularly pine sawtimber. In this Unit, inventory of pine sawtimber was down by one third.

Hugo could not have chosen another area in the Southeast where it could have done more damage to pine sawtimber. For example, in conducting the periodic forest surveys, the U.S. Forest Service divides the five southeastern states into 21 Survey Units. Prior to this storm, Unit 2 contained the largest concentration of pine sawtimber, in terms of volume per acre of timberland, in these 21 Units. The Unit now ranks 20th.

Prior to the storm, Berkeley County, South Carolina, alone contained more than two billion board feet of pine sawtimber, the largest inventory of the 472 counties in the Southeast. This latest survey shows 2/3 of the pine sawtimber that was in Berkeley County is gone.

Finally, prior to the storm, the Francis Marion National Forest in Unit 2 contained almost 15 percent of all the pine sawtimber on national forests in the Southeast. This latest survey shows 3/4 of this pine sawtimber is gone. The Francis Marion now contains less than 5 percent of the pine sawtimber on national forests in the Southeast.

Fortunately, all the statistics are not negative, and there is evidence the recovery is already well underway. For example, the new stand-age distributions show more than one million acres of pine stands 10 years and younger (Table 1). This measure is almost double the acreage of pine in this age class in the 1986 survey.

As I will confirm with statistics later in this presentation, many of these young pine stands had already been established prior to the storm through the Conservation Reserve Program (CRP) and other regeneration efforts. These young pine stands were not seriously affected by Hugo.

Because of the big increase in pine sapling stands, number of 2-inch pine trees almost doubled over the 6-year remeasurement period (Table 2). Fortunately, this large concentration of young pine stands will provide thinning opportunities for pulpwood within the next 10 to 15 years. The big problem is it will be another 30 years or longer before these young stands can replace the pine sawtimber stands destroyed by Hugo.

In the meantime, mills producing lumber and other solid-wood products in this region are going to be drawing timber supplies from a greatly diminished resource.

After this lengthy introduction, I will move on to a more orderly assessment of the timber resources. I would like to (1) call attention to some of the long-term trends, (2) measure the impact of Hugo on these trends, and (3) conclude with a few remarks about the prospective outlook for timber supplies from this region over the next several decades.

RESOURCE TRENDS

Seven regularly-scheduled surveys of the forest resources in the Northern Coastal Plain of South Carolina have been conducted since 1936. Results from these seven surveys document 56 years of the Region's forestry history. In addition, there was an interim survey following Hugo, and perhaps other partial surveys of the Unit over the years.

Timberland

About 65 percent of all land in Unit 2 is forest land, and 98 percent of this forest land qualifies as timberland. In contrast to many other areas of the Southeast, area of timberland in Unit 2 has remained relatively stable at around 4.7 million acres over the past 50 years.

Seemingly, the CRP reversed a slight downward trend in timberland in the mid 1980's. Because of the establishment of pine trees on land previously used for agriculture, area of timberland increased by more than 140,000 acres between 1986 and 1992. Over this same period, area in cropland and pasture declined by more than 230,000 acres.

Between 1978 and 1986, the annual rate of pine regeneration on nonforest land averaged only 7,000 acres. Between 1986 and 1992, this rate jumped to 23,000 acres. Hugo did not affect the total amount of timberland.

Forest Type

In our discussions of forest type, pine forest type includes all stands where pines account for 25 percent or more of the live-tree stocking. The oak-pine stands are included with the pine.

Table 1--Area of timberland, by stand-age and broad management classes, all ownerships, Northern Coastal Plain of South Carolina, 1992.

Stand-age class (years)	All classes	Broad management class: Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
	---------- Acres ----------					
0-10	1,369,043	450,782	265,454	297,555	151,805	203,447
11-20	492,395	177,832	107,122	91,744	44,731	70,966
21-30	367,817	131,247	124,285	37,069	37,246	37,970
31-40	373,998	61,630	114,308	35,992	38,866	103,202
41-50	359,313	6,399	139,349	49,003	63,911	100,651
51-60	315,605	---	86,025	36,154	40,808	152,618
61-70	250,971	---	54,202	26,042	19,147	151,580
71-80	132,988	---	22,115	8,011	4,519	98,343
81+	218,813	---	13,670	12,917	7,234	184,992
No manageable stand	837,506	21,675	111,520	157,419	197,045	349,847
All classes	4,718,449	869,565	1,038,050	751,906	605,312	1,453,616

NOTE: From Table 13, page 22 of Sheffield and Thompson, 1992.

Table 2--Number of live trees on timberland, by species and diameter class, Northern Coastal Plain of South Carolina, 1992.

Species	All classes	Diameter class (inches at breast height): 1.0-2.9	3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-28.9	29.0 and larger
	---------- Thousand trees ----------												
Softwood													
Longleaf pine	37,530	12,208	6,260	6,185	4,977	2,512	2,399	1,595	891	314	182	7	--
Slash pine	35,146	9,039	9,550	6,398	5,611	2,494	1,295	442	234	65	18	--	--
Shortleaf pine	7,600	2,820	1,624	1,741	539	354	278	107	82	43	--	12	--
Loblolly pine	731,309	393,297	153,690	85,520	43,873	23,644	13,590	8,286	4,650	2,555	1,184	973	47
Pond pine	36,090	14,445	7,949	4,749	3,985	1,956	1,589	662	376	272	86	21	--
Spruce pine	1,184	1,088	---	---	51	---	--	14	11	20	--	--	--
Baldcypress	19,429	5,861	3,063	3,084	1,988	1,440	1,125	847	560	594	312	507	48
Pondcypress	10,894	3,801	2,279	1,607	987	1,054	558	221	200	90	48	48	1
Cedars	9,178	5,066	2,481	919	567	101	--	--	--	23	9	12	--
Total softwoods	888,360	447,625	186,896	110,203	62,578	33,555	20,834	12,174	7,004	3,976	1,839	1,580	96
Hardwood													
Select white oaks	32,140	16,251	5,879	2,940	2,718	1,551	1,051	814	371	282	114	166	3
Select red oaks	7,169	3,744	1,001	1,048	291	266	251	200	142	58	66	79	23
Other white oaks	42,576	27,028	6,298	3,627	2,352	1,020	823	634	274	154	80	229	57
Other red oaks	365,065	249,899	56,406	26,278	13,493	8,291	4,576	2,370	1,334	855	654	746	163
Hickory	48,090	31,006	7,506	3,502	2,839	1,295	763	581	263	102	94	125	14
Hard maple	1,768	1,434	147	151	---	36	--	--	--	--	--	--	--
Soft maple	364,784	260,892	57,876	21,823	11,622	4,890	3,500	2,008	886	679	329	233	46
Beech	2,675	2,226	149	108	46	65	--	37	12	12	--	17	3
Sweetgum	450,144	315,204	69,058	28,139	16,261	9,303	4,953	3,376	1,876	922	461	531	60
Tupelo and blackgum	299,692	165,441	56,855	24,788	17,156	12,290	7,721	7,389	3,691	2,055	1,240	983	83
Ash	120,262	85,878	23,558	4,460	2,442	1,606	879	675	377	180	68	119	20
Cottonwood	4,195	2,121	769	317	416	139	186	117	56	43	9	9	13
Basswood	62	---	---	---	62	---	--	--	--	--	--	--	--
Yellow-poplar	25,795	14,035	2,970	2,655	1,690	1,387	754	733	620	334	301	299	17
Bay and magnolia	87,986	71,181	11,233	3,877	1,108	353	129	18	55	32	--	--	--
Black cherry	29,604	23,750	3,623	1,631	355	101	66	54	13	11	--	--	--
Black walnut	297	---	143	---	47	34	26	15	--	20	--	12	--
Sycamore	2,249	1,498	303	161	47	28	99	--	26	22	17	45	3
Black locust	298	155	143	---	---	---	--	--	--	--	--	--	--
Elm	37,981	24,982	6,570	3,296	1,442	585	476	338	160	49	50	27	0
Other eastern hardwoods	449,172	352,763	66,400	18,983	7,599	1,807	882	425	136	74	35	66	2
Total hardwoods	2,372,004	1,649,488	376,887	147,784	81,986	45,047	27,135	19,784	10,292	5,884	3,518	3,686	513
All species	3,260,364	2,097,113	563,783	257,987	144,564	78,602	47,969	31,958	17,296	9,860	5,357	5,266	609

NOTE: From Table 32, page 33 of Sheffield and Thompson, 1992.

Between 1940 and 1960, area in pine type declined about 14 percent as hardwoods replaced pines on about 400,000 acres. Between 1960 and 1985, area in pine type remained fairly stable at around 2.5 million acres. Since 1985, area of pine has increased about 5 percent. Again, most of this recent increase can probably be attributed to pine planting under the CRP.

Within the pine type, the big change has been the shift from natural to planted stands. Since 1940, area in natural pine has decreased from 2.9 to 1.7 million acres, or by 40 percent. Over this same period, almost one million acres of pine plantations have accumulated. Plantations now account for about 1/2 of all pine stands 30 years and younger. Between 1978 and 1986, pine plantations were established at an average annual rate of 33,000 acres. Between 1986 and 1992, pine plantations were established at the rate of 59,000 acres per year. Both the CRP and Hugo contributed to this recent increase.

Total area in hardwood forest type has remained fairly stable at around 2.1 million acres, with the only variations being an increase back in the 1940s and some decline since 1980.

Ownership

Figure 1 shows the trends in timberland, by ownership. Currently, nonindustrial private forest (NIPF) owners control 2/3 of the timberland, forest industry 23 percent, and public agencies 10 percent.

Over the past 30 years, the most significant changes have been in the amount of timberland in industry ownership. Between 1958 and 1986, timberland in industry ownership increased by 63 percent to 1.3 million acres. Between 1986 and 1992, the trend reversed as timberland in industry ownership decreased by 15 percent, down to 1.1 million acres.

This recent decline in industry ownership in Unit 2 seems to be part of a regionwide decline across the Southeast. This recent decline follows several decades of increase.

Inventory Volume

Figure 2 shows the trend in softwood growing stock. Pines account for about 90 percent of this softwood.

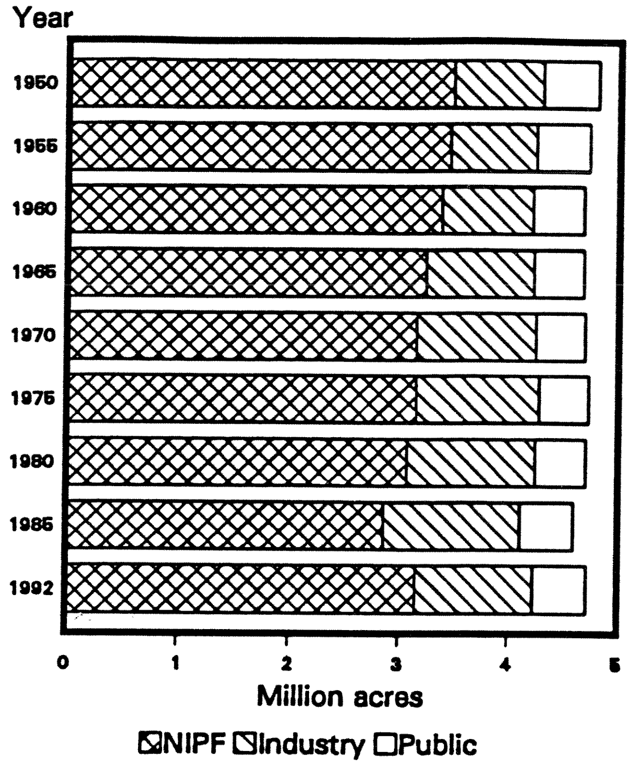

Figure 1--Timberland ownership in the northern coastal plain forest survey unit in South Carolina, 1950-1992.

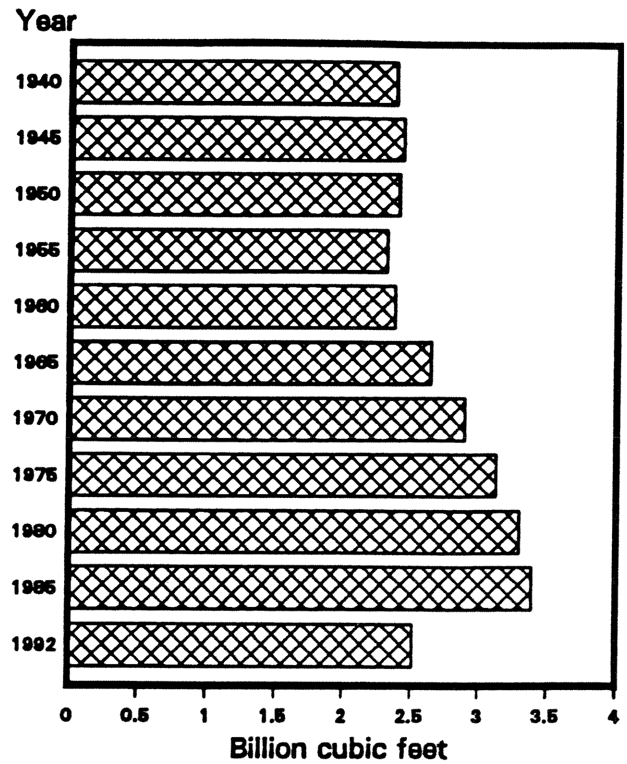

Figure 2--Softwood growing stock in the northern coastal plain forest survey unit in South Carolina, 1940-1992.

Most of the remainder is cypress, and there is a small amount of cedar.

Between 1940 and 1960, inventory of softwood remained fairly stable at about 2.4 billion cubic feet. Between 1960 and the occurrence of Hugo, the inventory increased more than 40 percent, up to 3.4 billion cubic feet.

The new survey measured a 26-percent drop in softwood inventory, all the way down to 2.5 billion cubic feet. So three years after Hugo, the inventory of softwood is the smallest it has been in 30 years. Without Hugo, there would have been little or no reduction in softwood inventory.

Another way to measure the impact of the storm is to relate inventory to average annual rates of cutting. Prior to the storm, the inventory contained a 21-year supply of softwood, without any additional growth, based on the 1986 rate of cutting. The new survey measured a 16-year supply based on the 1986 cutting rate, and only a 14-year supply based on the 1992 cutting rate.

Although you can expect a sharp upturn in softwood growth to follow the storm, mills within this region will be drawing softwood supplies from a greatly diminished softwood inventory at least through the 1990's. The storm's impact on softwood sawtimber supplies will extend over a much longer period.

Figure 3 shows the trend in hardwood growing stock. For several decades, inventory of growing stock in Unit 2 had been fairly equally divided between softwood and hardwood. Although its impact was much smaller than it was on the softwoods, Hugo also took a heavy toll out of the hardwood inventory.

Between 1945 and 1960, inventory of hardwood declined about 13 percent, down to 2.6 billion cubic feet. Between 1960 and Hugo, hardwood increased 40 percent, up to 3.6 billion cubic feet. The new survey measured a 13-percent reduction, down to 3.1 billion cubic feet. Again, without Hugo there would have been little or no reduction in hardwood.

One interesting aspect of the storm's impact on the hardwoods was a significant difference between species groups. Gums and other soft-textured

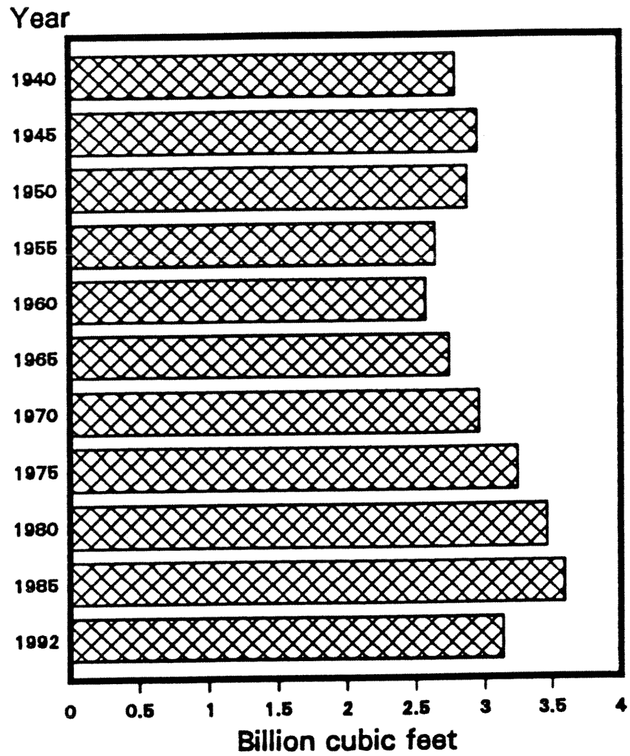

Figure 3--Hardwood growing stock in the northern coastal plain forest survey unit in South Carolina, 1940-1992.

species dominate the hardwood inventory. These soft-textured species fared much better than the oaks and other hard-textured species. Inventory of soft-textured species was down less than 10 percent, while inventory of hard-textured species was down more than 20 percent. Again, this is not good news for the producers of solidwood products.

One reason the hard-textured species suffered a greater loss was a difference in tree-size distribution. A higher percentage of the hard-textured species was in trees over 20 inches in diameter. These large trees were harder hit than smaller trees.

Prior to the storm, the inventory contained about a 50-year supply of hardwood, without any additional growth, based on the 1986 cutting rate. The new survey measured a 42-year supply based on the 1986 cutting rate, and a 36-year supply based on the 1992 cutting rate.

While there was less loss of hardwood than softwood, the recovery of hardwoods will take longer. First of all, it takes more time to grow a new stand of hardwoods up to merchantable size. Secondly, in contrast to the pine situation, the Unit does not have a million acres of well-stocked hardwood stands already established in the 0 to 10-year age class. The comparable figure for hardwood stands is 355,000 acres.

Timber Growth

Over the past 25 years, periodic remeasurements of permanent sample plots have provided consistent and reliable estimates of timber growth. In the earlier surveys, estimates of timber growth were developed from increment borings.

Figure 4 shows the trend in softwood growth since 1940. Between 1940 and 1978, net annual growth of softwood just about doubled, increasing from 96 to 196 million cubic feet. Between 1978 and 1986, softwood growth turned down slightly and averaged about 177 million cubic feet per year. Between 1986 and 1992, net annual growth of softwood averaged only 28 million cubic feet because of the high mortality associated with Hugo. In fact, some counties in this Unit even experienced negative net growth over this period.

In the absence of another natural catastrophe, softwood growth should quickly recover to the pre-Hugo level or higher over the next 10 years. As mentioned earlier, there are more than one million acres of pine seedling and sapling stands already established.

Figure 5 shows the trend in hardwood growth. Between 1940 and 1960, net annual growth of hardwood remained fairly stable in a range between 54 and 62 million cubic feet. Between 1960 and 1978, hardwood growth more than doubled, reaching 134 million cubic feet. Between 1978 and 1986, hardwood growth dropped back off to 98 million cubic feet. Between 1986 and 1992, hardwood growth averaged 23 million cubic feet, because of the high mortality associated with Hugo.

Because so much of the timber management effort in this Unit has been directed toward pine, the recovery in hardwood growth will be somewhat slower than that for softwood.

Timber Removals

Over the past 25 years, periodic remeasurements of permanent sample

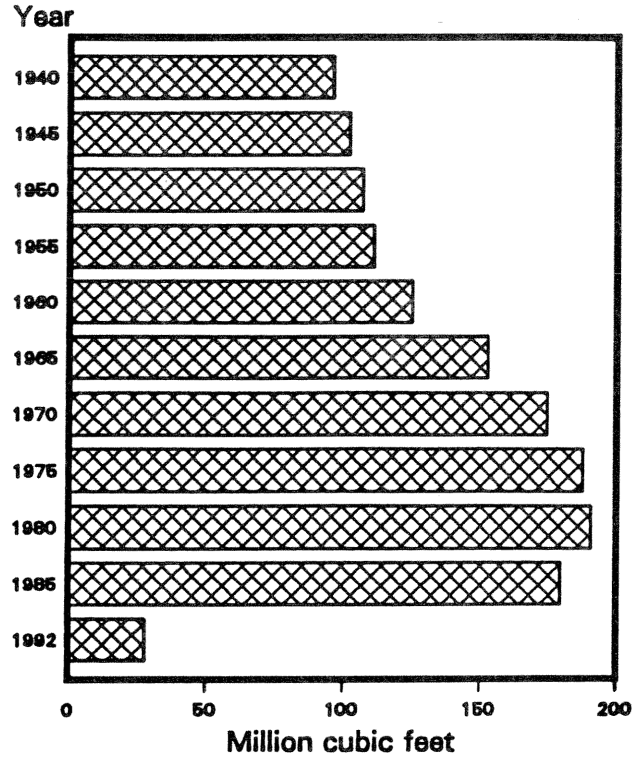

Figure 4--Net annual growth of softwood growing stock in the northern coastal plain forest survey unit in South Carolina, 1940-1992.

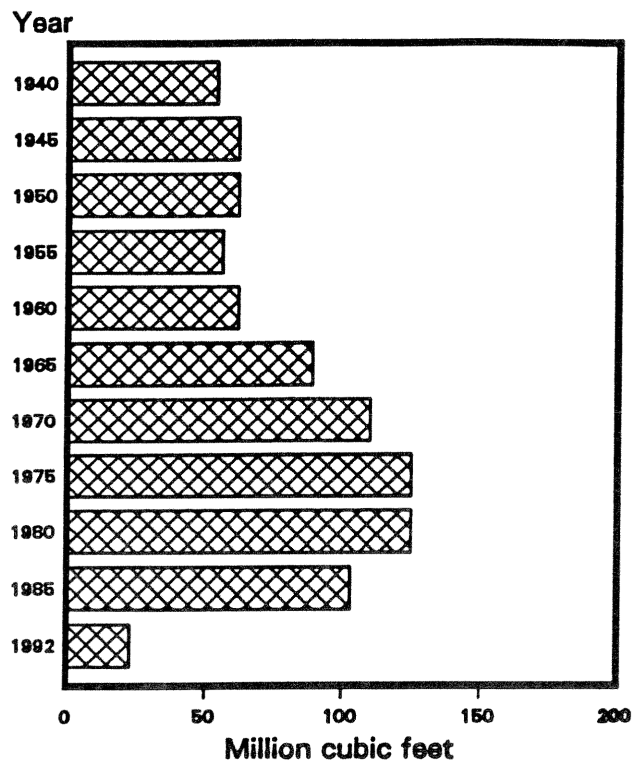

Figure 5--Net annual growth of hardwood growing stock in the northern coastal plain forest survey unit in South Carolina, 1940-1992.

plots have provided consistent and reliable estimates of timber removals. In the earlier surveys, estimates of timber removals were developed from stump counts and measurements. In this analysis, the removal estimates include all man-caused removal of growing stock from the inventory, not just commercial logging.

Figure 6 shows the trend in softwood removals since 1940. Between 1940 and 1960, softwood removals averaged around 95 to 100 million cubic feet per year. Between 1960 and 1986, removals increased to 160 million cubic feet.

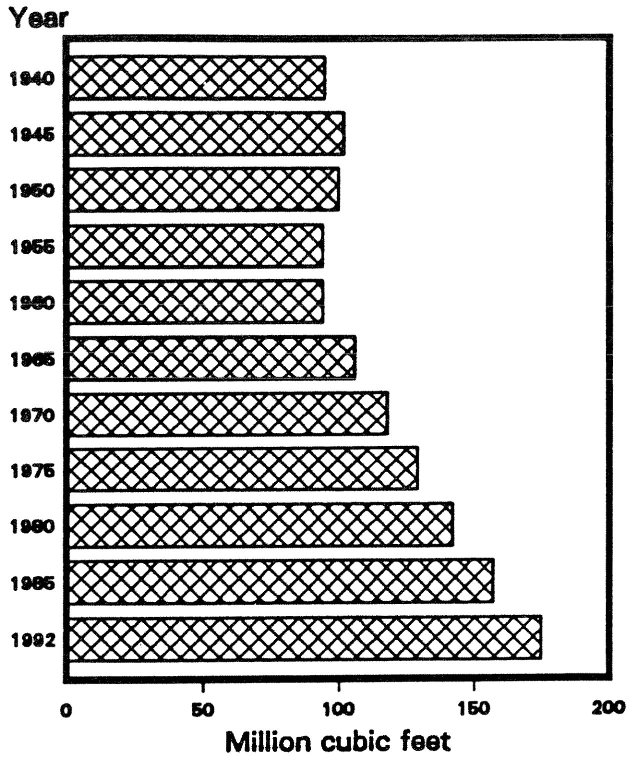

Figure 6--Annual removals of softwood timber in the northern coastal plain forest survey unit in South Carolina, 1940-1992.

Between 1986 and 1992, annual softwood removals averaged 175 million cubic feet. Roughly, 35 percent of the softwood destroyed by Hugo was salvaged over about a 9-month period following the storm. By mid 1990, most of the pine killed by Hugo was no longer merchantable for conventional products.

Now I would like to make clear that the estimate of softwood removals shown in this chart for 1992 excludes the salvage of dead trees. In this survey, the salvage of dead trees was included with the mortality rather than with the removals. Generally, field crews are unable to determine whether a tree was dead or alive when it was cut. Because of the interim survey conducted shortly after the storm, crews were able to make this determination in this latest survey.

If the salvaged dead trees had been included in the removals rather than in the mortality, annual removals of softwood between 1986 and 1992 would have averaged 233 million cubic feet rather than the 175 million shown in this chart.

Timber products output (TPO) data collected from the mills each year provide some insight on how the softwood removals fluctuated during the period. Keep in mind the salvage operations extended over parts of two calendar years, 1989 and 1990. The TPO statistics suggest the high was 195 million cubic feet, reached in 1989. By 1991, softwood output had dropped back to 147 million, which was almost 20 percent below the pre-Hugo level.

Figure 7 shows the trend in hardwood removals since 1940. Between 1945 and

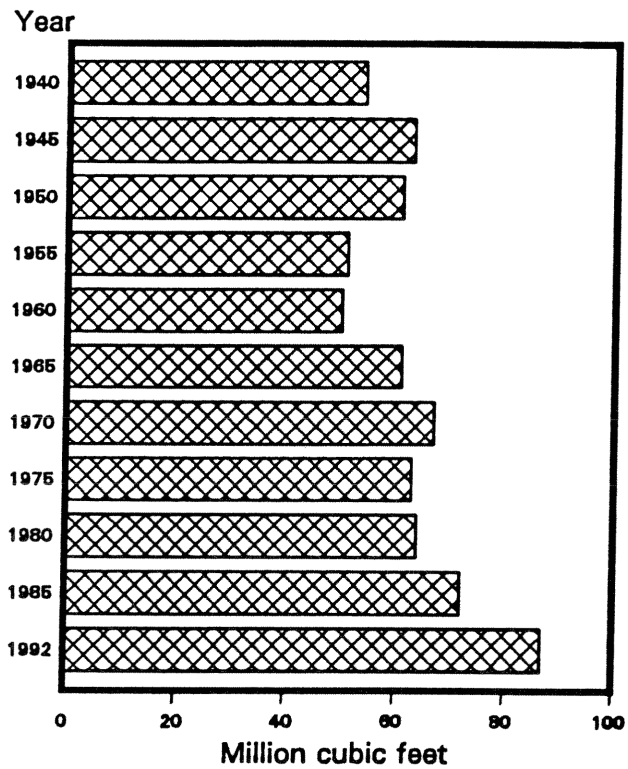

Figure 7--Annual removals of hardwood timber in the northern coastal plain forest survey unit in South Carolina, 1940-1992.

1960, there was about a 20-percent reduction in the average annual removals of hardwoods, down to about 50 million cubic feet. Hardwood removals then increased up to about 64 million cubic feet, a level it maintained between 1965 and 1980. By 1986, annual removals had climbed to 74 million cubic feet.

Between 1986 and 1992, annual hardwood removals averaged 87 million cubic feet. Only an estimated 10 percent of the hardwood destroyed by Hugo was salvaged, although the salvage period was somewhat longer than that for pine.

Again, the estimate of hardwood removals shown in this chart for 1992 excludes the salvage of dead trees. If the salvaged dead trees had been included in the removals rather than in the mortality annual removals of hardwood between 1986 and 1992 would have averaged 94 million cubic feet rather than the 87 million shown in this chart.

The hardwood TPO data are well below the survey removal measure over the period. This kind of difference has been common across the Southeast. Generally, the TPO data exclude a lot of hardwood chipped for export, a lot of hardwood fuelwood, and a lot of hardwood logging residue. The hardwood TPO data confirm there was a low rate of hardwood salvage, but still there was a significant reduction in hardwood output in 1991 compared to the pre-Hugo level.

CURRENT INVENTORY

Now that we have looked at some of the Unit trends, let us look more closely at the current timber inventory. Again, we will look at the recent changes in some of the key distributions.

Pine Growing Stock

Currently, the inventory of pine growing stock totals 2.3 billion cubic feet. Some 57 percent is on NIPF lands, 29 percent is on forest industry holdings, and 14 percent is on public timberland (Table 3).

A net reduction of 27 percent in pine growing stock occurred between 1986 and 1992. The largest reduction was on public land, where the pine inventory was down 40 percent. The largest timber was on public land, and the Francis Marion National Forest took a direct hit from Hugo. The next largest change was on NIPF, where the pine inventory was down 32 percent. There was only a 5-percent reduction on industry land, because so much of the inventory is in small trees in pine plantations.

Again, the storm damage was heavily sensitive to tree size. Only 28 percent of pine growing stock is in trees 16 inches and larger (Table 4). Prior to the storm, 35 percent was in trees 16 inches and larger. Figure 8 shows the percentage changes by d.b.h. between 1986 and 1992. The reductions ranged from 3 percent in the 6-inch class up to 50 percent for trees 22 inches and larger.

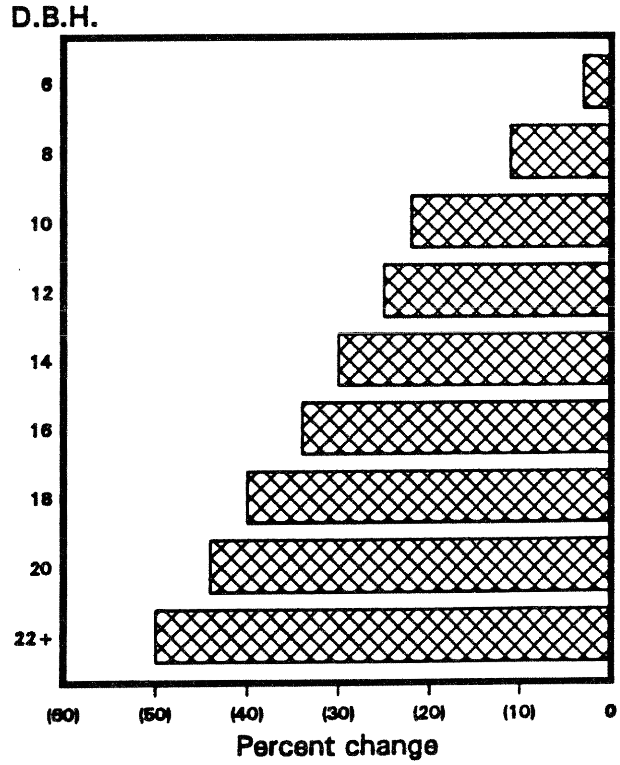

Figure 8--Percent change in pine growing stock in the northern coastal plain forest survey unit in South Carolina, 1986-1992.

Finally, looking at the current distribution of pine by species, loblolly pine accounts for more than 3/4 of the total, longleaf pine 10 percent, slash pine 6 percent; and pond pine accounts for most of the remainder.

Hardwood Growing Stock

Currently, the inventory of hardwood growing stock totals 3.1 billion cubic feet, which is almost 40 percent

Table 3--Merchantable volume of live trees and growing stock on timberland, by ownership class and species group, Northern Coastal Plain of South Carolina, 1992.

Ownership class	Live trees					Growing stock				
	All species	Pine	Other softwood	Soft hardwood	Hard hardwood	All species	Pine	Other softwood	Soft hardwood	Hard hardwood
	Thousand cubic feet									
National forest	260,416	91,791	36,740	99,476	32,409	239,079	91,040	35,114	86,519	26,406
Other public	338,826	221,679	21,337	47,420	48,390	315,866	220,890	21,337	39,290	34,349
Forest industry	1,536,694	636,640	78,825	601,798	219,431	1,426,111	631,334	76,263	531,930	186,584
Forest industry-leased	31,340	20,539	1,417	4,716	4,668	29,913	20,539	1,417	4,352	3,605
Other private	3,969,335	1,304,667	130,104	1,652,244	882,320	3,639,482	1,293,828	123,771	1,468,449	753,434
All ownerships	6,136,611	2,275,316	268,423	2,405,654	1,187,218	5,650,451	2,257,631	257,902	2,130,540	1,004,378

NOTE: From Table 27, page 31 of Sheffield and Thompson, 1992.

Table 4--Merchantable volume of live trees on timberland, by species and diameter class, Northern Coastal Plain of South Carolina, 1992.

Species	All classes	Diameter class (inches at breast height)									
		5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-28.9	29.0 and larger
	Thousand trees										
Softwood											
Longleaf pine	231,271	16,692	32,775	31,960	48,357	43,833	32,283	14,205	10,549	617	---
Slash pine	126,728	17,376	33,979	27,153	23,775	11,868	8,557	3,173	847	---	---
Shortleaf pine	28,510	4,260	3,329	5,258	5,415	3,115	3,159	2,753	---	1,221	---
Loblolly pine	1,754,071	201,761	255,981	272,177	260,017	235,894	190,692	142,673	84,524	102,024	8,328
Pond pind	132,080	10,816	22,903	20,199	27,334	17,457	12,743	12,672	5,514	2,442	---
Spruce pine	2,656	---	360	---	---	524	587	1,185	---	---	---
Baldcypress	204,451	9,344	13,816	17,369	19,869	22,356	20,638	28,803	18,806	46,052	7,398
Pondcypress	55,014	5,404	5,490	12,823	9,328	5,244	6,517	3,901	2,582	3,621	104
Cedars	8,958	2,224	3,094	1,064	---	---	---	859	586	1,131	---
Total softwoods	2,543,739	267,877	371,727	388,003	394,095	340,291	275,176	210,224	123,408	157,108	15,830
Hardwood											
Select white oaks	135,365	8,434	16,529	17,868	18,844	21,721	13,155	15,102	6,897	16,085	680
Select red oaks	41,583	3,161	1,524	3,108	3,997	5,087	5,918	2,961	4,190	7,236	4,401
Other white oaks	100,888	8,862	13,427	9,499	13,484	12,500	7,758	5,103	4,483	16,820	8,952
Other red oaks	593,263	72,567	77,322	87,347	74,252	59,335	46,933	40,467	39,388	67,419	28,233
Hickory	96,036	7,889	15,656	12,192	13,145	14,492	8,921	5,121	6,246	9,993	2,381
Hard maple	726	386	---	340	---	---	---	---	---	---	---
Soft maple	392,103	64,593	70,310	53,333	58,652	48,788	28,561	27,523	17,904	16,442	5,997
Beech	4,279	210	31	555	---	931	461	543	---	1,310	238
Sweetgum	700,737	74,129	101,225	109,915	92,620	96,218	74,347	48,284	31,449	59,586	12,964
Tupelo and blackgum	997,499	74,702	107,128	136,931	135,610	185,548	128,092	86,965	67,296	66,892	8,335
Ash	117,287	10,411	14,809	18,612	15,803	18,685	13,980	8,262	4,289	10,034	2,402
Cottonwood	21,997	663	2,263	1,613	4,047	3,578	1,943	1,920	528	1,327	4,115
Basswood	285	---	285	---	---	---	---	---	---	---	---
Yellow-poplar	160,978	7,632	10,354	16,589	13,958	21,368	24,452	16,822	19,370	27,969	2,464
Bay and magnolia	25,194	10,015	5,882	3,877	2,182	399	1,617	1,222	---	---	---
Black cherry	9,404	3,887	2,064	901	736	986	532	298	---	---	---
Black walnut	3,576	---	311	460	453	451	---	897	---	1,004	---
Sycamore	10,352	666	529	419	1,665	---	1,077	954	1,170	3,543	329
Elm	53,734	7,558	8,815	6,058	8,248	7,351	5,666	2,534	3,604	2,547	1,353
Other eastern hardwoods	127,586	38,269	35,211	16,852	13,017	9,334	4,574	2,818	2,158	5,037	316
Total hardwoods	3,592,872	394,084	483,675	496,469	470,713	506,772	367,987	267,796	208,972	313,244	83,160
All species	6,136,611	661,961	855,402	884,472	864,808	847,063	643,163	478,020	332,380	470,352	98,990

NOTE: From Table 34, page 35 of Sheffield and Thompson, 1992.

greater than the inventory of pine. Before the storm, inventory of hardwood exceeded the inventory of pine by only 16 percent. Almost 71 percent is on NIPF, 23 percent is on industry, and only 6 percent is on public holdings.

Hardwood growing stock showed an overall 13 percent reduction between 1986 and 1992. Again, the largest reduction, 19 percent, was on public land. Both NIPF and industry suffered 13-percent reductions.

Table 4 shows the current distribution of hardwood growing stock, by d.b.h. class. The largest amount is in the 14-inch class. More than 35 percent is in trees 16 inches and larger.

Figure 9 shows the percentage change by d.b.h. between 1986 and 1992. As with the pines, the larger trees suffered the greatest reductions. Reductions ranged from 1 percent for 10-inch trees up to 36 percent for trees 22 inches and larger.

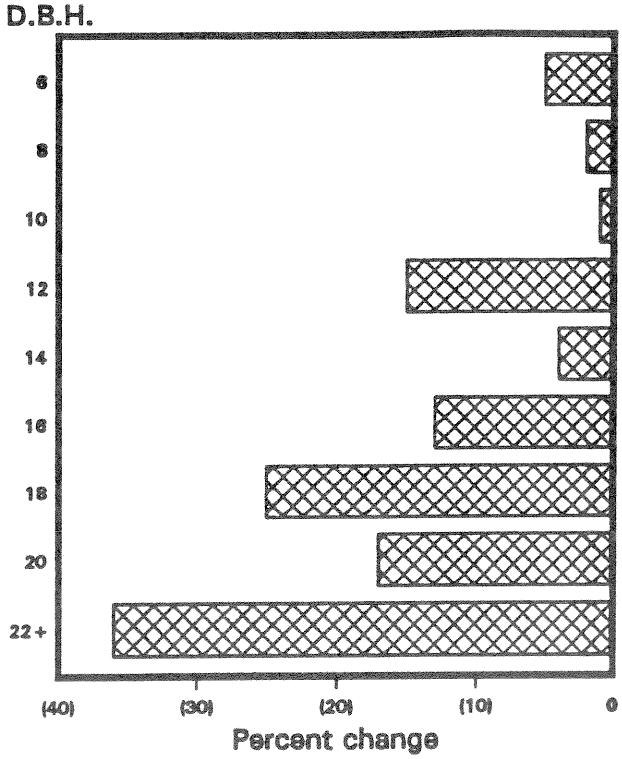

Figure 9--Percent change in hardwood growing stock in the northern coastal plain forest survey unit in South Carolina, 1986-1992.

When considering the current distribution of hardwood by species groups, gums dominate and account for almost 1/2 of the total. Oaks account for 1/4 of the total. Before the storm, oaks accounted for almost 30 percent.

STAND-AGE DISTRIBUTIONS

Distributions of timber stands, by age class, by forest type, probably provide some of the best measures of current and prospective timber supplies in the Unit. Stand-age distributions reflect past rates of harvesting and regeneration, and identify prospective deficiencies in the flow of timber supplies. As you will see, Hugo significantly altered the age distribution.

Pine Stands

Figure 10 shows the age distribution of the 2.5 million acres in pine and oak-pine type as of 1986, divided into planted and natural stands. Keep in mind, this distribution was prior to Hugo. Some 304,000 acres included with these pine stands were so poorly stocked, a manageable stand did not exist. These acres show up in the 0-0-age class. Some of those were recently harvested acres not regenerated.

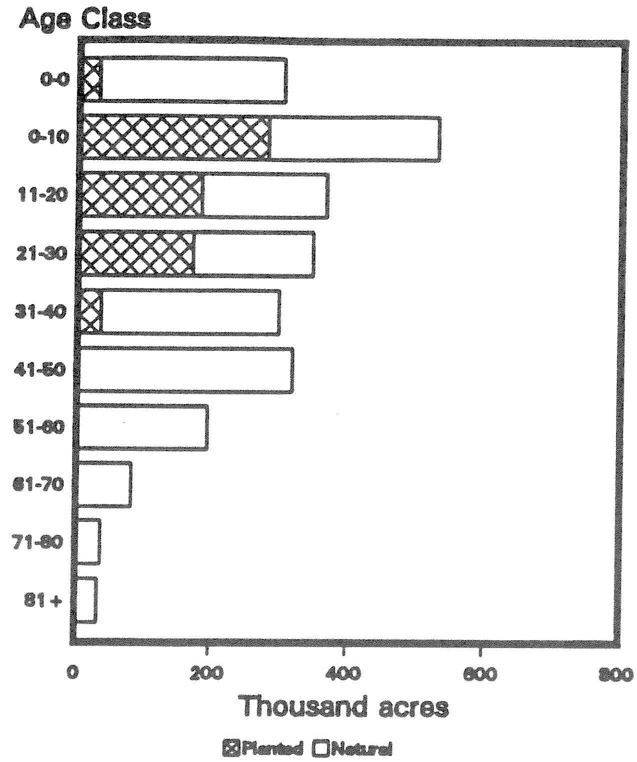

Figure 10--Age distribution of pine stands in the northern coastal plain forest survey unit in South Carolina, by stand type, 1986.

This distribution shows a large concentration of pine stands 10 years and younger, and then a fairly even distribution of age classes up through age 50. About 30 percent of the manageable stands were more than 40 years old, which was slightly above the Southeast average. Most of the 700,000 acres of pine plantations were under 30 years of age.

Figure 11 shows the age distribution of the 2.7 million acres of pine stands in 1992, some 3 years after Hugo. We still have about 290,000 poorly-stocked acres in the 0-0-age class, but the manageable stands are now heavily skewed toward the younger age classes.

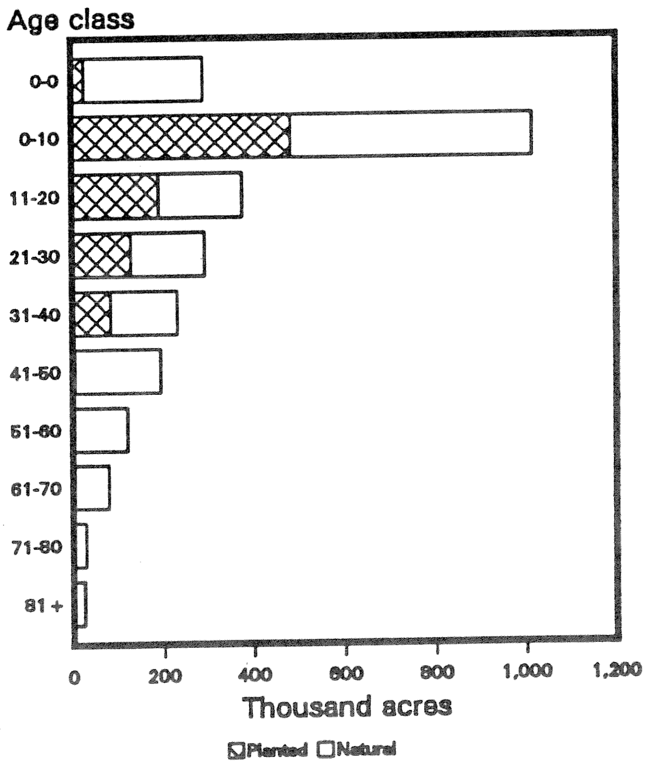

Figure 11--Age distribution of pine stands in the northern coastal plain forest survey unit in South Carolina, by stand type, 1992.

Because of the CRP, other regeneration efforts, and Hugo more than one million acres have accumulated in the 0-10-year age class. There have been significant reductions in stands over 20 years old. Less than 20 percent of the manageable stands are more than 40 years old, which is well below the Southeast average.

As promised earlier, I would like to confirm that many of the pine stands in the youngest age class, 0-10, had already been established prior to the storm. Figure 12 shows breakdowns of pine stands 12 years and younger into 3-year classes as of 1986, and as of 1992. The chart shows 2/3 of the pine stands in the 0-10-year class in 1992 were established between 1983 and 1988, or prior to the storm.

Figure 13 shows the changes in the age distribution of pine stands in this Unit between 1986 and 1992. As you can see, Hurricane Hugo really took a heavy toll out of the 20-to-60-year old stands. Over this 6-year period, these age classes supplied more than 3/4 of the pine harvest.

The current age distributions promise no significant recovery in these age classes over the next 10 years. In fact, it will be at least 20 years before there is any significant recovery in pine stands older than 30 years. In the meantime, mills producing solid-wood pine products are going to be drawing timber supplies from a greatly diminished resource in this Unit.

Hardwood Stands

Figure 14 shows the age distribution of the 2.1 million acres in hardwood type as of 1986. Again, this distribution was prior to Hugo. Some 513,000 acres, or 1/4 of the total, were poorly stocked and show up in the 0-0-age class. This distribution indicates deficiencies in well-stocked hardwood stands between 11 and 40 years of age. These deficiencies can be traced back to low rates of hardwood harvesting and regeneration between 1945 and 1975. About 60 percent of the manageable stands were more than 40 years old.

Figure 14 also shows the age distribution of the 2.1 million acres in hardwood type as of 1992. We now have almost 550,000 acres that are poorly stocked. There was a 45-percent increase in hardwood stands 10 years and younger, and a smaller increase in 11-to-20-year stands. The deficiency in 11-to-40-year stands in 1986 has now extended into the 41-to-50-year class. About 54 percent of the manageable stands are over 40 years old.

Figure 15 shows the changes in the age distribution of hardwood stands between 1986 and 1992.

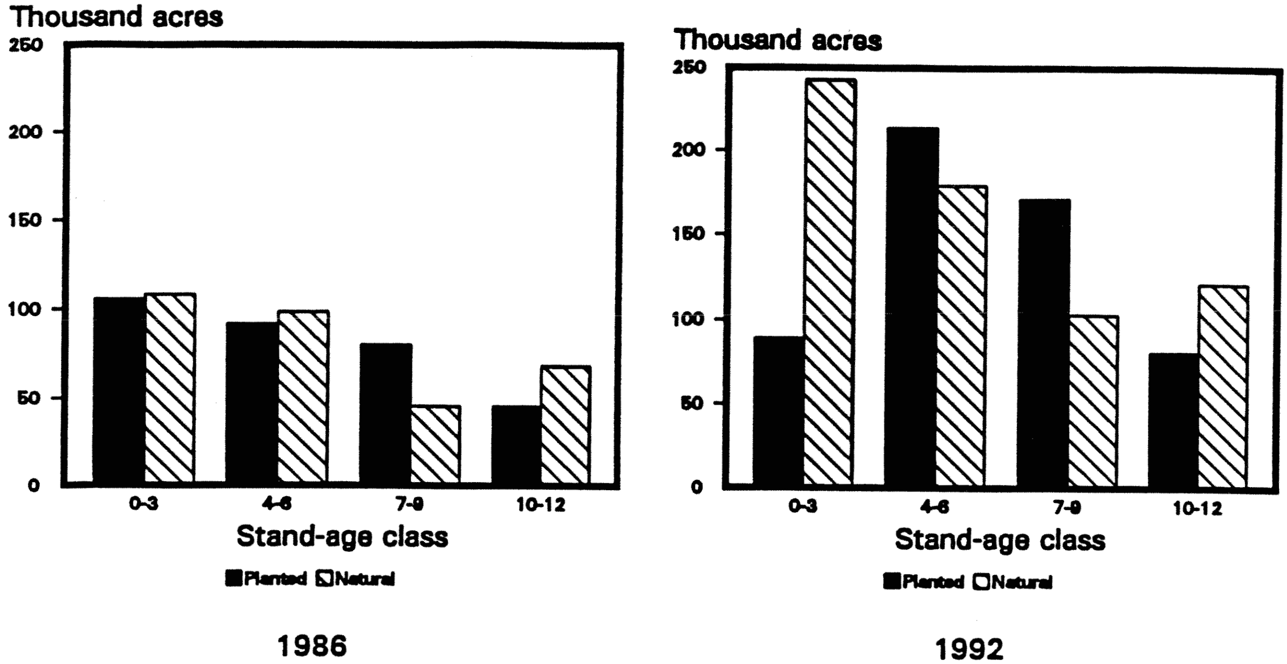

Figure 12--Age distribution of pine stands 12 years of age and younger in the northern coastal plain forest survey unit in South Carolina, by stand type, 1986 and 1992.

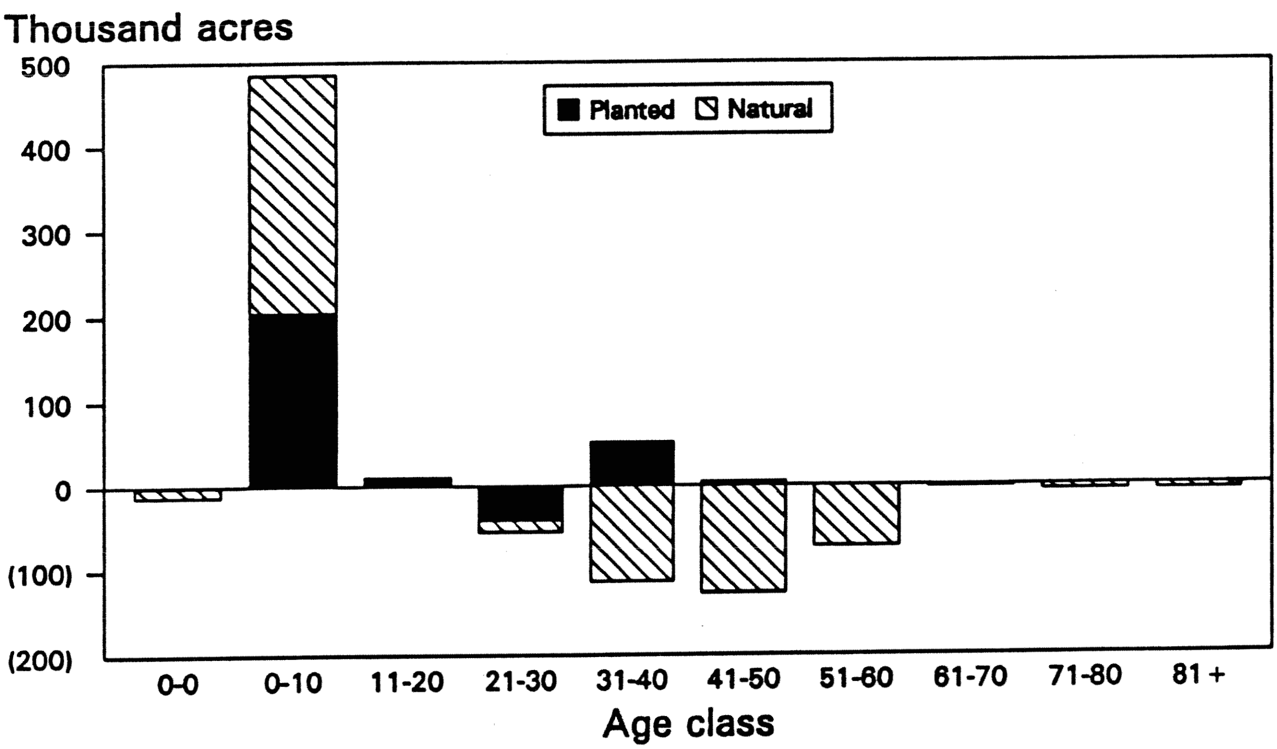

Figure 13--Changes in the age distribution in pine stands in the northern coastal plain forest survey unit in South Carolina, by stand type, from 1986 to 1992.

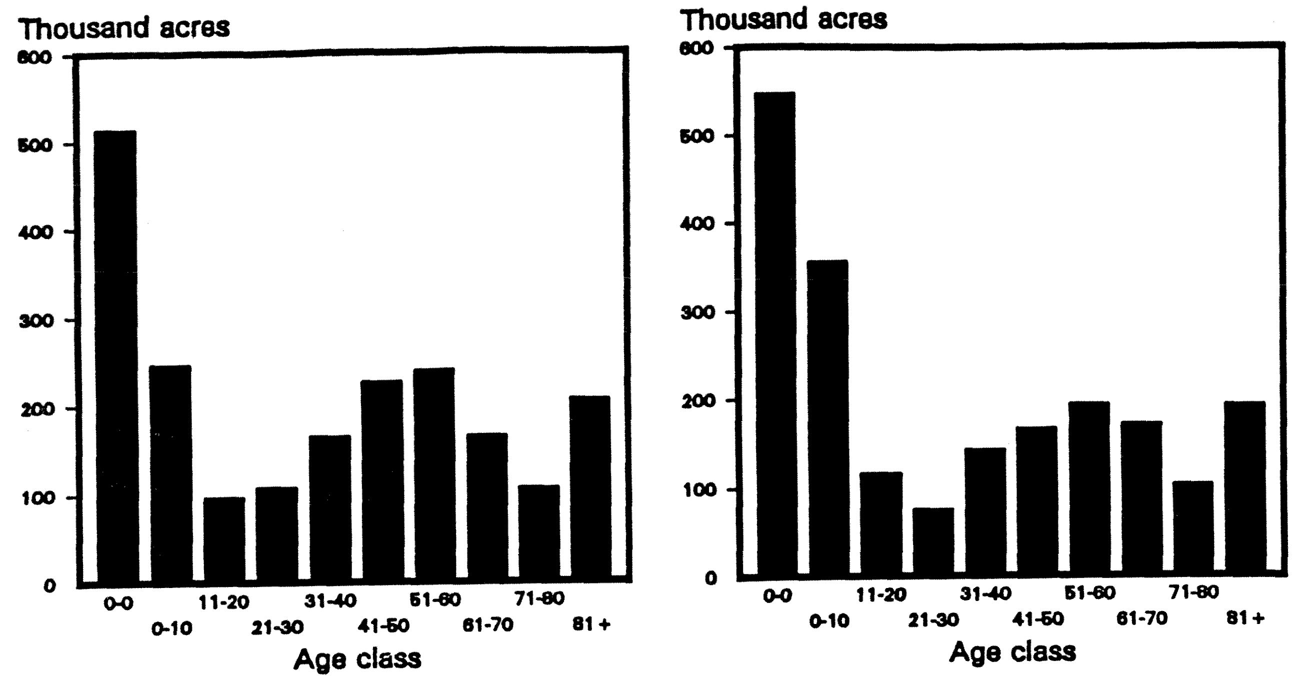

Figure 14--Age distribution of hardwood stands in the northern coastal plain forest survey unit in South Carolina, 1986 and 1992.

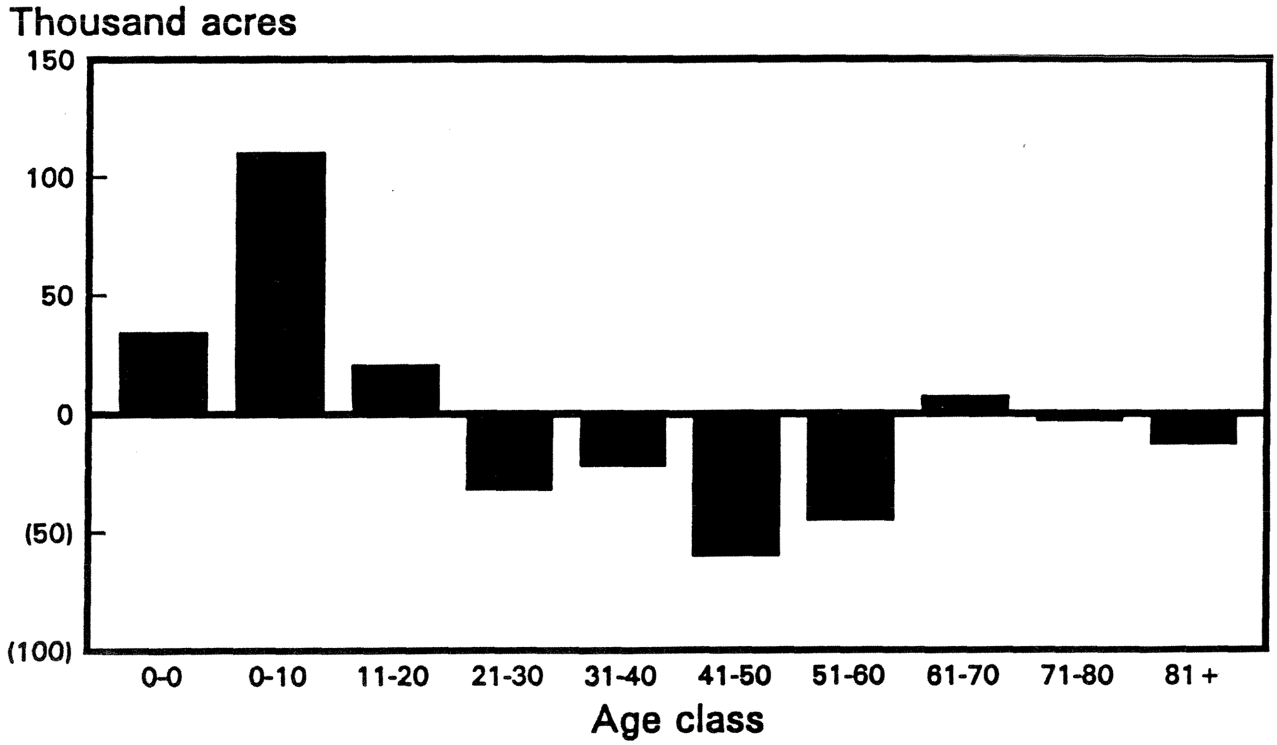

Figure 15--Changes in the age distribution in hardwood stands in the northern coastal plain forest survey unit in South Carolina, from 1986 to 1992.

PROSPECTIVE OUTLOOK

I would like to conclude with a few remarks about the prospective outlook for timber supplies in Unit 2. First, I would like to focus on the outlook for pine, and then look at the prospective hardwood future.

Pine Outlook

I do not envision any serious deficiencies in pine pulpwood supplies in Unit 2. The large concentration of some 1.0 million acres of pine stands 10 years and younger will greatly boost thinning opportunities within the next 10 to 15 years. In the meantime, an additional 1.0 million acres of pine stands over 20 years old, in the current inventory, can supply the recent rates of pine harvest.

The main concern in this Unit, and for the Southeast as a whole, is the prospective outlook for pine sawtimber. Because of uncertainty surrounding prospective supplies of softwood sawtimber in the western US, some resource analysts believe the South will have to supply a greater share of the solid-wood demand in the near future.

While the overall inventory of pine growing stock across the Southeast declined slightly between the 5th and 6th forest surveys, inventory of pine sawtimber showed little change. Increases in North Carolina and Virginia offset small decreases in Florida and Georgia, while the inventory of pine sawtimber in South Carolina remained about the same between 1978 and 1986. Hurricane Hugo alone reduced the inventory of pine sawtimber in the Southeast by 3 percent or more in just a matter of hours.

Unit 2 provides the earliest results from the 7th survey of the forests in the Southeast. As stated earlier, inventory of pine sawtimber is down by 1/3, primarily because of the storm. Unit 2 still contains 1.5 billion cubic feet of pine sawtimber and has great potential for recovery.

In my opinion, it will require at least 40-year rotations of pine stands to replenish the size and quality of pine sawtimber demolished in the storm. Although timber growth potential varies by site, and management objectives vary by ownership, let us assume these 2.7 million acres of pine in Unit 2 are going to be managed on 40-year rotations, on the average. Some will be shorter; others will be longer. This assumed management strategy would call for 66,500 acres to be harvested and regenerated each year.

Between 1978 and 1986, pine stands were harvested in Unit 2 at an average rate of 67,900 acres per year (Figure 16). Between 1986 and 1992, pine stands were harvested at a rate of 84,200 acres, but this rate was inflated by the Hugo harvest. These recent rates of pine harvest confirm that the assumed cutting rate is a reasonable estimate for supplying recent demand.

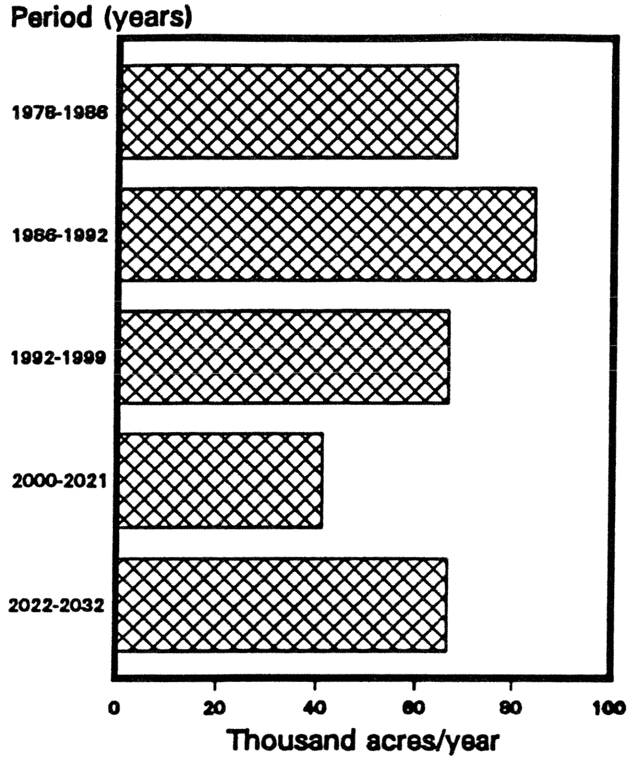

Figure 16--Measured and projected sustainable annual rate of harvest of pine stands in the northern coastal plain forest survey unit in South Carolina, 1978-2032.

At the assumed cutting rate of 66,500 acres per year, Unit 2 had a 7-year supply of pine stands 40 years and older, as of 1992. These remaining older stands would satisfy the harvest assumption out through year 1999. The 1992 age distribution also contained the large concentration of 0-10-year old pine stands that would start to feed into the harvest age in 2022. We have now confined any pine supply deficiencies into a 22-year period between 2000 and 2021.

The 1992 age distribution indicates Unit 2 would only be able to sustain a harvest rate of 41,000 acres per year of 40-year old pine stands over this 22-year period. By shortening the rotation on some 350,000 surplus acres now in the 0-10-year class, the annual harvesting rate could be pushed up to about 57,000 acres.

Without some increase in average yield, these statistics suggest a 15-percent shortfall in pine sawtimber supplies each year over this period between 2000 and 2022. While all of this prospective shortfall cannot be attributed to Hugo, the storm certainly hastened the shortfall's onset and extended its duration.

Because of a backlog of some 300,000 acres of pine regeneration need, the annual rate of pine regeneration over the next 40 years would need to average about 74,000 acres. Figure 17 compares this rate with recent past rates. Between 1978 and 1986, pine regeneration in Unit 2 averaged 64,500 acres per year. Between 1986 and 1992, the average was about 126,000 acres. This latter rate included more than 23,000 acres per year on nonforest.

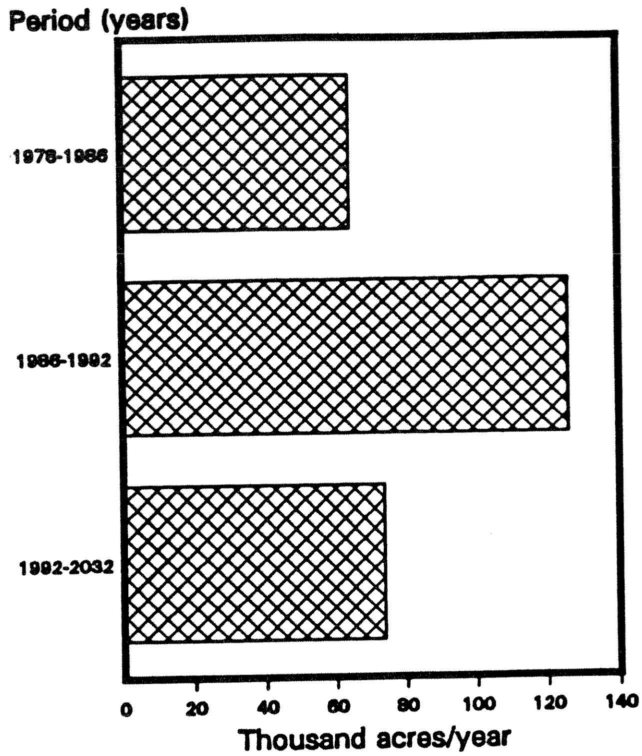

Figure 17--Measured and projected pine regeneration rates in the northern coastal plain forest survey unit in South Carolina, 1978-2032.

Hardwood Outlook

Finally, let us try and assess the prospective outlook for hardwood timber supplies. While the Southeast is often perceived as primarily a pine timber region, hardwoods account for 57 percent of the growing stock across the 5-State Region. Here in Unit 2, hardwoods account for 55 percent of total growing stock.

After several decades of custodial management, low usage, and increasing inventories of hardwood timber across the Southeast, recent forest surveys are measuring some significant changes in this resource. Between the 5th and 6th surveys inventory of hardwood growing stock in the Southeast increased about 6 percent, which was a significant slowdown from the earlier trend. Most all of this recent increase was in large trees. Inventory of hardwood pulpwood actually declined about 5 percent. Indications are that the longtime buildup in hardwood inventory in the Southeast is coming to an end.

Between the 5th and 6th surveys, annual cut of hardwoods increased about 30 percent while hardwood growth declined about 12 percent. Much of this recent increase in hardwood cut can be attributed to increased chip production. Much of the recent decline in hardwood growth can be attributed to an aging resource with high mortality.

After several decades of low harvesting and regeneration, there is a deficiency in well-stocked hardwood stands between 10 and 40 years old, and a large accumulation of mediocre hardwood stands 50 years and older. One of the problems with this resource is that many of the older stands are on wet sites, steep slopes, or public holdings and may not be readily available for timber production.

Now, let us focus on the prospective outlook for hardwood supplies from Unit 2. As with the pine, I would like to start with a theoretical management strategy for the 2.1 million acres of hardwood type in the 1992 inventory. Here, I would like to assume an average rotation of 60 years. Again, some will be shorter; others will be longer. This assumed management strategy would call for 34,300 acres to be harvested and regenerated each year (Figure 18).

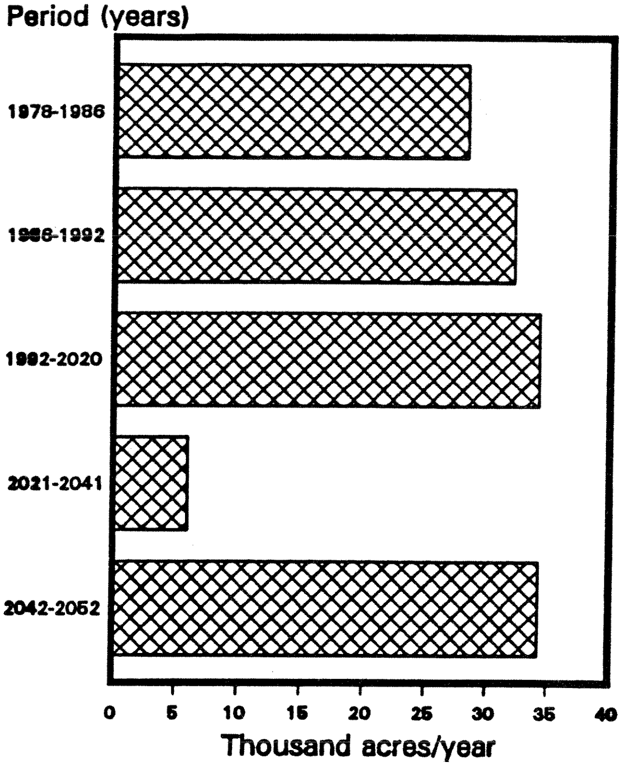

Figure 18--Measured and projected sustainable annual rate of harvest of hardwood stands in the northern coastal plain forest survey unit in South Carolina, 1978-2032.

Between 1978 and 1986, hardwood stands were harvested in Unit 2 at an average rate of 28,300 acres per year. Between 1986 and 1992, hardwood stands were harvested at a rate of 32,200 acres, a rate not significantly inflated by Hugo. Again, the assumed cutting rate of 34,300 seems reasonable and in line with the recent trend.

If all hardwood stands were available, the 1992 age distribution suggests they could supply an annual harvest of 34,300 acres of 60-year and older stands for about 28 years, or through 2020. A fairly large concentration of stands in the 0-10-year class would start to feed the harvest age in 2042. We have now confined any hardwood supply deficiencies into a 21-year period between 2021 and 2041.

The 1992 age distribution indicates Unit 2 would only be able to sustain a harvest rate of 6,000 acres per year of 60-year old hardwood stands over this 21-year period. Without some increase in average yield, a significant reduction in poorly-stocked stands, or shortened rotations, these statistics suggest an 80 percent shortfall in hardwood sawtimber supplies over this 21-year period. Most of this prospec-tive shortfall is attributed to inade-quate hardwood management practices in the past rather than to Hugo.

Because of the backlog of nearly 550,000 acres of hardwood regeneration need, the annual rate of hardwood regeneration over the next 60 years would need to average about 43,500 acres. Figure 19 compares this rate with recent past rates. Between 1978 and 1986, hardwood regeneration in Unit 2 averaged 28,800 acres. Between 1986 and 1992, the average was 50,400 acres.

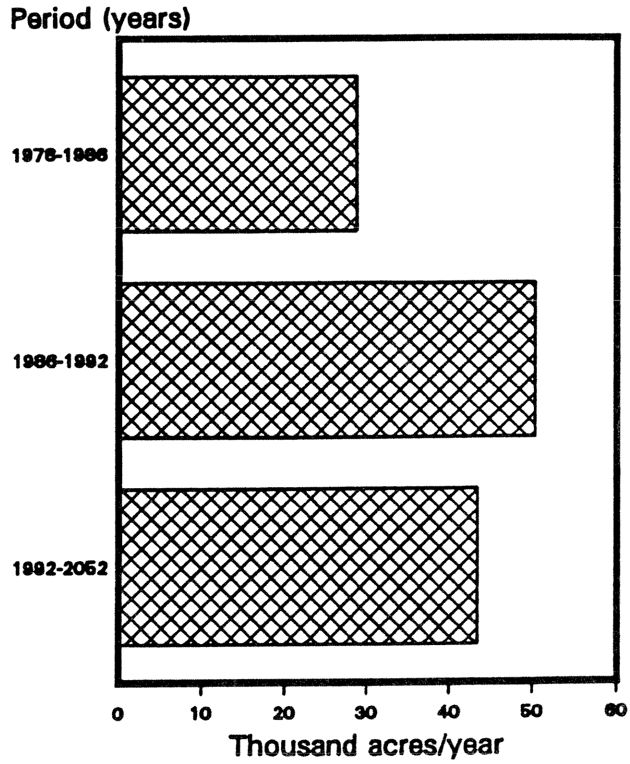

Figure 19--Measured and projected hardwood regeneration rates in the northern coastal plain forest survey unit in South Carolina, 1978-2032.

In this hardwood analysis, we did not discount the gross hardwood acreage because of adverse sites nor public ownership. If we exclude the wet sites and public holdings, the prospective deficiency could occur as early as 2012.

The conclusion is that the prospective deficiency in hardwood sawtimber, while further out in the future, will be considerably greater than the prospective deficiency in pine sawtimber supplies. This conclusion is understandable, considering the greater investment made in pine management over the years.

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ASSESSING THE FOREST-BASED RECREATION IMPACTS OF HURRICANE HUGO IN SOUTH CAROLINA

William E. Hammitt, Robert D. Bixler, and Theresa A. Herrick[1]

Abstract--Hurricane Hugo struck the central coast of South Carolina and the immediate inland area with 140 mph winds on the night of 21 September 1989. Over one-third of South Carolina's forest land was devastated. Ten counties suffered extensive or moderate forest resource damage and 13 counties lesser, but significant, levels of forest damage. Forest-based recreation sites and facilities, habitats and settings, and participation opportunities were impacted to various degrees on these same forest/park lands. The purpose of this report was to assess the forest-based recreational impacts in South Carolina of Hurricane Hugo. The impact assessment was limited to the 10-county area most heavily damaged by Hugo. Impacts assessed included the type and extent of damage to the physical (i.e. structures and facilities), biological (i.e. habitat and natural resources), social (i.e. accessibility and visitation), and economic (i.e. fee receipts and revenue) forest recreation resources within the study area. Resource managers and other agency personnel of forested lands within the study area were surveyed by telephone and letter to inventory the impacts and obtain empirical data, when available.

INTRODUCTION

Hurricane Hugo, which swept through South Carolina on September 21, 1989, was the single greatest natural disaster ever to strike the state. Over one-third of South Carolina's forest land was devastated. Ten counties suffered extensive or moderate forest damage and thirteen counties lesser, but significant, levels of forest damage. Loss or damage of timber was estimated to have affected 4.5 million acres of timberland and 2.5 billion cubic feet of timber valued at $1.2 billion (Smith and Smith 1989). The Francis Marion National Forest, a 250,000-acre multiple-use resource with abundant wildlife recreation opportunities, hiking trails, and camping areas, was heavily impacted by Hugo. An estimated 70 percent of the trees above 10 inches DBH were blown down or broken off in the forest.

Associated with severe timber impacts of Hurricane Hugo were other multiple-use forest resource impacts, particularly forest-based recreation. Hunting, hiking, camping, and picnicking often depend on a natural, forested setting for a quality recreation experience. The 1985 South Carolina Statewide Comprehensive Outdoor Recreation Plan indicates that 16.3, 15.1, 14.9, and 65.2 percent of residents participate in the four activities, respectively. Among state park visitors interviewed in the 1985 study, the majority reported staying in public campgrounds (85.6 percent). Several of

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the state parks and their facilities were damaged by Hugo. The same is true for the Francis Marion National Forest and other agency areas. Forest interpretive programs on Hugo's effects, as well as rehabilitation of forest trails, campground, and other recreational facilities occurred after the hurricane on the Francis Marion. However, the full extent and type of impacts to forest-based recreation resources of all agencies is not well understood.

While the general impacts of Hugo affected many resources and uses of South Carolina's forests, the direct impacts are no more obvious and visible to the general public than during on-site recreation visits to these forests. Therefore, the full range of Hugo's impact on forest resources can not be evaluated without also understanding the forest recreation impacts of Hugo.

Purpose

The primary purpose of this research was to assess the forest-based recreational impacts in South Carolina of Hurricane Hugo. The assessment focused on recreational settings, facilities, and opportunities directly dependent upon forest environments for their existence. Impact assessments included type and extent of damage to the physical (i.e. structures), biological (i.e. resource setting), social (i.e. activity participation) and economic (i.e. fee receipts) forest recreation resources for the 10-county study area most affected by Hugo. Specific objectives addressed in the paper include: (1) the type and extent of damage caused by Hurricane Hugo to forest-based recreational facilities, structures, habitat settings, and access routes; (2) the influence of Hugo on forest-based recreation activity participation, visitation, and fee receipts in special use areas; and (3) the influence of Hugo on the natural characteristics and quality of forest recreation opportunity settings.

METHODS

Study Area

The impact assessment was limited to the 10 South Carolina counties that suffered the most extensive or moderate levels of forest damage (Figure 1). The specific counties were Charleston, Berkeley, Dorchester, Williamsburg, Clarendon, Sumter, Lee, Darlington, Florence, and Georgetown. Within these counties, forest-based recreation agencies (both public and private) were surveyed for Hugo related impacts.

Data Sources

Secondary data provided by forest-based recreation agency personnel served as the major source of impact data. An inventory of the type of recreational impacts and their extent was generated from the secondary data collected. This inventory included physical impacts to structures and facilities, biological impacts to recreational habitats and settings, social impacts on activity participation and visitation, and economic impacts on fee receipts to parks and special use areas (i.e campgrounds). Visitation records and fee receipts were obtained from agencies, when available.

The influence of Hugo on the natural characteristics and related quality of forest recreation opportunity settings was determined by asking recreation resource managers to estimate the degree of disturbances to various natural settings.

Data Collection Procedure

An initial list was compiled for forest-based recreation resources in the 10-county study area by first examining a South Carolina state map and identifying agencies managing forest-based recreation resources within the identified area. These agencies were then contacted by telephone to determine who was responsible for compiling statistics on Hurricane Hugo damage. In some of the agencies one individual was the main contact. In others several agency employees were responsible for tracking hurricane damage. Some statistics were reported through telephone conversations. Other agencies wanted a written letter of request for information with background information about the purpose and objectives of the study. All agencies contacted were asked to supply information in the following categories: (1) attendance and use figures for the site 12 months prior to Hurricane Hugo and 12 months after Hurricane Hugo; (2) descriptions and monetary value of damage to recreational structures, roads and trails used by visitors; (3) percentage of tree cover lost on the forest-based recreation resource due to the hurricane, including total acres of forest cover and percent type of forest

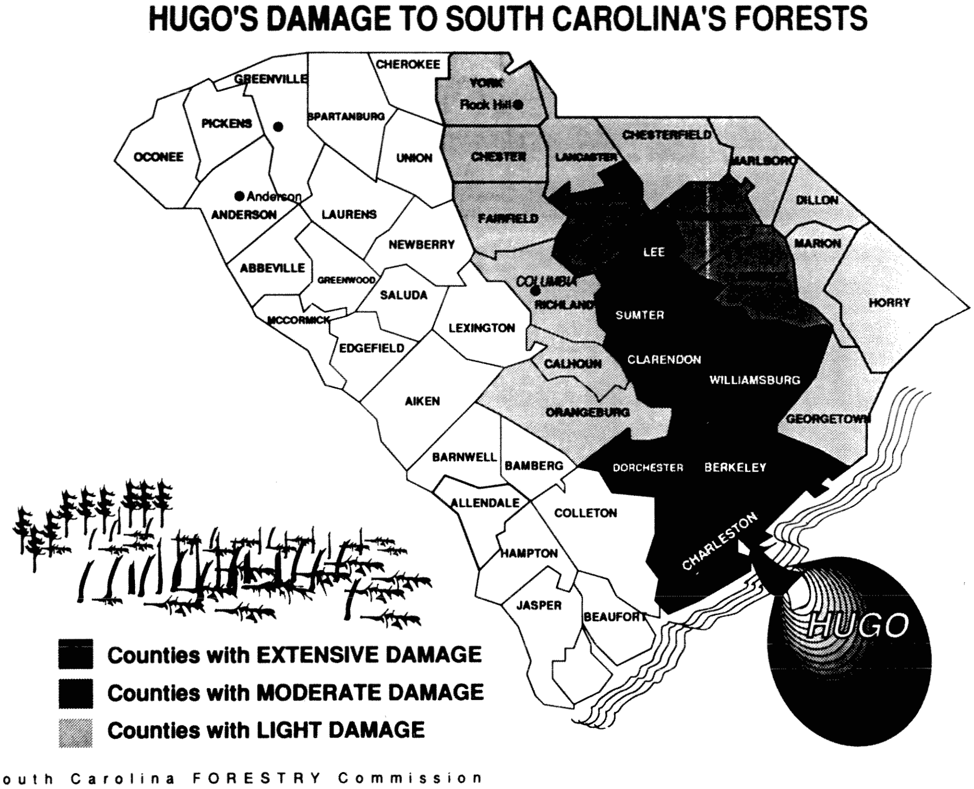

Figure 1--Distribution of the counties of South Carolina with forests damaged by Hurricane Hugo, 1989. Source: South Carolina Forestry Commission.

cover lost; (4) changes in wildlife species due to the storm, as well as any significant changes in habitat; and (5) some comments about how long the site was inaccessible to visitors because of the hurricane and steps taken to ameliorate the damage.

Several commercial timber companies that lease land for hunting in the 10-county study area were also contacted. A list of these timber companies and the individuals who supervise hunting leases was provided by the South Carolina Forestry Association. Other agencies contacted because of their ownership or management of forest-based recreation resources in the study area included: Francis Beidler Forest (Audubon Society) and the South Carolina Public Service Authority which leases recreation resources along the lake fronts in the 10-county study area. Again, information about damage from Hurricane Hugo was pro-vided by telephone contact or through written letter of request following the same format as the one used for state and federal agencies. In total, 26 agencies and management areas were contacted (Hammitt 1993).

Data Analysis

Because of considerable variation, and even absence in the type, amount, and format of data recorded and provided by the various agencies, a comparative analysis among the sources was impossible. Therefore, compilation and descriptive analysis of the impact data furnished by agencies was the main means of analysis. The data was analyzed and is reported by the four impact categories of physical, biological, social, and economic impacts for the major different types of agencies and land units contacted.

RESULTS AND DISCUSSION

Results indicated that damage to physical structures and facilities were extensive for the Francis Marion National Forest, State Parks and National Wildlife Refuges. Damage assessments to Forest Service developed sites by Hugo totaled $920,000. All developed recreation sites received some damage, all trails were blocked by down timber, wilderness area signs and boundary markings were damaged and needed re-establishment, and several archeological sites were damaged (Table 1). Total damage was estimated at $2,676,000. State Park facilities at the major parks in the study area suffered structural and debris removal damages totaling $390,276. Damage was greatest at Givhans Ferry and Poinsett parks (Table 2). Cape Romain National Wildlife Refuge experienced the most physical impact, where the visitor center and support office buildings were destroyed (estimated at $2,100,000 to rebuild), nature trails and bridges extensively damaged ($20,000+), and water-retaining dikes required repair ($650,000). Industrial Forest Lands and State Forests contained few to no recreation structures, except for some structures constructed and maintained by hunting clubs.

Biological impacts were extensive to the forest and wildlife resource/habitats that support wildlife recreation opportunities. The U.S. Forest Service established that 70 percent of the sawtimber was down or broken by Hugo, and some State Wildlife Management Areas lost up to 80 percent of the forest cover. The interior of Bulls Island (US Fish & Wildlife Service) was closed for 1.5 years after Hugo. Biological impacts to fish/wildlife habitat and species reduced fishing and hunting opportunities for recreationists. All hunting was canceled at Cape Romain for the 1989 fall season. Rail hunting re-opened for the fall of 1990 and a limited deer hunt was planned for 1991. Freshwater fishing at Cape Romain had not re-opened by fall 1991, but saltwater fishing was not affected. At Santee Refuge, deer, squirrel, dove, raccoon, and opossum hunting was canceled in 1989. However, the post-Hugo 1990 deer harvest on Santee was one of the best, showing a 95 percent increase over the number of deer taken during the last hunts held pre-Hugo in 1988. The U.S. Fish & Wildlife Service reported that "the cancellation of the 1989 hunts had a definite impact on the Santee Refuge's deer population" (U.S.D.I. 1990:34). Several of the State Wildlife Management Areas also reported positive impact related to Hugo, with increases in certain types of habitats and species after Hugo. The Francis Beidler National Audubon Forest also reported mixed results from Hugo, with some songbirds more abundant after Hugo, and an increase in open pond habitat for alligator viewing by the public.

Lack of accessibility and damage to physical facilities impacted the

Table 1--Damage Assessment Report for Structure and Facility Impacts Related to Hurricane Hugo on the Francis Marion National Forest.

		Initial Estimate	Actual Estimate
1.	Developed Sites		
	Buck Hall Campground	$ 135,000	$ 450,000
	Huger Campground	50,000	70,000
	Canal Day Use Area	32,000	60,000
	Tarpit Day Use Area	35,000	Eliminated
	Guilliard Lake Campground	5,000	5,000
	Boggy Head Rifle Range	4,000	4,000
	Honey Hill Hunt Camp	11,000	11,000
	Elmwood Campground	11,000	11,000
	McDonnell's Landing	3,500	3,500
	Twin Ponds Rifle Range	1,500	1,500
	Half-Way Creek Campground	11,000	11,000
	Wambaw Trail Head	11,000	11,000
	Preconstruction/Construction	80,000	80,000
	Engineering Overhead	60,000	60,000
	Recreation Planning	N.D.[a]	60,000
	Total Developed Sites	$ 450,000	$ 920,000
2.	Trails (Clearing, Trailheads, Signing, and Blazing)		
	Swamp Fox Trail	$ 20,000	$ 40,000
	Wambaw Motorcycle Trail	60,000	60,000
	Hellhole Bay Canoe Trail	1,000	3,000
	Wambaw Creek Canoe Trail	4,000	4,000
	Total Trails	$ 85,000	$ 107,000
3.	Wilderness (Re-establish Boundaries and Signing		
	Hellhole Bay	$ 9,000	N.D.
	Wambaw Swamp	13,000	N.D.
	Little Wambaw Swamp	18,000	N.D.
	Wambaw Creek	18,000	N.D.
	Total Wilderness	$ 8,000	$ 215,000
4.	Special Areas		
	Guilliard Lake Scenic Area (Re-establish Boundary Markings)	$ 6,000	$ 6,000
	Sewee Shell Meddon	N.D.	3,000
	Total Special Areas	$ 6,000	$ 9,000
5.	Cultural/Archeological Resources		
	Cultural Resource Inventory	$ 480,000	N.D.
	Cultural Resource Evaluations	150,000	N.D.
	Cultural Resource Treatment	100,000	N.D.
	Total Cultural Resources	$ 730,000	$1,400,000

Table 1 (continued)

		Initial Estimate	Actual Estimate
6.	Landscape and Aesthetic Planning for Timber Salvage Areas		
	Landscape Architect for Six Months	$ 25,000	
	Total Landscape/Aesthetic Planning	$ 25,000	
	Total Cost for Recreation	$1,354,000	$2,676.000

[a] N.D. = No Data

Table 2--Monetary Damage Estimate to State Park Structures and Facilities Within the 10-County, Hurricane Hugo Study Area.[a]

Park	Disaster Survey Report Estimate	Structure/Facility Description
Givhans Ferry	$ 6,300	Picnic area facilities
	38,336	Debris
	391	Damaged building
	11,647	Destroyed building
	344	Damaged building
	390	Damaged building
	2,866	Damaged building
	2,374	Damaged building
	10,530	Destroyed building
	---	Damaged building
	---	Campsite
	---	Chainlink fence
	---	Climbing facilities
Hampton Plantation	$ 38,129	Debris
	2,095	Damaged building
	306	Damaged well pump
	420	Picnic tables
	733	Damaged building
Lee	$ 34,145	Debris
Lynches River	$ 9,506	Debris
	900	Parking lot lights
Old Dorchester	$ 800	Interpretive kiosk
	763	Picnic area/facilities
	32,283	Debris
Poinsett	$ ---	Electrical distribution lines
	---	Recreation equipment
	117,727	Debris
	829	Damaged building
	250	Water heater equipment
	3,111	Building contents equipment
	231	Damaged building
	283	Damaged shed
	8,157	Table and shelter
	827	Chainlink fence
	748	Chainlink fence
	16,939	Electrical distribution lines
Woods Bay	$ 16,198	Debris
TOTAL	$ 390,726	

[a] Source: South Carolina State Park Disaster Survey Report

activity participation and visitation on the Francis Marion National Forest after Hugo. However, the Forest Service reported that pre-Hugo and post-Hugo visitor use figures are only estimates, not based on sound data, since most of their effort and funds were devoted to keeping up facilities and not toward recording recreational use. Reports of "Recreation Visitor Days" (RVD) of use prior-to and after Hugo reveal an estimated decrease in total use of 73,000 RVD or -60 percent (Table 3). Recreational use decreased for all the activities, except sight-seeing (view South Carolina) and tours. In terms of decreased use, camping (-91 percent), picnicking (-89 percent), and hiking (-87 percent) were the forest-based activities showing some of the largest decreases in post-Hugo participation.

Although Hurricane Hugo hit the State Parks after the busy use season and the park system had the off-season period to repair facilities before the spring use season of 1990, there was still a 49.8 percent decrease in attendance between FY 1988-89 and FY 1989-90 for the 8 study parks (Table 4). The greatest decreases were for Givhans Ferry (-75 percent), Old Dorchester (-72 percent), and N.R. Goodale (-37 percent). All 8 parks registered decreases in visitor attendance between the 2 years. Decreases in visitation were noticeable in every activity group of state park visitors: picnickers (-59 percent), cabin users (-45.5 percent), fishermen (-38.4 percent), campers (-36.2 percent), and swimmers (-16.7 percent).

The National Wildlife Refuges reported a drop in visitation ranging from 23 percent for Cape Romain to 26 percent for Santee. The biggest decreases took place during the 4 months directly after the September 1989 hurricane. State Wildlife Management Areas and Industrial Forest Lands did not have accurate, or any records, of visitor use.

Economic impacts related to reduced recreational revenues and fee receipts were greatest for State Parks, since they rent cabins, have developed campsites and charge for swimming and other special uses. However, total revenues were reduced only 3.4 percent for the 8 state parks as a result of Hugo (Table 5). The lack of economic impacts at State Parks can be partially explained by the fact that Hugo occurred in the off-use season (September 21) and time was available for repair of damaged facilities before the 1990 heavy use, summer season. Economic impacts related to the physical damage of structures/facilities have already been reported.

CONCLUSIONS

Impacts of Hurricane Hugo on recreational use seemed to be greatest for hunting, particularly since Hugo struck South Carolina at the beginning of the 1989 fall hunting season. Several of the National Wildlife Refuges and State Wildlife Management Areas had to cancel the 1989-1990 hunting season. Most areas were re-opened in 1990, and some showed increased harvests for deer and certain other species. In the case of summer use activities, agencies had enough time between Hugo (21 September 1989) and the following summer use season to repair cabins, campgrounds and other facilities accompanying recreational use. Forest-based recreation impacts would have been greater if the hurricane had occurred during the heavy visitor use, summer season.

The overall impacts (physical, biological, social, and economic) of Hurricane Hugo on forest-based recreation in South Carolina were extensive; as were the impacts to the forest resource that support wildland recreation opportunities. It is important to realize that many forest recreation opportunities are heavily dependent upon forest resources and habitats, and those opportunities will recover only as fast as the forest resource-base recovers. However, some impacts to forest-based recreation were much shorter-term that those to South Carolina's timber resource. While it will take decades for the timber resource to recover to pre-Hugo status, much of the recreation resource, in terms of facilities, settings, and visitation opportunities, had recovered within 2 years after Hugo. Certainly by 1995, little impact related to recreational opportunities will be evident other than habitat damage. Even with habitat, the recreational impacts of Hugo were not all negative. Some forms of wildlife habitat and hunting opportunities were improved as a result of Hugo. Yet, the interior of Bulls Island was so devastated that it probably will never be the same.

Table 3--Recreation Visitor Days (RVD) of Use on the Francis Marion National Forest, Before and After Hurricane Hugo.

Activity	Participation[a] 1989	1990
Camping	27.3	2.5
Picnic	13.5	1.5
Swim	.7	0
Water Ski	.1	0
View South Carolina	5.6	15.0
Auto Travel	19.8	10.0
Motorcycle	10.2	0.5
Nature Study	4.2	1.0
Hiking	7.5	1.0
Horse Riding	2.7	.2
Canoe	.4	.2
Hunting	24.8	15.0
Forest Products	4.2	1.0
Tours	.5	1.0
Interpretation	.5	.1
Total	122.0	49.0

[a] Units are 1,000's of Recreation Visitor Days (RVD). One RVD = 12 hours, thus 1.0 - 12,000 hours.

Table 4--Total Visitation to Forest-Based State Parks in the 10-County, Hurricane Hugo Study Area, for the Fiscal Years of 1987-88, 1988-89, 1989-90 (Fiscal Year July 1 to June 30).[a]

Park	Total Park Visitation FY 1987-88	1988-89	1989-90
Givhans Ferry	78,478	79,828	20,007
Hampton Plantation	7,228	10,910	6,979
Lee	36,596	35,776	29,696
Lynches River	64,167	63,424	46,605
N.R. Goodale	111,746	94,468	59,188
Old Dorchester	127,868	138,040	38,980
Poinsett	60,567	46,687	31,959
Woods Bay	17,752	17,474	10,916
Totals	504,402	486,607	244,330
Annual Difference		-3.5 "pct"	-49.8 "pct"

[a] Urban and historical parks within study area not included in data set.

Table 5--Total Revenue to Forest-Based State Parks in the 10-County, Hurricane Hugo Study Area, for the Fiscal Years of 1987-88, 1988-89, 1989-90

Park	Total Visitor Revenue		
	FY 1987-88	1988-89 (Timber Salvage)	1989-90 (Timber Salvage)
Givhans Ferry	$ 49,137	$ 33,017 (+77,069)	$ 12,103 (+10,286)
Hampton Plantation	8,562	10,737	10,215 (+148)
Lee	19,944	26,231	27,178 (+16,246)
Lynches River	28,913	29,056	35,028
N.R. Goodale	14,919	15,205	17,836 (+122)
Old Dorchester	1,956	2,178	1,444
Poinsett	43,604	49,913	56,935 (+4,423)
Woods Bay	N.D.[a]	N.D.	N.D.
Totals	$167,035	$166,337	$160,729
% Annual Difference		-0.4 "pct"	-3.4 "pct"

[a]N.D. = No Data

The aesthetics of forest environments and sightseeing opportunities/benefits to recreationists will be affected by Hugo for 30 plus years. These impacts are difficult to document empirically, but are known to be important, as sightseeing in natural environments is the dominant outdoor recreational activity in the U.S.

There were obvious limitations to the type and extent of recreation data available from the various agencies managing forest recreation lands. Accurate records of visitor use were particularly lacking and affected our determination of Hugo on activity related, visitation impacts. Better records of total visitor use, and individual activity use, would have been beneficial.

ACKNOWLEDGEMENTS

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IMPACTS OF HURRICANE HUGO ON PRIVATE LANDOWNERS' ATTITUDES AND PERCEPTIONS[1]

S. K. Nodine[2]

Abstract--Nonindustrial private forest (NIPF) landowners from the area in South Carolina hardest hit by Hurricane Hugo were surveyed to examine their responses to the storm's damage and to determine their needs and attitudes toward reestablishing their forest stands. More than 51 percent of the landowners had discussed their damages with a forester, and 62 percent of the landowners tried to salvage timber. Only 19 percent indicated that they had made plans to regenerate their forest by either natural or artificial means. Landowners' expectations for the future of their land were mixed for the first two years, but they became more positive when considering a longer time frame. Landowners offered a wide variety of suggestions to encourage recovery of damaged forest land, including many forms of financial and technical assistance. The importance of cost-share assistance is noted, but direct contacts with landowners by foresters is recommended as essential to achieving post-hurricane reforestation.

INTRODUCTION

The events surrounding Hurricane Hugo provided an open window into the minds of NIPF landowners. This storm brought their worst fears to reality, forced them to face forest management decisions that many had managed to avoid before, and exaggerated their latent tendencies – both those that are positive and those that are negative. By surveying those landowners we have tried to peer through that window to give some direction to post-Hugo assistance programs and to better understand the nature of the enigma we call NIPF landowners.

This project was funded and supported by the South Carolina Forestry Commission as a part of its post-Hugo reforestation education and technical assistance initiative. The Commission had the responsibility for designing and delivering the most effective and useful programs of assistance for landowners. In addition, it is important to understand the factors that influence landowners following disaster situations.

The study consists of two mail surveys. The first was conducted during the summer of 1990, and the second is to be completed in the spring of 1993.

THE FIRST SURVEY

The primary objective of the first survey was to gauge the responses and needs of the affected landowners so that reforestation assistance could be directed most effectively. To understand the implications on long-term forest management decisions and priorities, we also needed to assess any changes in landowners' attitudes. It was important to understand both what landowners were up against as they contemplated possible recovery of their forest land and what the assistance agencies would be up against as they tried to encourage reforestation.

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[1] A paper presented at the 72nd Annual Meeting of the Appalachian Society of American Foresters held at Greenville, S.C., on January 20-22, 1993.
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The survey and its conclusions were built upon two foundation stones. First, a landowner's decisions are part of a decision strategy based upon the interaction of motivations, objectives, and constraints (Kurtz and Lewis 1981). Second, landowners follow different patterns of adopting new ideas (Fraser 1981, Doolittle and Straka 1987, Haymond 1988).

The area studied included 14 counties covering the full range of moderate and severe damage from Hugo. Landowners were sampled at random from tax rolls. A total of 434 landowners who had experienced hurricane damage responded to a mail survey. Questions dealt with the landowners' background in forest management activities, the damage they incurred from the hurricane, their responses to date, and their perceptions as to the future prospects for their forest land's health and its role in their financial futures.

Description of Sampled Landowners

Landowners who were affected by the hurricane were fairly typical of landowners in South Carolina (Nodine 1992). They had a tendency more towards being retired, as well as a slightly stronger connection to farming backgrounds than the statewide average (Marsinko and others 1987). They also tended more to live close to or on their forest land (60 percent compared to 40 percent), although their personal concepts of how close is close enough was somewhat clouded. They were more likely to have acquired their land through inheritance than purchase, and their average size of ownership was slightly larger than the statewide average.

These landowners had slightly more experience than average in past reforestation work, but they were somewhat less experienced in terms of past harvesting. This may have hindered their potential salvage opportunities, but was anticipated to increase their propensity toward reforestation. Typically, they were relatively unfamiliar with various forms of assistance already available to them, with only one-fourth being familiar with cost-share programs and less than 17 percent familiar with various income tax benefits. More than half of the sampled landowners had some previous contact with professional foresters. Consulting foresters had provided information or assistance to the most landowners, followed by state agency foresters and industry foresters.

Landowners' Responses to the Damage

The impact of the damage that each landowner incurred seemed to transcend income, social status, age, and other normally distinctive characteristics which can influence attitudes and actions. The newspaper publisher, the real estate agent, and the low-income farmer were all joined together in a common experience. Their responses eventually have varied based in part on available resources, but the usual patterns have not always been followed. In spite of their varied reactions to common experiences, most landowners were set back both in their financial condition and their confidence. Their general characteristics and tendencies were exaggerated by their experiences.

Most of the sampled landowners had taken some actions to assess the damages they incurred and to make some responses to those damages. Ninety-five percent of the landowners had visited their land, and 51 percent had discussed the damages with a forester. Sixty-two percent tried to salvage damaged timber, and nearly two-thirds of them had completed a salvage harvest. Almost 55 percent of the landowners indicated they would use part of any salvage receipts for reforesting their land. This is a positive sign among those who have recovered some value from their damaged stands, but it leaves many who apparently are not yet ready to reinvest some of those earnings.

Only 19 percent of the landowners had made plans for reforesting their land. Of these landowners nearly 60 percent planned to request cost-share assistance. Of those who indicated no reforestation plans, nearly two-thirds said they want to reforest their land, but barriers such as cost and a lack of information stood in their way. Fewer than one-fourth of these landowners had discussed reforestation with a forester, and nearly 54 percent said they needed more information. Fifty-eight percent said the availability of cost-share assistance might change their plans.

Landowners' Outlook

In general, landowners had become less dependent on their land for income, with less of a focus on growing timber as a main objective. While they had higher than average expectations for income before Hugo, their expectations shifted further into the future or disappeared altogether after the storm. Only a few landowners actually moved their income expectations more toward the present. Similarly, although these landowners indicated a higher-than-average priority for timber production before Hugo, the number with timber as their top land ownership priority dropped by almost one-third after Hugo. Some of those who commented on such a change shifted their priority from timber production to investment, while others were uncertain about their top priority.

Even though landowners anticipated many problems in the recovery of their forest land, there was a general acceptance of the need for reforestation and forest recovery. The majority agreed that reforestation is necessary to restore forest productivity (74 percent) and to improve the environment (62 percent). When asked if they would reforest their land if all financial and technical constraints were removed, 82 percent said yes, 15 percent said no, and 3 percent were unsure.

Generally landowners' expectations for their land within the first two years began on less than a positive note, but they became more positive when looking ahead five years. This seems to reflect a belief in the intrinsic regenerative power of the forest. Only 34 percent of those responding predicted a positive condition for their land in two years, while 58 percent had a positive prediction after five years. At the same time, negative predictions dropped from 20 percent to 16 percent and uncertain responses dropped from 42 percent to 26 percent. Non-qualitative responses dropped from three percent to one percent, and were primarily related to changing land use away from timber production. Most of the shifting attitudes were among those who were uncertain after only two years, but who anticipated more positive conditions after a longer interval after the storm.

Landowners' Needs and Suggestions

When asked what needs to be done to encourage the recovery of damaged forest lands and who should do it, 60 percent of the landowners offered suggestions. Various forms of financial assistance dominated the suggestions, led by cost sharing (40 percent) and tax assistance (16 percent). Eighteen percent suggested technical assistance to landowners, reflecting the sense of landowners that perhaps the tried-and-true management practices of the past might not quite fit the needs of post-Hugo forest stands. All segments of the forestry community were recognized as having certain responsibilities for accomplishing the recovery.

OUR RECOMMENDATIONS

This first survey provided us with a good cross-section of landowners in the affected area. From their actions and responses we can draw several conclusions about the types of reforestation assistance efforts that should yield the greatest results. Landowners expressed concerns about the prospects of their forests providing the same financial returns that they had previously expected, and their confidence in their abilities to manage an effective reforestation program had been shaken. They expressed guarded optimism about the future, but many were unsure as to how a favorable outcome could be achieved. Their reservations, coupled with the long time required for those stands which are reforested to reach maturity, indicate that supplies of timber in this region will be affected for many years. Future market conditions in the area may be positive for forestry investments, but their impact on reforestation decisions is uncertain at this time.

The extent of damage received and a landowner's economic position will have an impact on his or her response to the storm. Neither of these, however, can serve as a reliable predictor of reforestation intentions or accomplishments. Each landowner is responding to Hugo in a very personalized manner, each based on a sometimes complex set of circumstances. Therefore it is necessary to approach each landowner with a personalized and flexible set of incentives and assistance.

Nearly 70 percent of the sampled landowners have conducted some type of natural or artificial reforestation work on their land in the past. Sixty-two percent have conducted some type of thinning or final harvest. This familiarity with two basic forest management activities should provide a good framework for planning recovery regeneration. However, many forest landowners deal with these activities only infrequently, and they tend to become less confident in their own abilities as time passes.

Regarding programs which might be targeted toward landowners, most of the traditional assistance programs have a lower recognition and utilization rate than foresters might expect. This opens the door for several opportunities in providing the most help possible to landowners. Educational programs describing the availability and conditions of reforestation tax incentives may provide significant motivation to many landowners who realize the opportunity for quick deductions for their expenses. Such incentives are available now to all landowners and should be emphasized in any contacts with landowners.

Cost-share programs are very helpful to those landowners who use them, but as shown above many landowners do not know about them. Because of the limited funding which is available for these programs and the uncertainty about future funding, these programs should not be expected to carry the burden of financial assistance to landowners. For those who need the funding to be able to accomplish any work, however, such programs may be vital. And, based on a recent study, those who wait for such funds will not likely suffer financially due to the delay (Nodine 1990).

The fact that two thirds of the landowners have had contact with a forester is very encouraging in planning a reforestation campaign. In a regeneration study, Royer and Kaiser (1985) found "the presence of a professional forester was positively associated with, and likely the reason for, much of the pine management activity both during and following harvesting in the South." Although they report that the optimal time for landowner contacts with foresters is before or during harvest, the main advantage to be gained by early contacts is the opportunity to coordinate harvesting and subsequent reforestation work. The opportunity for such preplanning is obviously precluded by a sudden event such as Hugo, but contacts after the storm can still have significant effects on reforestation plans.

Royer and Kaiser recommended that public foresters might become more effective if their emphasis was shifted from being technical assistants to being facilitators. As such they could serve to promote forest management, discuss factors which affect the landowner's situation and decisions, and encourage contacts with consulting foresters.

Birch (1986) suggested an approach of targeting segments of the NIPF owners who have similar conditions and customizing informational programs to each group. He recommended the use of multi-media contacts which multiply the communication potential of each forester. Examples included the use of articles on forest management in nontraditional publications which are read by forest landowners, correspondence courses, and computerized information systems and decision-making software. Doolittle and Straka (1987) reported that although mass media are the most efficient method for diffusion of awareness information, direct contacts by a forester may be necessary to translate awareness into reforestation actions. They recommend special training for foresters to improve communications with reluctant landowners.

Given the importance of landowner contacts with foresters and the unique circumstances resulting from Hugo, the effective use of public and private foresters cannot be overemphasized. With the support and funding which is available from the federal Dire Emergency Supplemental Appropriations Act, and the broad interest and commitment on the part of all segments of the forestry community, priority should be given to enabling all available foresters to advise and assist landowners in their recovery efforts. Training on both communications skills and technical aspects of post-hurricane reforestation should be undertaken to maximize the impacts of the reforestation efforts.

Not surprisingly, there are significant difficulties to be overcome in the quest for encouraging and implementing the massive reforestation needs of this region. Traditional programs and practices have a place in the response of the forestry community to the damage. Additional resources surely are needed, but simply "more of the same" will not be sufficient. A reallocation of human resources following the suggestions of Royer and Kaiser, with an emphasis on personal contacts between foresters and landowners, is essential to meet the challenge. The destruction of Hurricane Hugo is indelibly marked in the minds and hearts of all landowners who felt its impact, and the repercussions will be present for many years.

THE FOLLOW-UP SURVEY

It has been found that forest landowners' eventual actions do not always exactly correspond to their original intentions (Turner and others 1977). It is also true that there still existed a great deal of uncertainty in the minds of sampled landowners as to how certain reforestation techniques would work out and how financial assistance programs would develop. For these reasons a second survey is currently underway. This survey will revisit those who responded to the first survey to evaluate their ability to accomplish their stated intentions. It will also survey a new random sample of landowners in the area. The objective of these contacts will be to study in greater detail reforestation behavior under the extreme circumstances created by Hurricane Hugo. We will be testing predictions of landowner behavior based on current behavioral research. We will also try to assess the effectiveness of current post-Hugo landowner assistance efforts in encouraging reforestation. In testing the conventional wisdom as to what will explain or predict landowners' reforestation behavior, we will focus on several key factors that can be readily isolated. We will also be working with the U.S. Forest Service and faculty from Duke University's Institute of Policy Sciences and Public Affairs to analyze landowner assistance policy decisions and the effectiveness of various efforts in motivating reforestation.

Specifically, we will be trying to address the following questions:

1. Did wildfire protection help reassure landowners and reduce their anxiety?
2. Did success or failure with salvage harvesting provide support (source of capital, reduced costs, reduced wildfire threat, etc.) for reforestation?
3. Did regeneration inspections provide landowners with guidance and confidence?
4. Did HIP cost sharing provide the necessary capital?
5. Was there any interactive effect from these programs/activities?
6. Can we characterize reforestation tendencies of those who received (and responded to) certain types of assistance, as well as those who did not?
7. Based on the above, were resources allocated in an optimal manner?

We will also try to determine the current constraints that are being faced or perceived by landowners.

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IMPACTS OF HUGO TIMBER DAMAGE ON PRIMARY WOOD MANUFACTURERS IN SOUTH CAROLINA

John H. Syme and Joseph R. Saucier[1]

PREFACE

This report describes a three-part study of the economic impact of Hurricane Hugo on primary wood manufacturers in South Carolina.

Obviously, the State's third largest manufacturing industry--wood products --has been severely damaged by Hugo. This study indicates that there is simply not enough suitable remaining timber to support the industry in its past configuration. Significant changes have already taken place and more will follow.

Operations that cannot compete in the new environment must recognize that their survival depends on changing their business strategies. They must increase their operating margins to be able to pay rising prices for timber, or they must reduce their dependence on scarce forms of timber.

Relatively small firms appear to be hardest hit by Hugo. Unfortunately, these firms typically do not have the resources to make strategic changes to better secure their futures. The results from this project provide a potential opportunity to assist highly vulnerable firms in making the changes that would reduce their dependence on timber raw material that is in short supply.

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EXECUTIVE SUMMARY

To assess impacts of Hurricane Hugo on forestry industry, primary wood-products manufacturers in South Carolina that sustained timber damage were contacted. The storm-damaged area was divided into primary and peripheral regions, and two counties outside the damaged area were selected to serve as a control region. Eighty-three primary manufacturing plants were identified in the three regions. A questionnaire was mailed to each plant, and 83 percent of the firms responded. In addition, 41 plant managers were personally interviewed.

In total, nonpaper wood-products plants reported a considerable drop in timber raw-material consumption since Hugo. They forecasted additional declines in future consumption in the primary region but foresaw slight increases in the peripheral region. Consumption volumes in the control region remained the same as before Hugo, and no changes were predicted for the next 3 years. Timber procurement has become a severe problem for most plants in all three regions. Competition is intense, timber and log prices have risen dramatically, procurement areas have been enlarged resulting in much longer log-hauls, and quality of available timber is lower. The effect of Hugo on timber procurement has extended far beyond the damaged area, as plants reach out farther to satisfy their needs. Most plants expect the situation to worsen in the future.

Major concerns expressed most often by the respondents were increasing competition for timber, higher timber prices, lower available timber quality, inadequate timber supply, reduced

profitability, increasing competition from large corporate firms, and inability to survive in the future. Twenty percent of the 69 respondent plants indicated they had experienced some type of curtailment or closure due to Hugo. Information from both the mail survey and personal interviews showed that three plants have been closed permanently, twelve more appear to have short-term survival problems, and five additional plants have longer-term survival problems. The few plants that have not been seriously impacted by Hugo appear to have strengths that enable them to better cope with major threats.

Based on the information gathered in this project, it appears that there is not enough available timber to meet the projected needs of the primary wood-products manufacturers in the study area. Most of the vulnerable plants are located in small rural communities and are important contributors to their economies. Further curtailment or closure will seriously impact the economies of the rural areas in which the plants are located. Therefore, it is extremely important that appropriate assistance be identified and provided to the threatened plants so they can continue to operate. Preliminary investigations conducted during this study indicate that these firms need several different kinds of assistance in order to become less dependent on timber raw materials that are in short supply or to increase their operating margins to be able to pay higher prices for the raw materials.

INTRODUCTION

On September 22, 1989, Hurricane Hugo struck the South Carolina coast with the full force of 135 mile-per-hour winds. Hugo swept through central South Carolina into North Carolina, creating extensive damage to timber and property, in a swath 50 miles wide. Severe damage to timber occurred in 23 counties. In six of these counties, more than 90 percent of the timberland sustained damage. Estimates placed the total timber destruction at $1.18 billion, with the equivalent of 4 years' harvest of sawtimber destroyed. Large-diameter trees were most prone to hurricane losses.

Forest industry is extremely important to the economy of South Carolina. Timber is the State's leading cash crop, forest products manufacturing is the third largest industry, and forest products make up the largest volume export product. Forest industry is a particularly important economic factor in the counties that sustained the greatest timber destruction. Wood-products manufacturers believe that too much timber was destroyed for the remaining timber resources to sustain the existing level and type of timber-processing industries. Curtailment or closure of a number of harvesting, manufacturing, and related operations is likely. Severe negative effects on the counties' economies will include both direct and indirect loss of jobs and reduced income and tax revenues.

The first objective of the research described here was to accurately assess the impact of Hurricane Hugo on primary timber-processing firms in the affected area. The second objective was to identify establishments whose survival is threatened as a result of Hugo and to suggest strategies for reducing their dependence on local timber resources that are in short supply.

METHOD

Twenty-eight South Carolina counties were selected for the study. These counties were in three regions: (1) 10 **primary** counties (Berkeley, Clarendon, Dorchester, Florence, Georgetown, Kershaw, Lancaster, Lee, Sumter, and Williamsburg) that sustained major Hugo timber damage, (2) 16 **peripheral** counties (Bamberg, Calhoun, Charleston, Chester, Chesterfield, Colleton, Darlington, Dillon, Fairfield, Horry, Lexington, Marion, Marlboro, Orangeburg, Richland, and York) that were adjacent to the primary counties and sustained moderate timber damage, and (3) 2 **control** counties (Allendale and Newberry) that sustained no timber damage (Figure 1). Eighty-three establishments were identified as producers of primary wood products in the study area. Primary wood products are defined as those produced directly from the timber raw material. Examples include pulp chips, pulp & paper, lumber, veneer, plywood, and poles.

The project was divided into three phases. In Phase I, a questionnaire was mailed to the 83 primary wood-processing plants in the study area. In Phase II, personal followup interviews were conducted with selected establishments. In Phase III, firms with serious survival problems were studied, and the resources needed to

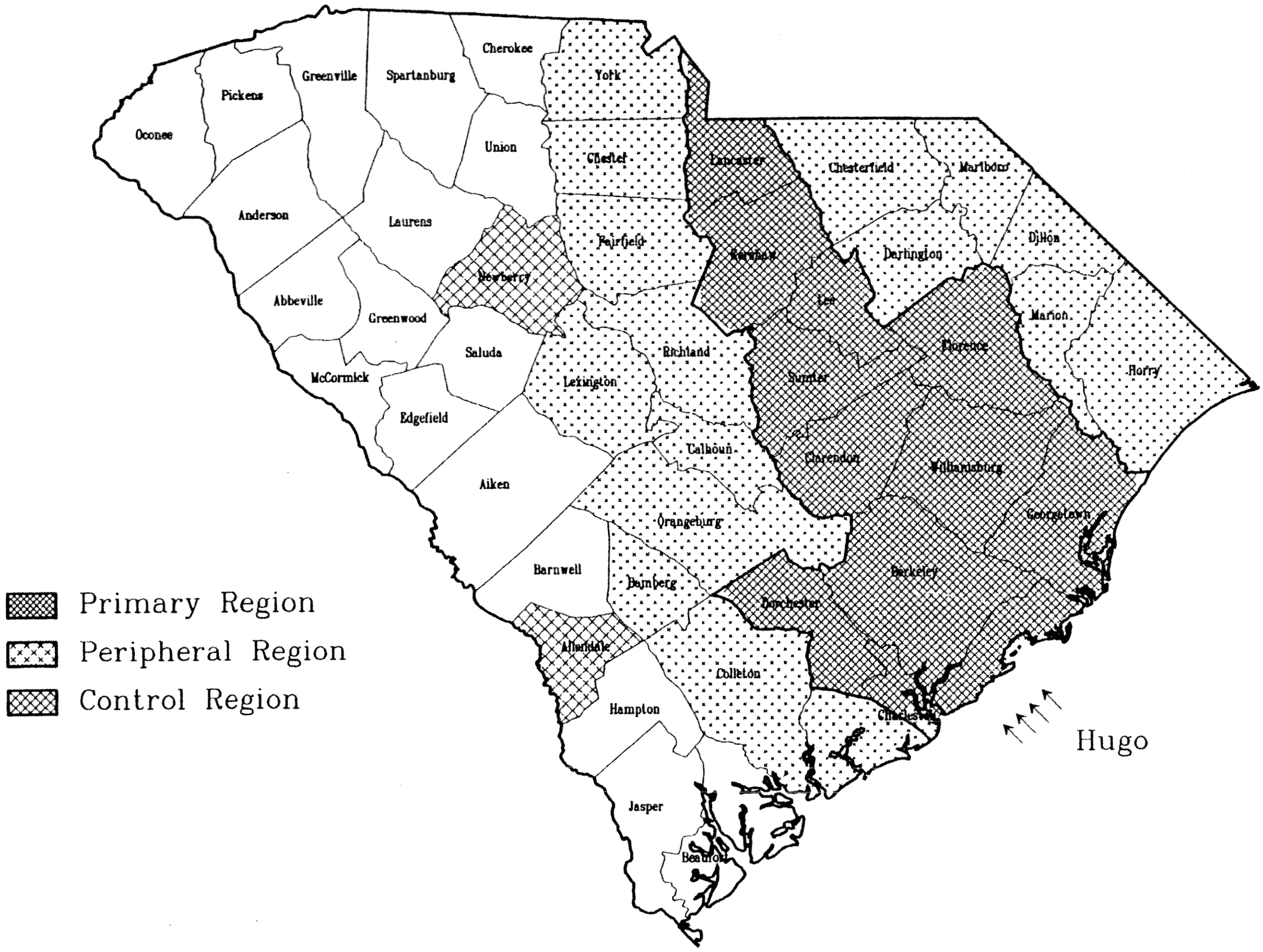

Figure 1--The three study regions.

improve their ability to continue in business were identified.

Phase I: Mailed Questionnaire

The information required from the identified processing establishments was determined. A questionnaire was then developed, pretested, and mailed to each processor in the study area. The questionnaire was designed to gather information about current and long-term changes in processors' operations, resulting from Hugo. In June 1991, a letter sent to each firm explained the purpose of the study, assured confidentiality of replies, and stated the importance of returning the completed questionnaire which they would receive in a few days. Questionnaires were then mailed to the 83 wood-processing plants. Two weeks later, a followup letter was mailed to firms that had not responded. A second letter was mailed 3 weeks after the initial followup letter to the nonrespondents. The information gathered from the questionnaires was analyzed with a computer spreadsheet program.

Phase II: Personal Interview

Personal followup interviews were conducted with 41 of the respondents to the mailed questionnaire. Respondents who indicated an interest in participating in Phase II, or who stated they had serious business problems related to Hugo, were selected for personal interviews. The manager or owner of each firm, along with its timber procurement supervisor, were interviewed at their locations over a 2-month period in early 1992. The interviews focused on major changes and problems in the current situation and in forecasts for the future brought about by Hugo. Three major topics provided guidelines for the interviews:

Major Impact on Timber Raw Material
· Changes in competition
· Prices
· Procurement area
· Quality of available timber

Major Impact on Processing Operations
· Curtailed or closed operations
· Programs to increase efficiency or expand current operations, or
· Programs to diversify or expand into new areas such as secondary manufacturing

Long-Term Major Concerns
· Open-ended question that permitted respondents to name areas of greatest concern about current and future business operations

Responses were recorded and tabulated. The resulting data were analyzed (1) for all operations combined, (2) by size of operation, (3) by type of operation, and (4) by region (primary, peripheral, and control).

Phase III: Identification of Firms With Serious Problems

Firms with serious survival problems resulting from Hugo were initially identified from information in returned questionnaires. The final list of firms was verified from information gathered during the followup interviews. Critical needs of the threatened firms were sought in the personal interviews.

RESULTS

The results from Phases I, II, and III are described in separate sections. Table 1 (Appendix) shows the composition of the respondent plants to the mailed questionnaire and the personal interviews.

Phase I

A total of 69 valid responses to the questionnaire was received. The overall response rate was 83 percent. Responses by region and type of mill were:

	Plants sent questionnaire *Number*	Response rate *Percent*
Region		
Primary	33	79
Peripheral	39	85
Control	11	91
Mill type		
Sawmill	46	78
Plywood/veneer	14	79
Chip mill	8	100
Pole plant	5	80
Paper	6	100
Basket	3	100
Fiberboard	1	100

The data gathered from the questionnaire are presented on a question-by-question basis. In most cases, data from paper mills are separated from data from other mills. Paper mills use larger volumes of wood and procure their wood from a larger geographic area and from a wider variety of sources than do most sawmills and veneer mills. Paper-mill procurement is more regional than local. Separating out paper mills permitted more sensitive analyses for small geographic areas.

For purposes of the study, the nonpaper mills were divided into the following size groups, based on their annual consumption of timber:

Small	Less than 20,000 tons
Medium-small	20,000-79,000 tons
Medium	80,000-200,000 tons
Large	More than 200,000 tons

Raw Materials Used

Question: Please show the annual volumes of timber raw material used by your mill by species and type of timber (veneer logs, saw logs, pole timber, and pulpwood) for the period prior to Hugo, currently, and your projected volumes 3 years from now.

Responses are summarized as follows:

	Changes in total annual volume used	
	1991	1994
	----Percent----	
Nonpaper	-8	-7
Paper	+4	+21

	Changes in annual volume used, by timber type (nonpaper)	
	1991	1994
	---Percent---	
Softwood		
Veneer logs/ saw logs	-5	-6
Pulpwood	-5	-2
Hardwood		
Veneer logs/ saw logs	-13	-3
Pulpwood	-25	-14
Poletimber	-11	-18

The reduction in current usage for nonpaper plants is probably not entirely attributable to Hugo. Market demand for lumber, plywood, and most other wood products was depressed at the time this census was taken, and these data partially reflect the market's influence on timber consumption. The forecast for usage 3 years from now (1994) is probably more representative of Hugo's influence on timber consumption.

Overall, the 7-percent drop in projected 1994 consumption appears to be modest. However, the data show that the decrease is more severe in certain groups. For example, the primary region shows a projected decline of 17 percent, as compared with a small change in the peripheral and control regions. Further, the 38-percent projected decline for small mills is much greater than for larger mills; however, the overall effect is not as significant, due to the comparatively minor volume consumed by the small-mill group. Certain types of mills, such as pole plants and veneer mills, predict a much greater decline in raw-material consumption than do other mill types. Table 2 (Appendix) provides the response data in greater detail.

Sources of Raw Materials

Question: Please list the sources of the timber raw material used by your mill for the period prior to Hugo, currently and your projected sources 3 years from now.

Sources of timber include purchased logs (PL), purchased government stumpage (PGS), purchased private stumpage (PPS), and company timberland (CT). Overall, the responses show (1) an increase in the proportion of raw material from PL, both currently and in the future; (2) a current increase in raw material from CT, followed by a slight reduction in the future; and (3) decreases in the proportion of both PGS and PPS, currently and in the future. The results are summarized in the following tabulation. Tables 3, 4, and 5 (Appendix) provide more detail.

	Raw-material mix			
	PL	PGS	PPS	CT
	------Percent------			
Before Hugo	50	5	39	6
Currently (1991)	56	2	34	8
Future (1994)	54	3	33	5

Changes in the Timber-Procurement Environment

Question: Indicate the degree to which each of the following factors has changed in your operation as a direct result of Hugo.

Change factors listed in the questionnaire related primarily to the availability, quality, cost, and competition for logs and stumpage; the procurement area covered; and the average log-haul distance. Changes in all raw-material-related factors were moderately or highly negative. The greatest reported increase was in competition for timber and logs, followed by cost of stumpage and delivered logs, log-hauling distance, and size of procurement area. Availability and size of timber and logs decreased moderately. This pattern was consistent for each of the groups analyzed (Table 6, Appendix).

Effects on Support Services

Question: Briefly describe any changes, including employment levels, which have taken place in your area related to timber suppliers, logging contractors, and other businesses which supply forest industry support services, as a direct result of Hugo.

Responses to this open-ended question were grouped into the 10 categories shown in Table 7 (Appendix). Sixteen mills did not respond to this question, and 12 mills gave an invalid response. Of the total responses received, the one named the most was "decrease in available loggers," followed by "no change."

Changes in Raw Material Availability

Question: Briefly describe important changes, related to timber raw material availability in your area, which you believe will take place during the next 3 years.

Responses to this open-ended question were grouped into 10 general categories. "Increasing levels of competition" was named most often, followed by "decreasing timber quality," "increasing stumpage costs," "fewer or no timber sales in area," and "additional mill closures." Table 8 (Appendix) shows how responses varied among the groups analyzed.

Effect of Hugo on Business

Question: From an overall viewpoint, how will the above Hugo-related changes affect your business? Short-term? Long-term?

A choice of five responses ranging from "very detrimental" (1) to "very beneficial" (10) was provided separately for the short-term impact (first 3 years) and the long-term impact (5-10 years). In both the short and long term, respondents saw Hugo as being "somewhat detrimental" to their businesses, with an average response value of 3.7.

Changes in Business Operations

Question: How much have you changed, or are you willing to change, your business operations in each of the following areas, as a direct result of Hugo?

Response factors listed in the questionnaire covered major business activities, including raw-material procurement, manufacturing, products, markets, sales programs, closure or curtailment of existing operations, and additions of new operations. In total, respondents indicated that they had made minor to moderate changes for each factor listed. The analysis of the individual groups followed a similar pattern, except for fiberboard and pole plants, which showed major changes in raw material used and in procurement programs. Respondents tended to give the same response for both the operational changes they have made and for the changes they are willing to make. Therefore, only responses related to changes that have already been made are shown in Table 9 (Appendix).

Curtailment and Closure of Operations

Question: Have you closed or curtailed permanently, or expect to close or curtail, any operations as a direct result of Hugo?

Responses to this open-ended question were grouped into nine general categories. They show that there have been some closures and curtailments of operations due to Hugo, but the majority of plants indicated that no change has been made or is contemplated. "No change" was reported by 47 respondents. Closure or curtailment was reported by 15. Of the 15 reports of change, 5 related to closure of part of the operation and 6 to temporary layoffs, temporary reduction in production, or postponement of growth plans. Only one respondent indicated a permanent plant closure. Table 10 (Appendix) provides a detailed listing of the responses.

Interest in Followup Program

Question: As a second phase of this project, we are offering assistance in developing alternative business strategies for companies which are experiencing raw-material-related problems as a result of Hugo. What is your interest in having your company participate in this follow-up program?

In total, only 5 respondents expressed unqualified interest in participating, 33 respondents indicated they were interested in participating but wanted more information. Twenty-five "not interested" responses were received. The response patterns were similar for all groupings. All responses are listed in Table 11 (Appendix).

Phase II

Responses from the personal interviews were separated into three major topics: (1) impact on timber raw-material procurement, (2) impact on operations, and (3) long-term major concerns. Responses were placed in three groups for analysis: (1) region [primary, peripheral, control]; (2) mill size [small (< 20,000 tons/year), medium-small (20,000-79,000 tons/year), medium (80,000-200,000 tons/year), and large (> 200,000 tons/year)]; and (3) mill type [pine sawmill, hardwood sawmill, pole plant, and other]. Table 12 (Appendix) provides a general summary of the results from Phase II.

Major Impact on Timber Raw-Material Procurement

Overall, 34 of the 41 mills indicated that Hugo has had, and will continue to have, a major negative impact on their timber procurement. The remaining seven plants reported that some areas of procurement had been affected, but they were not experiencing an overall major impact. Thirty-eight of the 41 plants indicated they were experiencing increased competition for timber raw material, and they expected increasing competition in the future. Thirty-six plants were impacted by higher stumpage or log prices, 32 plants have expanded their procurement areas, and 31 are experiencing a decline in quality of available material.

The responses revealed little difference between primary, peripheral, and control regions except for the decline in quality of raw material (Table 13, Appendix). A decline in raw-material quality was reported by 4 out of the 9 plants in the control region, 12 out of 13 in the primary region, and 14 out of 19 in the peripheral region.

The responses by mill size (Table 13, Appendix) indicated that the medium category was impacted the most, followed by the medium-small and large categories, with the small category reporting the least impact. Within the medium-size category, the plants in the primary, peripheral, and control regions all showed maximum impact. Within the large category, the impact on the control plants is somewhat less than on those in the primary and peripheral regions. In the medium-small category, plants in the primary region exhibit greater impact than those in the two other regions.

Responses reveal little difference in overall impact among pine sawmills, pole plants, and hardwood sawmills (Table 13, Appendix). Plants in the "other" category, which includes veneer, plywood, and basket plants, reported less impact than those in the three specific categories. Pine sawmills reported greater impact in the primary region than in the peripheral or control regions. There were no pole plants in the control region, but pole plants in the primary region exhibited greater impact than those in the peripheral region. Responses from the hardwood sawmill category indicate that mills in the peripheral region were impacted more severely than those in the primary region; the response from the one mill in the control region indicated severe effect. In the "other" mill-type category, the responses disclosed that mills in the primary region experienced the greatest impact, while those in the control region experienced the least impact.

Major Impact on Operations

Table 14 (Appendix) summarizes the responses related to curtailment and closure of operations, improvements and expansion to increase processing efficiency, and diversifying processing or adding secondary manufacturing. This table gives the percentages of mills that responded affirmatively in each of the above categories.

Ten mills indicated they had curtailed or closed their operations as a result of Hugo. This total included five pine and three hardwood sawmills. Six of the mills were medium-size, two were large, and one was in each of the small and medium classes. Five mills were in the peripheral region, three in the primary, and two in the control region.

Ten mills said they were improving or expanding their current operations to increase production efficiency. This group included nine sawmills (five pine and four hardwood). Four mills were in the medium-small size class, three were medium size, and three were large. Four mills were in the primary region, four in the peripheral, and two in the control region.

Seven mills said they were adding secondary manufacturing or diversifying their operations into products that utilized lower cost or more available timber raw material. Six were sawmills (four pine and two hardwood). Three operations each were in the medium-small and large classes, and one was in the medium class. Four were in the primary region, two were in the control, and one was in the peripheral region.

Major Long-Term Concerns

Overall, the four areas of greatest concern to mill managers include reduced profitability, inadequate timber supply, increasing competition from larger firms, and future survival. Responses in these four areas are given in more detail in Table 15 (Appendix).

Of 41 managers interviewed, 24 indicated that reduced profitability was their major concern and that this concern was primarily related to Increasing timber raw-material costs. Twenty believe the existing timber resource is not adequate to provide for current demand. Thirteen plants considered increasing competition from large, integrated corporate firms to be a major concern. Twelve plants were concerned about their ability to continue in business at their current locations.

Nine plants considered environmental constraints, such as those associated with wetlands, to be a major area of concern. Hardwood plants (four sawmills, two veneer plants) provided six responses; the remainder came from two pole plants and one pine sawmill. Nine plants (seven hardwood sawmills and two hardwood veneer plants) are deeply concerned about the increased demand for hardwood pulpwood by paper firms. They specifically mentioned chipping saw logs and clearcutting young, vigorous hardwood stands as problems. Seven plants named their ability to obtain low-cost financing as being critical to survival. Five were pine sawmills, one was a hardwood sawmill, and one was classed as "other." Four hardwood sawmills were concerned about their inability to profitably process sweetgum and other less-desirable hardwoods because of poor market demand for products made from these species.

Combined Responses Related to Major Impacts and Concerns

Responses related to the nine concerns most frequently mentioned in personal interviews were combined to estimate effects of mill size, mill type, and location on Hugo impacts. Concerns included the four raw-material procurement factors, plus those relating to curtailed or closed operations, adequacy of the timber resource, profitability, increasing competition from larger firms, and ability to survive.

Table 16 (Appendix) summarizes the results. The response rate is the number of affirmative responses as a percentage of the total possible affirmative responses. Expressions of concern were slightly less frequent for the control region than for the other two regions. Medium-small and medium size plants appear to have experienced more injury from Hugo than have small and large size plants. Among plant types, hardwood sawmills had the highest affirmative response rate and "other" plants the lowest.

Phase III

Personal interviews verified that three plants and the main part of one other plant closed as a result of Hugo. All the closed plants were sawmills. The reason given for the closures was lack of suitable timber at an economically feasible cost. The research also revealed that the survival of 12 additional plants is in jeopardy, unless they receive near-term external assistance. Furthermore, at least five other plants have major problems which, if not corrected, may threaten their long-term survival.

The 12 plants whose survival is threatened are important economic entities in the rural communities where they are located. Four plants are in the primary region, five in the peripheral region, and three in the control region. Most are in the medium-small and medium size classes. Seven plants are pine sawmills, but at least one is in each of the other plant type categories. The near-term assistance needed by the 12 plants includes a number of different kinds of programs. Examples are:

- Identification of alternative sources of working capital.

- Determination of feasibility of changing to a more specialized product line or diversifying into secondary manufacturing; identification of funding sources for implementing the new programs.

- Location of potential new plant sites near suitable timber resources; identification of funding sources for relocating the plant.

- Assistance in carrying out feasibility studies to justify installation of new equipment to enable the plant to process a more-available type of raw material; identification of funding sources for purchasing and installing the new equipment.

- Development of a plan for identifying potential buyers of a plant and identification of funding sources for purchase of the plant.

- Assistance in carrying out marketing research projects that will identify market niches in which the company can be competitive and that are compatible with the company's resources and capabilities.

DISCUSSION

A few important inferences about the impacts of Hugo on primary wood-products manufacturers in South Carolina can be drawn from our data. Although some definite patterns are developing, there are exceptions in many areas. A few plants in the regions studied have experienced little impact from Hugo, while other plants are fighting for survival. Much seems to depend on each firm's situation--its location in relation to Hugo; its relationships with raw-material suppliers; its management, financial, and timber resources; its processing efficiency; the type of timber raw material it requires; and its ability and desire to change.

Volume and Type of Timber Raw Material Consumed

Overall, nonpaper processing plants project a reduction in volume of timber consumed. The projected reductions are largest in the primary region, smaller in the peripheral region, and insignificant in the control region. On the other hand, paper mills are projecting a substantial increase in consumption, particularly for hardwood pulpwood. For nonpaper plants, the purchase of government and private stumpage is expected to increase. The portion of the raw material from company land is projected to remain about the same as before Hugo.

Competition for Timber

The responses from both the mailed questionnaire and the personal interviews confirm that competition for timber has increased greatly since Hugo. As a result, prices for logs and stumpage have increased substantially. Competition appears to have increased uniformly in the three regions and for the different types of plants. As mills in the primary region expanded their procurement areas into the peripheral and control regions, plants in these outer regions, in turn, expanded beyond their normal procurement areas, with several going into Georgia and North Carolina.

The economic effects of Hugo, therefore, have spread over a much larger area than that which experienced damage. Many of the plants in this study describe timber procurement as a "war" or "battle for survival." Quality and size of available raw material have declined. This decline in quality appears to be more prevalent in the primary region than in either the peripheral or control regions. This conclusion is congruent with the fact that large timber suffered the greatest damage from Hugo.

Changes in Operations

Hugo has precipitated many changes in operation of the affected plants. The biggest change has been in raw-material procurement. In addition, a few plants are improving or planning to improve production efficiency and volume through installation of new equipment or other process changes. Some plants are diversifying their operations by integrating forward into value-added processing, with the purpose of either obtaining a higher margin from the more costly raw material or reducing demand for timber by buying lumber and other primary products for remanufacture.

Most plant operators, however, seem reluctant to change their strategies to reduce their vulnerability to the effects of Hugo. A few plants would like to make changes but lack the resources to do so. Other plants are not willing to risk major changes in their operations, apparently believing it is less risky to stay as they have been.

Major Concerns

Responses revealed that many firms share similar major concerns about the future of their businesses. Obviously, the major concerns relate to raw-material costs rising faster than selling prices for the products manufactured. Many plants believe the full effect of Hugo has not yet been felt. The depressed demand for wood products during the past few years has reduced demand for timber. As demand for wood products increases, the demand for timber will also increase, creating more severe competition than currently exists.

Reduced profitability currently, and fears of continuing low future margins, are of great concern to more than one-half of the plant managers surveyed. Plants located in the control region and large plants appear to be less concerned than those in other regions and size categories.

Increasing competition from large corporations is a major concern of several plants in all size categories. Smaller companies do not believe they have the resources to continue to compete with the large integrated firms for timber, especially as competition becomes more intense.

Plant Curtailment and Closures

One of the objectives of this research was to identify operations whose survival is threatened by the effects of Hurricane Hugo. Approximately 20 percent of the 69 plants responding to the mailed survey indicated they had closed or curtailed operations temporarily or permanently, as a direct result of Hugo. Twenty-five percent of the 41 plant managers that were interviewed reported some curtailment or closure.

Based on the information gathered, three plants have closed permanently. An additional 12 plants face serious near-term survival problems. Most of the threatened plants are of medium-small and medium size. They are in each of the regions and plant type groups. During personal interviews, changes that would make each plant more competitive were identified. These changes involved strengthening marketing, improving plant efficiency and processing capabilities, changing to a more specialized product line, adding secondary manufacturing, relocating the plant, strengthening management capabilities, and locating new sources of working and investment capital.

Plants Not Seriously Impacted by Hugo

A few plants reported that Hugo had not seriously impacted their operations. Three of these plants are in the primary region, three in the peripheral region, and one in the control region. Each of these plants appears to have some unique capabilities that enables it to better cope with major problems such as Hugo. These include important visible strengths in marketing, company-owned timber resources, specialty products, close relationship and good reputation with local timber owners, adequate financial resources, and operating efficiency.

GENERAL OBSERVATIONS

A large amount of information was gathered during this project. As we listened to people and analyzed our data, we were able to make some general observations. Not all these observations are fully supportable with collected data, but we believe they are of interest:

- The impact of Hugo extends well beyond the area where the storm damage actually occurred. Timber shortages in the area damaged by Hugo caused processors to expand their procurement activities into other areas in the state and into North Carolina and Georgia. The result is increasing competition for timber over a wide area, coupled with regional increases in prices.

- Because of the greatly increased competition for timber, it appears that there is not enough remaining timber for all processors of timber to continue operating at their anticipated levels of timber consumption. Therefore, the primary wood-processing sector's demand for timber will have to be reduced to reach a closer balance with supply. Plants using smaller and lower grade logs will be affected less than those using higher grade logs, such as saw logs and veneer logs.

- Processing plants within the study area are affected differently by Hugo, depending on each firm's resources and capabilities. Management skills, strong relationships with timber suppliers, niche marketing, efficient plants, and financial resources appear to be critical strengths. Plants possessing some or all of these attributes are less affected by Hugo than those which do not have them.

- Small and large plants tended to be affected less by Hugo than medium-size plants. Most small plants occupy specific market niches and require a relatively small volume of timber. Large plants tend to have more of the critical resources needed to survive during highly competitive periods.

- Two major threats were expressed by several plants. First, operators of small, medium-small, and medium size plants feel they cannot compete with the large firms during such highly competitive times as the aftermath of Hugo. Second, processors of hardwood veneer and lumber are deeply concerned about the rapid increase in consumption of hardwood pulpwood and the current practices of paper companies related to the chipping of hardwood saw logs and the clearcutting of young, vigorous hardwood stands for pulpwood.

• Managers of threatened companies seem reluctant to consider new business strategies that would reduce their dependence on timber raw material. Most appear to be willing to see their current business operations fail, rather than consider major changes in direction. A different business strategy, such as moving to more specialized products or secondary manufacturing, appears to be worth considering in view of the timber supply situation. Also, South Carolina lags behind most other southern states in value-added wood processing, which indicates that opportunities may exist in this area.

Reprinted from Impacts of Hugo timber damage on primary wood manufacturers in South Carolina. USDA Forest Service, Southeastern Forest Experiment Station, Gen. Tech. Rep. SE-80. 28 p.

APPENDIX

Table 1--Composition of respondent mills to mailed questionnaires and personal interviews

Type of mill	Mailed questionnaire				Personal interview			
	Primary	Peripheral	Control	Total	Primary	Peripheral	Control	Total
	Number of mills							
Pine sawmill	8	9	6	23	6	8	6	20
Hardwood sawmill	7	5	1	13	4	6	1	11
Hardwood veneer/plywood	2	6	0	8	0	2	I	3
Softwood plywood	1	1	1	3	0	0	1	1
Chip mill	2	5	1	8	0	0	0	0
Paper mill	2	4	0	6	0	0	0	0
Pole/piling	2	2	0	4	2	2	0	4
Basket	1	2	0	3	1	1	0	2
Fiberboard	0	1	0	1	0	0	0	0
Total	25	35	9	69	13	19	9	41

Table 2--Changes in timber raw material usage by mill size, by region, and mill type (nonpaper mills)

Mill size, by region, and mill type	Number of mills	Pre-Hugo volume	Change through 1991	Projected change from Hugo to 1994
		Thousand tons/year	Percent	
Mill size:				
Small (<20,000 tons)	16			
Primary		76	-34	-27
Peripheral		82	-68	-56
Control		17	0	0
Total		175	-47	-38
Medium-small (20,000-79,000 tons)	18			
Primary		297	-8	-12
Peripheral		494	-17	-1
Control		119	-38	-38
Total		910	-17	-8
Medium (80,000-200,000 tons)	15			
Primary		633	-8	0
Peripheral		1,101	-6	+9
Control		105	0	0
Total		1,839	-7	-7
Large (>200,000 tons)	14			
Primary		2,204	-15	-22
Peripheral		1,521	-5	-6
Control		1,965	+2	+2
Total	63	5,690	+5	-9
Mill type:				
Chip mill	8	2,026	-7	-6
Hardwood sawmill	13	562	-9	+1
Hardwood veneer-plywood	11	174	-40	-28
Pole	4	155	-9	-19
Softwood sawmill	23	4,414	-6	-4
Softwood plywood	3	1,105	-10	-20
Fiberboard	1	178	N/A	N/A
All regions:				
Primary	23	3,210	-14	-17
Peripheral	31	3,198	-9	-1
Control	9	2,206	0	0
Total	63	8,614	-8	-7

Table 3--Sources of raw materials by region

Region and material source	Raw-material mix Before Hugo	1991	1994
	Percent		
Primary region:			
Purchased logs	50	62	59
Purchased government stumpage	4	0	1
Purchased private stumpage	38	25	32
Company timber	8	13	8
Peripheral region:			
Purchased logs	57	56	54
Purchased government stumpage	3	0	1
Purchased private stumpage	35	39	42
Company timber	4	4	2
Control region:			
Purchased logs	31	40	42
Purchased government stumpage	14	9	9
Purchased private stumpage	52	47	46
Company timber	4	5	4

Table 4--Sources of raw materials for all paper and nonpaper mills, by mill type

Mill type and material source	Raw-material mix: Before Hugo	1991	1994
	---------------Percent---------------		
Nonpaper mills:			
Purchased logs	50	56	54
Purchased government stumpage	5	2	3
Purchased private stumpage	39	34	38
Company timber	6	8	6
Paper mills:			
Purchased logs	48	53	49
Purchased government stumpage	2	0	0
Purchased private stumpage	37	33	36
Company timber	13	14	15
Softwood sawmills:			
Purchased logs	38	50	46
Purchased government stumpage	11	4	4
Purchased private stumpage	42	35	40
Company timber	9	11	11
Softwood plywood:			
Purchased logs	39	63	54
Purchased government stumpage	11	5	5
Purchased private stumpage	43	30	38
Company timber	7	3	3
Chip mills:			
Purchased logs	19	15	15
Purchased government stumpage	0	0	0
Purchased private stumpage	77	81	83
Company timber	4	4	2
Hardwood sawmills:			
Purchased logs	58	61	61
Purchased government stumpage	0	0	1
Purchased private stumpage	33	26	35
Company timber	9	14	2
Hardwood veneer/plywood:			
Purchased logs	91	89	91
Purchased government stumpage	0	0	0
Purchased private stumpage	10	12	8
Company timber	0	0	2
Pole plants:			
Purchased logs	51	80	76
Purchased government stumpage	9	2	5
Purchased private stumpage	40	19	19
Company timber	0	0	0

Table 5--Sources of raw materials by mill size (nonpaper)

Mill size and material source	Raw-material mix Before Hugo	1991	1994
	Percent		
Small (<20,000 tons per year):			
Purchased logs	50	56	54
Purchased logs	76	80	75
Purchased government stumpage	0	0	0
Purchased private stumpage	21	10	24
Company timber	3	10	1
Medium-small (20,000-79,000 tons per year):			
Purchased logs	53	62	59
Purchased government stumpage	8	1	3
Purchased private stumpage	37	36	3's
Company timber	2	1	2
Medium (80,000-200,000 tons per year):			
Purchased logs	38	46	46
Purchased government stumpage	7	2	2
Purchased private stumpage	43	39	41
Company timber	12	12	10
Large (>200,000 tons per year):			
Purchased logs	33	39	37
Purchased government stumpage	5	3	3
Purchased private timber	54	48	51
Company timber	8	9	8

Table 6--Changes in the timber procurement environment as a direct result of Hurricane Hugo

Change factor	All responding nonpaper mills (63 mills)	Region: Primary (23 mills)	Region: Peripheral (31 mills)	Region: Control (9 mills)	Mill size: Small (<20,000 tons) (16 mills)	Mill size: Medium-small (20,000-79,000 tons) (18 mills)	Mill size: Medium (80,000-200,000 tons) (15 mills)	Mill size: Large (>200,000 tons) (14 mills)
Availability of suitable timber/logs	3.8	3.4	4.2	4.0	4.0	3.6	3.8	3.8
Diameter of timber/logs	4.5	4.0	4.6	5.2	4.8	4.2	4.0	5.0
Cost of stumpage	8.3	8.2	8.2	8.4	7.6	8.4	8.6	8.4
Cost of delivered logs	8.2	8.0	8.2	8.0	7.6	8.6	8.2	8.0
Procurement area covered	7.6	7.4	7.8	7.6	7.6	8.6	7.6	6.6
Average distance to haul logs	7.8	8.2	7.8	7.2	7.8	8.4	7.8	7.2
Competition for timber and logs	8.6	8.6	8.8	8.6	7.8	9.2	9.2	8.4

Change factor	Mill type: Chip mill (8 mills)	Hardwood sawmill (13 mills)	Hardwood veneer/plywood (11 mills)	Pole plants (4 mills)	Softwood sawmill (23 mills)	Softwood plywood (3 mills)	Paper mill (6 mills)
Availability of suitable timber/logs	4.0	3.4	3.8	3.6	4.2	3.4	3.6
Diameter of timber/logs available	4.6	4.4	4.6	5.0	4.6	4.0	4.6
Cost of stumpage	8.8	8.0	7.6	8.6	8.4	8.6	7.6
Cost of delivered logs	8.6	8.2	7.4	9.0	8.0	8.6	7.6
Procurement area covered	6.8	7.8	7.8	8.6	7.6	8.0	8.0
Average distance to haul logs	7.2	8.4	7.6	8.6	7.8	8.0	8.4
Competition for timber and logs	9.2	8.6	7.8	9.6	8.6	8.0	9.0

Scale: 0-2 = Decreased greatly
2-4 = Decreased moderately
4-6 = No change
6-8 = Increased moderately
8-10 = Increased greatly

Table 7--Effects on support services as a result of Hurricane Hugo

Change factor	All responding nonpaper mills (63 mills)	Region: Primary (23 mills)	Region: Peripheral (31 mills)	Region: Control (9 mills)	Mill size: Small (<20,000 tons) (16 mills)	Mill size: Medium-small (20,000-79,000 tons) (18 mills)	Mill size: Medium (80,000-200,000 tons) (15 mills)	Mill size: Large (>200,000 tons) (14 mills)
	Number of responses							
Decrease in available loggers	15	8	4	3	0	3	5	7
Increase in available loggers	3	1	2	0	0	0	2	1
Type of loggers changing	6	4	1	1	1	1	3	1
Equipment dealers out of business	2	1	1	0	0	1	1	0
Dealers changing product line	2	1	1	0	0	1	1	0
Decreased number of timber sales	2	1	1	0	0	2	0	0
No change	10	1	8	1	2	7	0	1
No response	16	7	7	2	8	2	3	3
Unrelated response	12	3	7	2	4	4	2	2
Too early to tell	3	1	2	0	1	0	2	0

Change factor	Mill type: Chip mill (8 mills)	Hardwood sawmill (13 mills)	Hardwood veneer/plywood (11 mills)	Pole plants (4 mills)	Softwood sawmill (23 mills)	Softwood plywood (3 mills)	Paper mill (6 mills)
Decrease in available loggers	3	1	0	2	6	2	1
Increase in available loggers	1	0	0	0	2	0	1
Type of loggers changing	0	2	1	0	1	1	0
Equipment dealers out of business	0	0	0	0	2	0	0
Dealers changing product line	0	0	0	0	2	0	0
Decreased number of timber sales	0	1	0	0	0	1	1
No change	1	1	4	1	3	0	1
No response	1	5	4	0	6	0	1
Unrelated response	2	4	1	1	4	0	2
Too early to tell	0	1	1	0	1	0	0

Table 8--Anticipated changes in raw material availability

Change factor	All responding nonpaper mills (63 mills)	Region: Primary (23 mills)	Region: Peripheral (31 mills)	Region: Control (9 mills)	Mill size: Small (<20,000 tons) (16 mills)	Mill size: Medium-small (20,000-79,000 tons) (18 mills)	Mill size: Medium (80,000-200,000 tons) (15 mills)	Mill size: Large (>200,000 tons) (14 mills)
	Number of responses							
Increase in logging costs	0	0	0	0	0	0	0	0
Increase in stumpage costs	13	1	8	4	4	5	2	2
Increase in levels of competition	15	4	9	2	2	3	5	5
Decrease in quality of timber	14	4	9	1	4	4	5	1
Decrease in size of timber	7	2	4	1	0	2	3	2
Mill closures expected	9	7	2	0	1	3	2	3
Fewer/no timber sales in area	11	7	4	0	0	5	3	3
No change	7	1	4	2	1	3	0	3
No response	11	7	3	1	6	1	3	1
Too early to tell	0	0	0	0	0	0	0	0

Change factor	Mill type: Chip mill (8 mills)	Hardwood sawmill (13 mills)	Hardwood veneer/plywood (11 mills)	Pole plants (4 mills)	Softwood sawmill (23 mills)	Softwood plywood (3 mills)	Paper mill (6 mills)
Increase in logging costs	0	0	0	0	0	0	0
Increase in stumpage costs	1	2	2	1	6	1	1
Increase in levels of competition	3	3	1	2	5	0	1
Decrease in quality of timber	1	3	3	1	4	1	1
Decrease in size of timber	1	0	0	0	5	1	0
Mill closures expected	2	3	0	0	3	1	0
Fewer/no timber sales in area	2	1	0	3	5	0	1
No change	0	1	2	0	3	1	1
No response	1	3	4	0	3	0	1
Too early to tell	0	0	0	0	0	0	1

Table 9--Changes in business operations as a direct result of Hurricane Hugo

Change factor	All responding nonpaper mills (63 mills)	Region: Primary (23 mills)	Region: Peripheral (31 mills)	Region: Control (9 mills)	Mill size: Small (<20,000 tons) (16 mills)	Mill size: Medium-small (20,000-79,000 tons) (18 mills)	Mill size: Medium (80,000-200,000 tons) (15 mills)	Mill size: Large (>200,000 tons) (14 mills)
	Number of responses							
Raw material used	4	4	4	3	4	5	3	3
Procurement program	4	4	4	4	3	5	5	4
Manufacturing process	2	1	2	2	2	2	2	1
Products produced	2	1	2	2	2	2	2	1
Markets served	2	1	2	1	3	2	1	1
Sales program	2	1	2	1	3	2	2	1
Closure/curtailment of existing operations	2	2	2	2	3	2	1	1
Addition of new operations	1	1	2	0	1	1	1	1

Change factor	Mill type: Chip mill (8 mills)	Hardwood sawmill (13 mills)	Hardwood veneer/plywood (11 mills)	Pole plants (4 mills)	Softwood sawmill (23 mills)	Softwood plywood (3 mills)	Paper mill (6 mills)
Raw material used	2	4	3	7	4	5	3
Procurement program	6	3	2	7	5	3	5
Manufacturing process	1	2	2	1	3	0	2
Products produced	1	1	2	1	3	0	2
Markets served	1	2	2	3	2	0	2
Sales program	1	2	2	1	2	0	2
Closure/curtailment of existing operations	1	3	2	0	3	0	3
Addition of new operations	1	1	0	1	1	0	3

Scale: 0 = No change
1-3 = Minor change
4-6 = Moderate change
7-10 = Major change

Table 10--Curtailment or closure of operations due to Hurricane Hugo

Change factor	All responding nonpaper mills (63 mills)	Region: Primary (23 mills)	Region: Peripheral (31 mills)	Region: Control (9 mills)	Mill size: Small (<20,000 tons) (16 mills)	Mill size: Medium-small (20,000-79,000 tons) (18 mills)	Mill size: Medium (80,000-200,000 tons) (15 mills)	Mill size: Large (>200,000 tons) (14 mills)
	-----	-----	-----	Number of responses	-----	-----	-----	-----
Plant closed temporarily	0	0	0	0	0	0	0	0
Plant closed permanently	1	0	1	0	1	0	0	0
Temporary layoffs	2	1	0	1	1	1	0	0
Temporary reduction in production	2	2	0	0	0	1	1	0
Permanent reduction in production	2	2	0	0	0	1	0	1
Portion of operation closed	5	3	1	1	1	1	2	1
Postponement of growth plans	2	1	0	1	1	1	0	0
Change in raw material source	1	0	1	0	1	0	0	0
No change	47	13	28	7	11	14	12	12

Change factor	Mill type: Chip mill (8 mills)	Hardwood sawmill (13 mills)	Hardwood veneer/plywood (11 mills)	Pole plants (4 mills)	Softwood sawmill (23 mills)	Softwood plywood (3 mills)	Paper mill (6 mills)
Plant closed temporarily	0	0	0	0	0	0	0
Plant closed permanently	0	0	1	0	0	0	0
Temporary layoffs	0	1	0	0	1	0	1
Temporary reduction in production	0	2	0	0	0	0	0
Permanent reduction in production	0	1	0	0	0	1	0
Portion of operation closed	2	1	0	0	2	0	3
Postponement of growth plans	0	0	0	0	2	0	0
Change in raw material source	0	0	1	0	0	0	0
No change	6	8	9	4	19	2	3

Table 11--Interest in followup program for alternative business strategies (nonpaper)

Region, mill size, and mill type	Number of mills	Want to participate	Interested, but want more information	Not interested
	Change factor			
	---Number of responses---			
Region:				
Primary	23	0	15	8
Peripheral	31	5	12	14
Control	9	0	6	3
Mill size:				
Small (<20,000 tons)	16	2	7	7
Medium-small (20,000-79,000 tons)	18	1	9	8
Medium (80,000-200,000 tons)	15	2	7	6
Large (>200,0o0 tons)	14	0	10	4
Mill type:				
Chip	8	0	4	4
Hardwood sawmill	13	2	6	5
Hardwood veneer/plywood	11	1	4	6
Pole	4	0	3	1
Softwood sawmill	23	2	13	8
Softwood plywood	3	0	2	1
Fiberboard	1	0	1	0
All responding nonpaper mills	63	5	33	25

Table 12--Summary of affirmative responses from personal interviews of selected mills

Impacts and concerns	Number of responses, by region Primary (13 mills)	Peripheral (19 mills)	Control (9 mills)	Total (41 mills)
Major impact on timber raw-material procurement:				
Increased competition	12	17	9	38
Increased stumpage/log prices	10	17	9	36
Expanded procurement area	11	14	7	32
Declining quality of available timber	12	15	4	31
Little or no major impact	3	3	1	7
Major impact on operations:				
Curtailed or closed operations	3	5	2	10
Improving or expanding to increase efficiency	4	4	2	10
Diversifying processing or adding secondary manufacturing	4	1	2	7
Long-term major concerns:				
Ability to obtain low-cost financing	3	3	1	7
Timber resource inadequate for current demand	6	13	1	20
Reduced profitability	10	11	3	24
Environmental constraints	2	7	-	9
Rapid increase in hardwood demand by paper firms	1	6	2	9
Increasing competition from larger firms	3	6	4	13
Utilization of sweetgum and other less-desirable hardwoods	1	2	1	4
Future survival questionable	4	5	3	12

Table 13--Major business impacts and concerns as a result of Hurricane Hugo, by mill type and size, by region

Mill type and size, by region	Number of mills	Impacts on raw-material procurement: Increased competition	Higher prices	Expanded area	Declining quality	Total	Affirmative responses
	Number of affirmative responses						Percent
Mill type:							
Pine sawmill--							
Primary	6	6	4	6	6	22	92
Peripheral	8	7	7	6	7	27	84
Control	6	6	6	5	3	20	83
Total	20	19	17	17	16	69	86
Hardwood sawmill--							
Primary	4	3	3	3	3	12	75
Peripheral	6	6	6	5	5	22	92
Control	1	1	1	1	1	4	100
Total	11	10	10	9	9	38	86
Pole plant--							
Primary	2	2	2	2	2	8	100
Peripheral	2	2	2	1	1	6	75
Control	0	--	--	--	--	--	--
Total	4	4	4	3	3	14	88
Other--							
Primary	1	1	1	0	1	3	75
Peripheral	3	2	2	2	2	8	67
Control	2	2	2	1	0	5	63
Total	6	5	5	3	3	16	67
Mill size:							
Small--							
Primary	3	2	2	1	2	7	58
Peripheral	2	1	2	2	1	6	75
Control	0	--	--	--	--	--	--
Total	5	3	4	3	3	13	65
Medium-small--							
Primary	2	2	2	2	2	8	100
Peripheral	11	10	9	7	8	34	77
Control	4	4	4	3	3	14	88
Total	17	16	15	12	13	56	82
Medium--							
Primary	4	4	4	4	4	16	100
Peripheral	4	4	4	4	4	16	100
Control	1	1	1	1	1	4	100
Total	9	9	9	9	9	36	100
Large--							
Primary	4	4	2	4	4	14	88
Peripheral	2	2	2	1	2	7	88
Control	4	4	4	3	0	11	69
Total	10	10	8	8	6	32	80
All regions:							
Primary	13	12	10	11	12	45	87
Peripheral	19	17	17	14	15	63	83
Control	9	9	9	7	4	29	81
Total	41	38	36	32	31	137	84

Table 14--Major business impacts and concerns on operations as a result of Hurricane Hugo, by region, mill size, and mill type

Region, mill size, and mill type	Number of mills	Impacts on operations		
		Closure or curtailment	Increasing efficiency	Diversifying processing
		Percent		
Region:				
Primary	13	23	31	31
Peripheral	19	26	21	5
Control	9	22	22	22
Mill size:				
Small	5	20	0	0
Medium-small	17	35	24	18
Medium	9	11	33	33
Large	10	20	30	30
Mill type:				
Pine sawmill	20	25	25	20
Hardwood sawmill	11	27	36	18
Pole plant	4	25	0	0
Other	6	17	17	17

Table 15--Long-term major concerns as a result of Hurricane Hugo, by mill type and size, by region

Mill type and size, by region	Number of mills	Long-term major concerns: Inadequate timber	Reduced profits	Large firms	Future survival	Total	Affirmative responses
		------Number of affirmative responses------					--Percent--
Mill type:							
Pine sawmill--							
Primary	6	4	4	2	2	12	50
Peripheral	8	6	6	3	2	17	53
Control	6	1	3	3	3	10	42
Total	20	11	13	8	7	39	49
Hardwood sawmill--							
Primary	4	2	3	1	1	7	44
Peripheral	6	4	4	3	1	12	50
Control	1	0	0	1	0	1	25
Total	11	6	7	5	2	20	45
Pole plant--							
Primary	2	0	2	0	1	3	38
Peripheral	2	2	0	0	1	3	38
Control	0	--	--	--	--	--	--
Total	4	2	2	0	2	6	38
Other--							
Primary	1	0	1	0	0	1	25
Peripheral	3	1	1	0	1	3	25
Control	2	0	0	0	0	0	0
Total	6	1	2	0	1	4	17
Mill size:							
Small--							
Primary	3	1	2	1	1	5	42
Peripheral	2	1	1	1	0	3	38
Control	0	--	--	--	--	--	--
Total	5	2	3	2	1	8	40
Medium-small--							
Primary	2	2	2	0	1	4	50
Peripheral	11	8	6	2	4	20	45
Control	4	0	2	3	2	7	44
Total	17	10	10	5	7	31	46
Medium--							
Primary	4	2	4	2	2	10	63
Peripheral	4	4	3	1	0	8	50
Control	1	0	1	1	1	3	75
Total	9	6	8	4	3	21	58
Large--							
Primary	4	2	2	0	0	4	25
Peripheral-	2	1	1	2	1	5	50
Control	4	0	0	0	0	0	0
Total	10	3	3	2	1	9	23
All regions:							
Primary	13	6	10	3	4	23	44
Peripheral	19	13	11	6	5	35	46
Control	9	1	3	4	3	11	31
Total	41	20	24	13	12	69	42

Table 16--Response rate for combined negative factors as a result of Hurricane Hugo, by region, mill size, and mill type

Negative factors	Combined mills	Affirmative response rate, by region			
		Primary	Periphery	Control	Mean
		------------Percent------------			
Increased competition for timber raw material	All responses	61	61	51	59
	Mill size:				
Increased stumpage/log prices	Small	48	50	--	49
	Medium-small	72	58	64	61
Expanded procurement area	Medium	75	67	89	71
	Large	50	78	31	48
Declining quality of available timber raw material	Mill type:				
	Pine sawmill	63	65	22	52
Curtailed or closed operations	Hardwood sawmill	56	83	56	71
	Pole plant	67	50	--	58
Timber resource inadequate for demand	Other	56	41	28	39
Reduced profitability					
Increasing competition from large firms					
Future survival questionable					

FOREST RESTORATION

POST-HURRICANE HUGO FOREST PEST POPULATIONS AND DAMAGE (IMPACTO DE LAS POBLACIONES DE INSECTOS FORESTALES POSTERIOR AL HURACAN HUGO)[1]

Harry O. Yates III and Thomas Miller[2]

Abstract--On 21 September of 1989, Hurricane Hugo slammed into the coast of South Carolina just north of the city of Charleston. Winds of 135 miles per hour and tidal surges of 12 to 18 feet caused damage without precedent to personal property and forest areas. It is estimated that the volume of broken or uprooted trees represented approximately 6.7 billion board feet. Since this natural disaster, a great deal of time has been spent studying forest insects and their ability to damage the surviving trees.

During the period 1990-1991, we maintained traps to determine the population levels of the reproduction weevils *Hylobius pales* (Herbst) and *Pachylobius picivorus* (Germar), *Monochamus titillator* (F.), the bark beetles *Dendroctonus terebrans* (Olivier), *Ips* spp. and *Dendroctonus frontalis* Zimm. The populations of *Ips* were reduced significantly during 1991. Very few individuals of *D. frontalis* were captured during the two years. No tree damage or mortality was observed to the trees in the area affected by the hurricane. Collections and observations were made of pathogens that can affect the trees; however, no significant damage was observed.

INTRODUCTION

Mexico and the United States share the coast-line rimming the Gulf of Mexico from the Yucatan northward and easterly to Key West, FL. This coastline shares the common threat of hurricanes each year during the period June to November. These storms are spawned in the tropical regions of the North Atlantic Ocean and frequently move northerly and westerly into the Gulf of Mexico where they eventually strike land. The unpredictable nature of hurricanes makes it virtually impossible to predict with any certainty their point of landfall any sooner than 24 hours in advance. In addition to winds blowing in excess of 120 kilometers per hour, associated cloud masses produce exceedingly heavy rains and are apt to spawn numerous destructive tornados. The northeastern coast of Mexico most recently experienced the ravages of a hurricane in the fall of 1988. This storm caused considerable destruction as far inland as the city of Monterrey.

During the late evening of September 21, 1989, an extremely dangerous hurricane with winds in excess of 215 kilometers per hour slammed into the Atlantic coast of the United States. This hurricane was named "Hurricane Hugo." Hurricane Hugo's eye crossed the coast of the state of South Carolina just north of the city of Charleston.

Hugo caused unprecedented property losses along the coastal areas with the complete destruction of entire housing

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developments. Adding to the wind-caused destruction the 4-6 meter storm surge washed many fishing and pleasure boats inland along the coast. The most destruction was to the timber resource throughout the area. Those trees not blown over or broken by the force of the winds sustained varying degrees of root disturbance and/or loss of branches or photosynthetic leaf surface. This left the residual stands in a stressed condition that predisposed them to attack by insects and disease organisms. It is estimated that the timber losses caused by Hurricane Hugo was equal to the combined losses of Hurricanes Camille and Frederick, the Mt. St. Helen's eruption, and the Yellowstone fires of 1988. Over 6.7 billion board feet of timber was destroyed.

An immediate priority was to salvage as much of this timber as possible. This included the use of helicopters to remove logs from areas inaccessible by vehicle. Even with the tremendous harvesting effort that continued throughout the year following the hurricane, it is estimated that only 25 percent of the damaged timber was harvested. In areas harvested or those too inaccessible to harvest, a tremendous quantity of broken trees and limbs covered the ground and soon became dry. This dry material created a serious fire hazard to the remaining forest trees and personal property within the forest. In order to reduce the threat of fire, a ban was imposed on all outdoor burning. Fire crews and equipment were also flown into the area from throughout the United States and Canada to combat fire.

These forest conditions were particularly favorable for the buildup of some potentially damaging forest insects and diseases. Therefore, in the spring of 1990 studies were begun to monitor pest populations and damage.

OBJECTIVES

Research was begun in the Francis Marion National Forest in March 1990. The objectives were to study the population dynamics and successional development by species over time of 10 primary and secondary forest insects (Table 1) and to identify and study the pathogens that attack damaged trees and their development and spread to adjacent damaged or healthy trees.

MATERIALS AND METHODS

Adult insect populations were monitored using bounce traps (Fatzinger 1985). The trap consists of a 1 m diameter plastic wading pool approximately 25 cm deep. Placed vertically in the center of the pool is a 1 m tall black stove pipe about 30 cm in diameter. A plastic bottle containing a bait is secured at the top of the stove pipe. A wick slowly releases the contents of the bottle to the atmosphere. The bait consists of a 50:50 mixture of freshly distilled turpentine and 95 percent ethyl alcohol. Insects attracted to the trap generally fly to and bounce off the upright stove pipe known as the "bounce column" and fall into the pool or "catch basin." The catch basin is half-filled with water to which is added about 15 ml of household detergent to reduce surface tension and cause trapped insects to sink.

During 1990, 35 bounce traps were located throughout the hurricane-ravaged forest area. Traps were visited weekly throughout the summer and collections were returned to the laboratory for separation and identification of trapped insects.

The extensive damage to trees provided a unique opportunity to evaluate the development of tree diseases. In particular, we wanted to look at the fungi attacking trees with seriously disturbed root systems. Efforts were concentrated within three general areas: (1) the hazard for the occurrence of the pitch canker disease, caused by *Fusarium subglutinans* (Wollenw. & Reinking) Nelson, Toussoun and Marasas, (2) the damage to lateral roots of *Pinus* sp. caused by the wind stresses and any resultant attacks by root pathogens, and (3) assessment of possible interactions between pine seedling damage by reproduction weevils and the pitch canker disease.

Petri plates containing a medium selective for the pitch canker fungus (Nash and Snyder 1962) were exposed for approximately 24 hours in March 1990. Twenty-five plates were placed at ca. 100-meter intervals around the periphery of an ca. 100 hectare stand of severely damaged pines and hardwoods. Another 23 plates were exposed in two areas; one planted two months earlier and the other planted in January 1989.

Table 1--Coleoptera species monitored from bounce traps in the Francis Marion National Forest in South Carolina

Family Scolytidae	
Ips avulsus (Eichhoff)	Small southern pine engraver
I. calligraphus (Germar)	Sixspined Ips
I. grandicollis (Eichhoff)	Eastern fivespined Ips
Dendroctonus frontalis Zimmermann	Southern pine beetle
D. terebrans (Olivier)	Black turpentine beetle
Family Curculionidae	
Hylobius pales (Herbst)	Pales weevil
Pachylobius picivorus (Germar)	Pitch-eating weevil
Pissodes nemorensis Germar	Eastern pine weevil
Family Cerambycidae	
Monochamus titillator (F.)	Southern pine sawyer
M. carolinensis (Olivier)	Carolina pine sawyer

In March 1990, the root systems of *Pinus taeda* L. and *P. palustris* Mill. trees, ranging in d.b.h. from 11.5 to 30.5 cm and in height from about 10 to 16 m were examined by excavation. These trees were selected on the basis of wind-induced lean from the vertical and ranged from 0 (no lean) to about 40°. Samples of lateral roots were examined from the direction of lean and at 90° and 180° from the lean.

In August 1990, roots were excavated from 11 moribund *P. taeda* and *P. palustris* trees ranging in d.b.h. from 10 to 41 cm and from 10 to 18 m in height. Emphasis was placed on roots with damage or symptoms that might indicate disease. Roots were returned to the laboratory for isolation procedures onto the Nash-Snyder medium and acidified malt extract agar.

Also, in August 1990, *P. taeda* seedlings with damage caused by reproduction weevils, *Hylobius* spp. and *Pachylobius* spp., were collected for isolation procedures.

RESULTS AND DISCUSSION

Insects

Five species of the family Scolytidae were monitored. These included three engraver beetles: *Ips avulsus* (Eichhoff), *I. grandicollis* (Eichhoff), and *I. calligraphus* (Germar), and the bark beetles *Dendroctonus frontalis* (Zimmermann) and *D. terebrans* (Olivier). Within the family Curculionidae, three species of weevils were monitored: *Hylobius pales* (Herbst), *Pachylobius picivorus* (Germar), and *Pissodes nemorensis* (Germar). In the family Cerambycidae trap catches were monitored for the pine sawyers, *Monochamus titillator* (F.) and *M. carolinensis* (Olivier).

The presence of severely weakened and stressed pines were a source for infestation by engraver beetles. Likewise, the large volume of fresh logs on the ground provided ideal conditions for the buildup of beetle populations. This beetle buildup is reflected in the high populations of engraver beetle trap captures in May and June following the hurricane (Figure 1). The dramatic drop in adult captors beginning in July coincides with the deterioration of the host material when it was no longer susceptible to attack. Adult captures during 1991 were extremely low. No significant buildup of engraver beetle-attacked trees has been observed in the surviving forest stands.

The black turpentine beetle breeds and feeds in fresh stumps or the trunks of weakened or damaged trees. Adult captures increased throughout the 1990 summer to a peak in August (Figure 2). As with the engraver beetles, very low populations were recorded during 1991. This dramatic drop in population also reflects the deterioration of host material suitable for feeding and breeding.

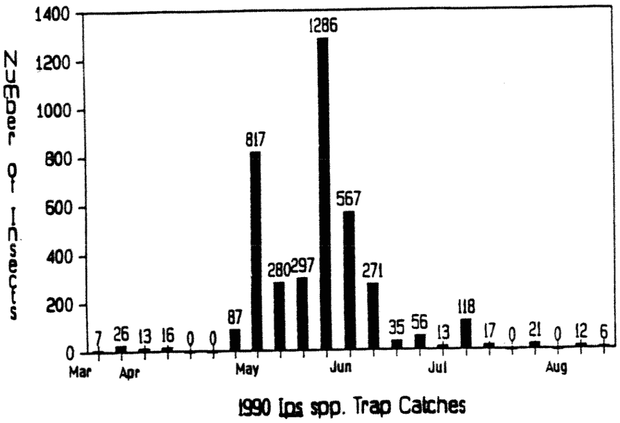

Figure 1--Weekly trap catches of *Ips* spp. during 1990.

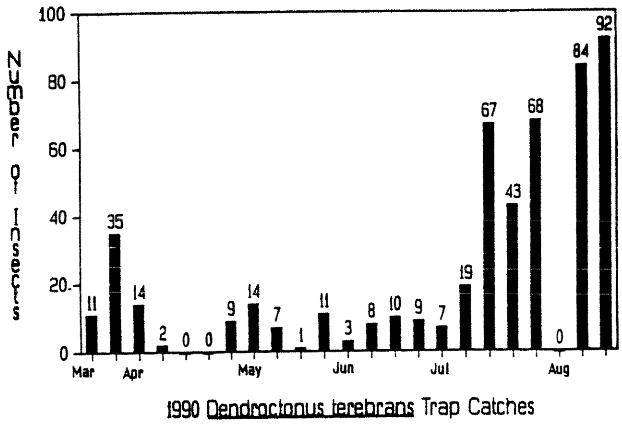

Figure 2--Weekly trap catches of *Dendroctonus terebrans* during 1990.

The southern pine sawyer attacks logs with the bark still intact. This secondary insect feeds and breeds in logs that have become dry. During 1990 trap captures remained high (Figure 3). These high populations of adults continued throughout 1991 as well. This insect does not create a problem to the surviving trees or adjacent pine stands.

The reproduction weevils, *Hylobius pales* and *Pachylobius picivorus*, pose a serious threat to natural pine reproduction or artificial regeneration (Nord and others 1982). Adults are attracted to areas where pines have recently been cutover or killed. Here they feed nocturnally on the inner bark of freshly cut slash and stumps. After this host material dries out, they feed on the inner bark of small twigs and stems of pine seedlings. Such feeding may result in seedling death.

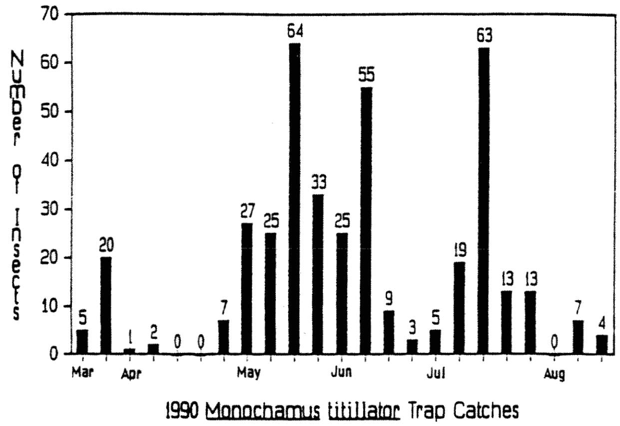

Figure 3--Weekly trap catches of *Monochamus titillator* during 1990.

Weevil populations built up through the 1990 season (Figure 4). This build-up was anticipated since ample breeding material was available in the field. However, continued trapping of high weevil populations during the 1991 season was not anticipated. With high weevil populations, we expected to find significant damage to recently planted seedlings and natural reproduction. While some weevil-caused mortality has occurred the incidence has been extremely low--less than 3 percent--compared to the adult weevil populations trapped.

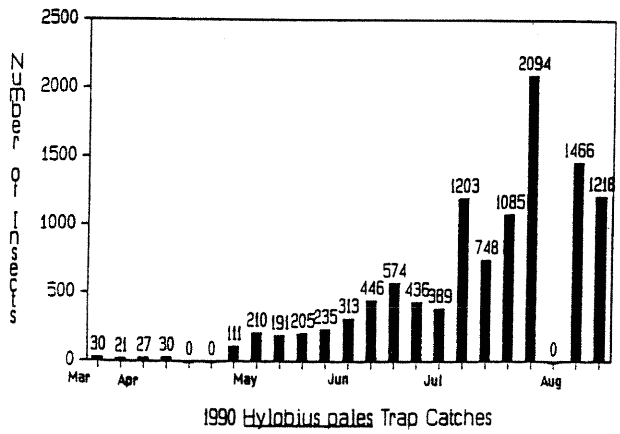

Figure 4--Weekly trap catches of *Hylobius pales* during 1990.

It remains a mystery on what these high weevil populations are feeding and where they are breeding. Furthermore, they do not appear to be causing significant seedling mortality. We plan to continue monitoring insect populations through 1992 in an attempt to answer some of these questions. Observations of and isolations from pine roots will also continue.

Pathogens

Roots of trees leaning at about 30° or less had no obvious damage. Roots of trees at >30° typically had roots broken and pulled apart from the 180° sample and either broken or severely bent in the 90° samples. Roots from the direction of the lean exhibited no apparent damage. Broken roots collected and taken to the laboratory for cultural isolations produced only some expected soil-inhabiting fungi. No potentially pathogenic organisms were isolated. Two *Fusarium* spp. and several isolates of a fungus with black, fluffy hyphae were obtained; however, they have not yet been identified. Identified species of *Fusarium* recovered from the area include *Fusarium anthophilum* (A. Braun) Wollenw., *F. oxysporum* (Schl.) en. Snyd. & Hans, *F. proliferatum* (Matsushima) Nirenberg, *F. semitectum* Berk. & Rav., and *F. sulglutinans*.

SUMMARY

The bark beetle explosion that was anticipated following Hurricane Hugo failed to materialize. Furthermore there was no indication of root disease development or significant pitch canker symptoms observed over the period of observation. Time will tell if reproduction weevils or root pathogens will become a serious threat to the residual pine forests and regeneration.

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RECOMMENDATIONS FOR SALVAGE AND ESTIMATES FOR RAPIDITY OF INVASION BY VARIOUS INSECT AND DISEASE ORGANISMS OF HURRICANE HUGO-DAMAGED TIMBER RESOURCES

Patrick J. Barry[1]

The area of immediate concern should be the severely damaged trees in the counties classed as having extensive and moderate timber damage.

Salvage should be concentrated in stands with uprooted trees, root sprung (leaning) trees and trees with main stem breakage.

If not salvaged promptly uprooted trees will probably be degraded by stains, decay, and secondary insects, such as bark beetles, borers, powder post and ambrosia beetles. The longer salvage is delayed, the greater the amount of degrade and weight loss from rapid drying.

Root sprung trees will not die immediately, but will show decline symptoms over a period of several years. However, these trees may be invaded by root rot organisms, and subjected to drought stress and insect attack immediately. Root sprung pines may be invaded by bark beetles and blue stain fungi. These pines can serve as prime habitat for the southern pine beetle and if conditions become favorable, an outbreak could occur. They can also harbor high populations of turpentine beetles. Hardwood trees with major root damage should be salvaged as soon as possible to avoid a value loss from degrade.

Trees with main stem breakage will be invaded by a variety of insects and disease-causing organisms. Hardwoods may not die but will be severely degraded by stain and decay fungi. Pines often will be infested and killed by bark beetles and infected with blue stain fungi. They can support high southern pine beetle populations immediately after breakage, but soon become unsuitable hosts, due to rapid drying and deterioration of the thin inner bark. Turpentine and bark beetles also commonly attack pines and can build to damaging populations in trees with main stem breakage.

Other areas of concern but with a longer planning and salvage operational period are the moderate to lightly damaged timber stands. Stands with trees having broken tops or branches, major wounds and bent trees.

Trees with broken branches that have exposed heartwood will be infected by stain and decay fungi at the point of injury. Stains will move vertically from the point of injury at a rate of 6 to 18 inches per year, depending on tree species and decay organisms. Decay fungi will follow the stain fungi in about 8 to 10 months. Breaks smaller than 3 inches in diameter, with no heartwood exposed, may be infected by sapwood decay fungi with no serious economic losses. Some broken branches in the tops of pine species may be attacked by bark beetles and infected with blue stain fungi. Trees with broken terminals and major limb damage (breaks, 3 inches or larger) should be removed during the next scheduled harvest.

Many trees sustain wounds caused by falling tops, adjacent uprooted trees, and major breakage. In hardwoods, wounds that do not penetrate more than 2 inches into the sapwood and have less than 144 square inches of surface area will have only localized stain, but no decay. Larger wounds will have stains and decay that will move at the rate described for broken branches. Pine trees with major wounds to the lower bole and roots may be attacked by bark beetles.

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These trees should be removed during the next scheduled harvest.

Bent hardwoods usually are not attacked by insects or disease because they are not severely stressed. Pine trees that are bent to the extent that cracks and resin flow occur may be invaded by bark beetles and disease-causing organisms.

Severely bent hardwoods should be salvaged during the next scheduled harvest. Inspect large pine timber for pitch flow. Many large, green standing pines may not be usable for veneer, poles, or lumber because of internal ring shake, splintering, and separation of wood fibers. Often the only external incidence of such damage is pitch flow. The characteristics are often overlooked, and considerable losses are incurred during a later harvest.

Another problem which could occur over the long-term period is some damage to pine reproduction planted in the next two years.

Reproduction weevils can build up in the stumps and heavy slash lying on the ground at the current time and in stressed trees that will be dying over time during the next two to three years.

High value trees, such as those in recreation areas, camp grounds, and seed orchards should receive special management considerations as follows:

(1) Properly prune broken branches to promote rapid healing.

(2) Spray residual pine trees with an insecticide to protect them from bark beetle attack.

(3) Complete a sanitation salvage operation of trees previously described above as severely damaged (uprooted, severely root sprung trees and trees with main stem breakage).

(4) Make sure the salvaged material is disposed of properly or removed from the area as soon as possible.

(5) Treat stumps in the seed orchard with insecticide to prevent black turpentine beetle build up.

The area affected by Hurricane Hugo could have insect activity through mid November, particularly bark beetle activity.

Date: October 9, 1989.

HURRICANE HUGO'S INITIAL EFFECTS ON RED-COCKADED WOODPECKERS IN THE FRANCIS MARION NATIONAL FOREST

Robert G. Hooper, J. Craig Watson, and Ronald E. F. Escano[1]

The Francis Marion National Forest (FMNF) in coastal South Carolina had the premier population of red-cockaded woodpeckers (*Picoides borealis*), a federally-listed endangered species. The population was the densest, the second largest and the only one known to have been increasing (Costa and Escano 1989). On the evening of 21 September 1989, Hurricane Hugo scored a direct hit on the FMNF. Immediate damage to the forest in the form of broken and wind-thrown trees was severe. Most of the cavity trees essential for woodpecker nesting and roosting, as well as much of its foraging habitat were destroyed. Many of the woodpeckers were probably killed.

This paper documents the initial impact of Hugo on red-cockaded woodpeckers in the FMNF, describes the immediate restoration effort and puts Hugo in historical perspective. Given that hurricanes are not rare events, we discuss possible strategies for lessening their impacts on this endangered species.

IMPACT ON THE RED-COCKADED WOODPECKER

Red-cockaded woodpeckers depend on the cavities they excavate in living pines for nesting and roosting. Excavation typically requires several years. Completed cavities are generally used for several years and sometimes for as long as 20 years. Cavity trees are critical to the woodpecker, and the lack of potential trees for cavity excavation is a primary reason the species is endangered (USFWS 1985).

After Hugo, Forest Service biologists attempted to visit all known colony sites (clusters of cavity trees) to assess damage and prescribe emergency management. The damage estimates that follow are based on these visits. Ninety-nine percent of all known colony sites were visited and 91 percent were censused for surviving woodpeckers.

Hugo destroyed 87 percent of the estimated 1765 cavities that were active prior to Hugo (ones with evidence of recent use by the bird). At 47 percent of colony sites that were occupied by red-cockaded woodpeckers before the storm, all the trees with active, inactive and incomplete cavities were destroyed. At 57 percent of colony sites with woodpeckers prior to Hugo, all trees with active cavities were destroyed.

In the 205 colony sites that had at least one active cavity remaining after the hurricane, the average number of active cavities was only 1.9. In 1988, the number of active cavities per colony averaged 3.7 in 100 randomly selected colony sites. Thus, the quality of surviving colony sites was less than prior to Hugo.

Only 10 dead red-cockaded woodpeckers were found. However, based on the mean number of surviving birds per colony (1.5) and the mean number of birds per colony determined in prior years for October (4.0), we estimate that 63 percent of the woodpeckers in FMNF were killed or missing. Seventy-seven percent of all colony sites, 89 percent of sites with surviving cavity trees,

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and 52 percent of those with no surviving cavity trees still had woodpeckers after the hurricane.

In 1987-88 there was an estimated 477 family groups of from 2-9 red-cockaded woodpeckers (clan) in the FMNF. After the hurricane there were 240 colony sites with some surviving cavity trees (active, inactive or incomplete cavity) that still had 1 or more woodpeckers. Another 128 former colony sites without any surviving cavity trees still had 1 or more birds. Thus, the most optimistic estimate for the post-Hugo population is 368 clans. However, only 67 percent of these had the 2 or more birds necessary for a potentially functional clan. Even under the best of conditions it is unlikely that all of these will survive for more than 1 year following the hurricane. We expect a continued loss of clans before the population stabilizes. When this occurs and where the population will be at the time depends on survival of birds over-winter without cavities, the success of single birds in finding mates, survival of the remaining cavity trees, survival of foraging habitat in the face of wildfire and beetle attacks, the juxtaposition of remaining foraging habitat to colony sites, reproductive success in the next few years, the rate of new cavity excavation, interspecific competition for cavities, and the success of restoration efforts.

IMPACT ON THE FOREST

The destruction of pines that were not cavity trees was also severe. Quantitative data are not yet available, but it is thought that at least 50-60 percent of the pine sawtimber trees on the FMNF were destroyed. These trees served as foraging habitat and replacement cavity trees. Not all pine stands were affected equally by winds of the same force. Damage to the forest appeared to be a function of both tree age and number of trees per acre. Sapling and young pole stands were frequently heavily damaged, but many of these may still be manageable without regeneration. Many stands in the 30-40 year age class escaped with moderate damage. Mature pine stands (more than 80 years old) with low to moderate basal areas (about 70 square feet per acre or less [16.1 m^2/ha]) typically had less than 10 square feet per acre (2.3 m^2/ha) in standing trees after the hurricane. Unfortunately, such stands are the most valuable to the red-cockaded woodpecker as both existing and potential new colony sites. Mature pine stands with high basal areas (more than 90 square feet per acre [20.7 m^2/ha]) escaped some of the strongest winds with moderate damage.

Hugo set the stage for a continuing process of destruction to the forest. Pines that survived the hurricane are subject to attack from engraver beetles (*Ips* spp.) and turpentine beetles (*Dendroctonus terebrans*). Additional trees will die from these attacks. Many of the pines that appear to have survived suffered root, bole and crown damage that will contribute to additional mortality. Also, with the enormous fuel loads the chance of a catastrophic wildfire is great. Only time will determine the final loss to the forest from Hurricane Hugo.

HUGO IN PERSPECTIVE

Hugo is called a "Cape Verde hurricane" because of its origin near Africa (Lawrence 1989). Only a small percentage of such hurricanes make landfall in the United States, but of the 13 that have since 1906, 9 were major hurricanes (category III-IV) (USACE 1986).

Hugo was a powerful category IV hurricane with maximum sustained winds estimated at 135 mph (217 km/hr) at Bulls Bay 20 miles (32 km) north of Charleston, S.C. (Lawrence 1989). Near the coast, hurricane force winds (more than 74 mph [119 km/hr]) appeared to have occurred in a band at least 55 miles (86 km) wide. The eye was about 24 miles (39 km) wide (J.V. Purvis, pers. comm.). Sustained winds of hurricane force occurred at least 90 miles (145 km) inland and gusts of 80 mph (129 km/hr) were reported at Hickory, N.C., 220 miles (354 km) inland (Lawrence 1989).

Approximately 14 other hurricanes approaching or exceeding Hugo's strength have made landfall within the range of the red-cockaded woodpecker (Texas to Virginia) since 1899 (NOAA 1977, USACE 1986). Thus, such a storm occurs in the birds range about every six years. Over 100 lesser hurricanes have made landfall during the same period (Neumann and others 1987).

In South Carolina, the periodicity of hurricane landfall is about every six years (about 34 between 1786-1985) (Langley and Marter 1973, USACE 1986). A probable category IV hurricane landed in South Carolina in 1893 and another in 1954 (USACE 1986). Including Hugo, South Carolina has had three category IV hurricanes in the past 96 years. Experts consider Hugo to be a 1 in 100 year event in South Carolina (J. C. Purvis, pers. comm.).

Since 1700, there appear to have been about 18 hurricanes that probably affected the FMNF (Langley and Marter 1973, Calhoun 1983, USACE 1986, Neumann and others 1987). These data suggest the FMNF is subjected to hurricane-force winds about every 16 years. This estimate may be inflated because it is impossible to get specific information about the early hurricanes. However, the mean elapsed time between hurricanes is fairly stable across centuries (1700s = 16.7, 1800s = 14.3, and the 1900s = 17.8). Clearly, not all these hurricanes had the same effect as Hugo, but cavity trees are at risk relatively frequently.

RESTORATION EFFORTS

Cavity excavation typically takes more than one year, and most clans without cavities probably would not survive. Artificial cavities are being constructed in colony sites where there are less than two natural cavities in good condition and at least a minimal amount of foraging habitat remains. Several experimental techniques are being used. The first involves drilling two intersecting holes and then plugging one to create a cavity. An abbreviation of this procedure involving one drilled hole to form a partially completed cavity is also being used. These two techniques were developed by Carole Copeyon, a graduate student at North Carolina State University. A third technique, developed by David Allen, a Forest Service biologist, involves inserting a preconstructed cavity into a rectangular hole cut into a pine tree with a modified chainsaw.

At this writing (15 March), 470 artificial cavities have been installed in 154 colony sites in most immediate need of cavities. These sites require additional artificial cavities as do nearly 100 other sites with inadequate or unsuitable cavity trees surviving.

At least 40 percent of the artificial cavities are in use. In time we think nearly all will be used. Copeyon (pers. comm.) has had red-cockaded woodpeckers nest successfully in the drill cavities. Thus far, birds have not had an opportunity to nest in the preconstructed cavities (Allen, pers. comm.). Hopefully, the man-made cavities will sustain the population long enough for the birds to excavate their own cavities.

Effort is being made to salvage as much of the approximately 1 billion board feet of destroyed timber as possible. Salvage benefits the red-cockaded woodpecker by reducing both fire and beetle hazard, and offers a better chance to control adverse midstory conditions that would be severely detrimental to the red-cockaded woodpecker. Unfortunately, less than 25 percent of the salvageable timber will probably be removed before it deteriorates. To benefit the woodpecker, all standing live pines, unless leaning more than 45 degrees (and thus most likely to have sustained fatal root damage) are being retained during the salvage.

Fire suppression efforts are intense. They are aimed at preventing fires through construction of about 100 miles (160 km) of fuel breaks and through public education, and at the rapid detection and suppression of fires. Thus far since the hurricane, 49 wildfires have been suppressed before they could develop into a major fire.

DISCUSSION

The red-cockaded woodpecker and the coastal plain forest evolved with hurricanes. A review of hurricane periodicity shows that hurricanes are not rare events in the southern coastal plain. Even major hurricanes such as Hugo should not be considered rare in the context of providing habitat for a viable population of red-cockaded woodpeckers in perpetuity. The question is not if a hurricane will hit, but when. Given that truism, a more important question is how then to protect the red-cockaded woodpecker in the face of continuing disasters.

The best biological answer is appealing but impractical: revert back to pre-Columbian conditions. In that era, hurricanes no doubt destroyed large areas of red-cockaded woodpecker habitat and killed large numbers of the birds, but had relatively little impact on the species as a whole. Now, with the bird existing in habitat islands, hurricanes are a menace to the species.

The next best answer is to have as many geographically large populations as possible. An extensive population is desirable because a single hurricane is less likely to destroy the entire population beyond the point that it can recover. Cooperative management agreements with owners of private land adjacent to public land with red-cockaded woodpeckers may be the most practical way to increase the geographic extent of a population.

More study is needed, but we are intrigued by the apparent direct relationship between stand density (trees per acre) and tree survival. Others have observed a similar relationship following hurricanes (Trousdell 1955, Trousdell and others 1965). It might be possible to "hurricane proof" a forest by having more densely stocked stands of pine than is currently practiced. Survival of pine stands appears to be age related also. Thus a balance of age classes and a spatially uniform distribution of stands within age classes seems beneficial. Cavity trees appear to be two to four times more vulnerable than trees without cavities and we doubt that many could survive hurricane force winds. However, the more foraging habitat and potential cavity trees that survive a hurricane, the more probable the recovery of a population.

The damaging effects of hurricanes are well delineated geographically and damage lessens as one moves out from the area of most intense winds. For example, with Hugo, cavity trees were destroyed in a band 52 miles (84 km) wide, but loss of cavity trees varied from more than 90 percent to less than 40 percent within this band. Thus, having colony sites uniformly dispersed within the geographic limit of a population (as opposed to having most of the colony sites clumped in one area) would lessen the chance of losing an entire population.

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ECONOMIC VALUATION OF THE RED-COCKADED WOODPECKER AND ITS HABITAT

Dixie Watts Reaves, Randall A. Kramer, Thomas P. Holmes[1]

Abstract--The issue of how to assign economic values to goods which are not traded in the marketplace is a controversial one. When goods have no proxy in an established market, a non-market valuation technique can be used. Natural and environmental resources generally fall into this category, and the endangered red-cockaded woodpecker (*Picoides borealis*) (RCW) is one such example. The red-cockaded woodpecker population and its habitat in the Francis Marion National Forest (near Charleston, South Carolina) suffered damages from Hurricane Hugo. The economic value of these losses was assessed using the contingent valuation method (CVM). A hypothetical market was developed for the good to be valued, and individuals were asked how much they would be willing to pay for the good, contingent on the described setting. Individuals were asked to value different population restoration levels of the RCW in Francis Marion National Forest, to value restoration of the Francis Marion National Forest if the endangered RCW did not exist there, and to value more intensive management of all RCW populations in the United States. Data were collected by mail survey from a randomly drawn national sample. Results indicated that individuals were willing to pay between 8 and 14 dollars, on average, for restoration activities.

BACKGROUND AND JUSTIFICATION

With the renewed interest in environmental quality, recent research has focused on improving methods to value environmental amenities. In order to value the commercial components of an environmental good, one merely uses market prices. However, there is often a need to value non-market components, and that was the focus of this research: to use the contingent valuation method (CVM) to determine the social value of protecting and restoring the endangered red-cockaded woodpecker (RCW) and its habitat, the old-growth longleaf pine (*Pinus palustris*) ecosystem.

Since the U.S. Forest Service is mandated to manage for multiple uses, there is a specific need for the valuation of these non-market goods:

> The Forest Service, U.S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation (USDA Forest Service).

The Forest Service, given this multiple use mandate, needs to know how to allocate limited budgets among competing needs. In an economic sense, the Forest Service needs to know the appropriate weights to use in a multiple use objective function. Market prices can be used as the weights for commercial outputs of a National Forest, but non-market techniques must be used to estimate weights for the non-commercial outputs.

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The Longleaf Pine Ecosystem

The longleaf pine ecosystem, ranging naturally from Virginia to Florida and west to Texas, is one of the most unique and diverse ecosystems in the temperate zone. It serves as habitat for numerous species including deer, quail, turkey, and squirrel, as well as providing forage for cattle. It is also home to the RCW, a federally-listed endangered species. The longleaf pine forest, when regularly burned, has an open, park-like appearance, and provides numerous recreation opportunities. The longleaf pine is an excellent timber tree, offering a wide range of forest products. Given its characteristics, the longleaf timber type is well adapted to multiple-use management because of the many forest products it supplies, the forage it produces, the wildlife it supports, and the recreation it affords (Boyer and Peterson 1983).

Only the forest product component of the longleaf pine ecosystem is valued in the marketplace. One objective of this research was to provide the U.S. Forest Service with an estimate of value for some of the non-commercial components. Valuation focused on one particular geographic component of the overall ecosystem (the Francis Marion National Forest), as well as one particular species (the RCW) which uses the old-growth longleaf pine forest as habitat.

Hurricane Hugo

On the evening of September 21, 1989, Hurricane Hugo scored a direct hit on the Francis Marion National Forest (FMNF), located in coastal South Carolina. The FMNF contained a significant remnant of old-growth longleaf pine forest, and served as the home to the RCW. The RCW population in the FMNF was the densest, the second largest, and the only known naturally increasing population. Most of the RCW cavity trees for nesting and roosting were destroyed (87%), much of its foraging habitat was damaged (50-60%), and many of the birds were killed (63%) [Hooper and others 1990]. The Forest Service is mandated by the Endangered Species Act to take steps to recover the species, and much restoration work has already been carried out, including the drilling of artificial cavities (Watson and others 1994). For future management decisions, the Forest Service needs to assess the benefits and costs of further restoration, and of potential prevention of similar destruction. Thus, they need estimates of the value of the endangered species, its habitat, and the unique ecosystem in which it lives. This valuation can be extended beyond the damages to FMNF to include the overall valuation of the unique and diverse old-growth longleaf pine ecosystem which serves as habitat for the RCW.

STUDY OBJECTIVES

Since these environmental goods are not typically valued in the marketplace, non-market valuation can be employed to estimate values for the goods. The contingent valuation method (CVM) was used to determine dollar values for the following:

(i) restoration of the RCW population to two different population levels in the Francis Marion National Forest in South Carolina,
(ii) preservation of all RCW populations in the United States, and
(iii) restoration of the Francis Marion National Forest if the RCW did not exist there.

A second objective of this research was to make contributions to the non-market valuation literature by testing hypotheses about the values obtained when using the contingent valuation method.

THE VALUATION OF NON-MARKET GOODS

Non-market goods are goods for which markets are nonexistent, incomplete, or institutionally restrained from reflecting the free interplay of supply and demand (Peterson and Randall 1984). Two common characteristics of non-market goods are nonrivalry, where consumption by one individual does not decrease the amount of the good available to other individuals (up to the point of congestion), and nonexclusiveness, which results from incomplete property rights. One public good that fits this category is the nation's highway and bridge system. Less common examples of this type of good are ecological diversity and stability, and the continued existence of endangered species. These environmental amenities can be enjoyed by many people simultaneously, either through sight-seeing, reading about them, looking at photographs, or just appreciating the fact that they exist in an undisturbed state. This represents the non-rivalry characteristic of the goods. The fact that these amenities can be enjoyed by people who do not pay directly for the preservation of the goods represents the nonexclusiveness of the goods.

When prices do not exist for goods in the market place, or when prices are institutionally set and do not truly reflect consumer preferences, such as in park entrance fees, some method of valuation is needed. Economists often turn to Hicksian measures (Mitchell and Carlson 1989). An equivalent measure is the amount of compensation, paid or received, which would bring the consumer to his subsequent welfare level if the change did not take place. For example, if environmental quality increases from Q to Q', an individual's utility increases from U to U'. If quality did not increase, willingness to accept (WTA) indicates the amount that the individual would have to be paid to attain utility level U'. Another Hicksian measure is the compensating measure and is the amount of compensation, paid or received, which would keep the consumer at his initial welfare level if change did occur. As an example, consider the case described above where an increase in quality from Q to Q' leads to an increase in utility from U to U'. Now, assume the change does take place. Willingness to pay (WTP) indicates the amount of money that one could take from the consumer and leave him or her at the initial utility level, U.

There are 4 Hicksian measures. In the compensated case, WTP^c refers to the willingness to pay for an increase in Q and is a measure of individual benefit. For example, an individual might be willing to pay to ensure a higher population level of the RCW. WTA^c refers to the willingness to accept a decrease in Q and measures individual costs or negative benefits. On the other hand, the equivalent measure, WTP^e, is the willingness to pay to avoid a threatened decrease in Q (for example, a decrease in RCW population size), and WTA^e is the willingness to accept compensation in lieu of a promised increase in Q. In this study, both types of willingness to pay measures were estimated.

Benefit-Cost Analysis (BCA) is one empirical test for potential Pareto-improvements (PPI's). A PPI is one where those who would gain from a proposed change could compensate those who would lose, to the full extent of their perceived losses. If this were the case, i.e. if the sum of the money-valued gains as judged by the gainers exceeded the sum of the money-valued losses as judged by the losers, then the change would be acceptable. In order to make use of the benefit-cost criterion in public policy decisions concerning environmental goods, one must have monetary measures of benefits and costs. Shaw (1984) raises 3 key questions that are relevant for the valuation of environmental resources:

(i) What are the environmental products that are being valued (recreational, aesthetic, educational, biological, social, and/or commercial uses)?
(ii) Who is benefitting from the resource (direct consumptive users, direct nonconsumptive users, and indirect or vicarious users)?
(iii) How well can the resource value be assessed in quantitative terms (i.e., how precise and valid are the valuation approaches, and how much of the total resource is being valued)?

This research addressed these 3 questions as they related to the valuation of restoration of Hurricane Hugo damages to the FMNF and the valuation of the unique ecosystem, the old-growth longleaf pine forest.

EMPIRICAL APPLICATION OF THE CONTINGENT VALUATION METHOD

The CVM is based on utility theory where an individual derives utility from market goods, X, and non-market environmental goods, Q, and maximizes that utility subject to a budget constraint. Borrowing from Bergstrom and Stoll (1987), let a multidimensional non-market good be denoted as

$$Q=Q(a_1,a_2,\ldots,a_n),$$

where, in this case, Q is the forest ecosystem and each a_i is a component of the ecosystem (e.g., the RCW). The components of Q are assumed to be provided in quantities exogenously determined by policy. An individual consumer's utility function can be defined as

$$U=U[X,Q(a_1,a_2,\ldots,a_n);S],$$

where S is a vector of attributes of the individual that may affect preferences (e.g., age, sex, and participation in outdoor activities). Each component of Q is assumed to have positive marginal utility:

$$\frac{\partial U}{\partial Q}\times\frac{\partial Q}{\partial a_1}>0.$$

Simply stated, an increase in the RCW population increases the individual's utility.

Suppose a policy change will increase all components of Q from the original level, $Q^0 = Q(a_{10},a_{20},...a_{n0})$, to some higher level, $Q^1 = Q(a_{11},a_{21},...a_{n1})$. To determine willingness to pay for this increase in Q, one needs to specify the indirect utility function, which is derived by maximizing utility with respect to the budget constraint, and substituting the resulting demand equations into the utility function. This yields the indirect utility function,

$$V=V[P,Q(a_1,a_2,\ldots,a_n),M;S],$$

where P is the price vector for market goods and M is money income. The expenditure function is the inverse of the indirect utility function,

$$M=E[P,Q(a_1,a_2,\ldots,a_n),U^*;S],$$

which is derived by minimizing expenditures subject to attaining a given level of utility, U^*.

The derivative of the expenditure function, with respect to Q, yields the inverse Hicksian demand function for changes in all components of the non-market good, Q:

$$g=\frac{\partial E}{\partial Q}=E_Q[P,Q,U^*],$$

where g is the marginal willingness to pay (WTP) for a change in Q, the vector of ecosystem outputs. Total WTP for a non-marginal change in Q from Q^0 to Q^1 is calculated as

$$WTP^Q=\int_{Q^0}^{Q^1}[E_Q(P,Q,U^*)]\,dQ.$$

One may also be interested in calculating the willingness to pay for an increase in one component of Q, say a_1, the RCW population. This can be done by differentiating the expenditure function with respect to a_1 while holding all other components constant. The resulting Hicksian demand function for a_1 is denoted by

$$Z=\frac{\partial E}{\partial a_1}=\frac{\partial E[P,Q(a_1,a_2,\ldots,a_n),U^*]}{\partial Q}\times\frac{\partial Q}{\partial a_1}.$$

Z represents the marginal WTP for a marginal change in a_1. Total WTP for a change in a_1 from a_{10} (the current RCW population size) to a_{11} (the desired RCW population size) can be calculated by integrating the Z function from a_{10} to a_{11}. This is one value that was estimated in this research project using the contingent valuation method. WTP for other components can be derived theoretically in the same manner.

For the environmental commodities of interest in this study (an endangered species, its habitat, and associated ecosystem), the primary sources of value are off-site use (e.g., viewing photographs and watching television specials) and the knowledge of their existence. Randall, Hoehn, and Swanson (1990) state that current methodology suggests the measurement of off-site values concurrently with existence values in a contingent valuation framework. Willingness to pay for an improvement in the commodity can be denoted EV (as in existence value), where EV is calculated as the decrease in income that the consumer is willing to accept in order to achieve an increase in Q. Initial utility is equal for initial levels, Q^0 and M, and subsequent levels, Q^1 and M-EV:

$$U^0=V(P,Q^0,M;S)=V(P,Q^1,M-EV;S).$$

The preference shifter, S, will be suppressed in future discussion. For the purposes of this study, the vector Q can be thought of as representing the unique and diverse old-growth longleaf pine ecosystem. Components of the ecosys-tem include numerous plant and animal species, including the endangered RCW. Individuals were asked to value the specific species, the species' habitat, and the eco-system in and of itself.

A NATIONAL SURVEY: DISCUSSION AND RESULTS

To elicit individual consumers' values for the goods in question, Dillman's (1978) Total Design Method (TDM) was used in a mail survey. In a pretest, the survey was sent to 200 individuals: 50 in South Carolina, 50 in Mississippi, 50 in Indiana, and 50 in Montana. *A priori*, it is expected that those people in the states where RCW exists (in the pretest, South Carolina and Mississippi) were more likely to be aware of the good, to have a positive value for the good, and to respond to the survey to indicate that value.

The goals of the pretest were to test the survey instrument, to determine appropriate dollar value ranges to use in the full survey, and to obtain some preliminary estimates of value for RCW population restoration. The overall response rate for the pretest was 21%. This level of response is to be expected for a mail survey which included only a reminder postcard follow-up. As expected, individuals in South Carolina seemed more concerned for the good in question, as proxied by their higher response rate to the survey (26%). Since the longleaf pine ecosystem and the RCW are also found in Mississippi, but not in Indiana or Montana, it was expected that Mississippi, too, would have a higher interest in the good and, therefore, a higher response rate. This was not true, however, as both Mississippi and Indiana had a response rate of 20%. Seventeen percent of the individuals surveyed in Montana responded to the survey.

In terms of the valuation questions, the pretest was not meant to reveal final valuations, but rather to give an idea of the range of expected values. The valuation questions were prefaced with a discussion of the contingent setting: first, individuals were asked to assume that the Endangered Species Act would not be reauthorized by Congress this year. Therefore, there would no longer be a federal mandate for the protection of endangered species, and there would be no provision for further federal funding for their protection. They were then informed of the hurricane damage to the RCW population in the Francis Marion National Forest. The probability of population survival was stated for different population sizes: at the post-hurricane population size, the population had a 50% chance of survival if minimal restoration activities were undertaken; if no restoration activities were undertaken, the population had a 0% chance of survival; and if intensive restoration activities were undertaken and the population was returned to its pre-hurricane size, it had a 99% chance of survival. These probabilities of survival were chosen so as to be able to estimate how individuals value the reduced risk of losing the population.

Given the contingent setting, individuals were asked how much they would be willing to pay into an independent foundation whose sole purpose would be the protection and restoration of the RCW. Four separate valuation questions were asked:

(i) How much would you be willing to pay into the preservation fund each year to keep the population chance of survival at 50% and to prevent it from dropping to 0%?
(ii) How much would you be willing to pay every year, over and above the amount already stated, to improve the population's chance of survival from 50% to 99%?
(iii) Rather than paying into a fund to restore and protect one single population, how much would you be willing to pay each year into a preservation fund to give all remaining RCW populations in the United States a 99% chance of survival?
(iv) Suppose the RCW did not exist in FMNF. How much would you be willing to pay to restore that ecosystem to its pre-hurricane condition?

The average willingness to pay for each of the 4 valuation questions fell in the 8- to 13-dollar range. Individuals in South Carolina had the highest valuations as expected, followed by Indiana, Montana, and Mississippi. Individuals were willing to pay twice as much, or more, for the higher probability of survival, indicating the higher value people place on reduced risk. However, they were not willing to pay substantially more for the restoration and protection of all U.S. populations versus a single population. This may indicate that a large component of the value that people place on endangered species is existence value: they are concerned primarily with the knowledge that the species exists and not so much with the number of remaining populations. However, this result may also be due to the small sample size used in the pretest. Recall that the primary goal of the pretest was to refine the survey in preparation for the full survey.

After making modifications to the survey instrument based on results and comments in the pre-test, the survey was sent to 1,500 individuals with 750 people randomly chosen in South Carolina, where the primary good being valued is located, and with 750 people randomly chosen throughout the other states of the U.S. This stratification was undertaken in keeping with suggestions in the literature to sample more heavily in areas where a rare trait (here, a positive valuation for the good in question) is most likely to occur (Kish 1965). The response rate[2] for the South Carolina subsample (58.6%) was higher than for the remainder of the United States (50.70%), although not significantly so. Average willingness to pay values for the 4 restoration activities for the two subsamples were as follows. For the 50% chance of survival of the RCW in the FMNF, South Carolina had an average willingness to pay $9.52 on average. For the 99% chance of survival of the RCW in the FMNF, the values were $13.18 and $8.74 for South Carolina and the U.S., respectively. To give all RCW populations in the U.S., a 99% chance of survival, South Carolina residents were willing to pay $8.56. Finally, willingness to pay to restore the FMNF if the RCW did not live there was $13.81 for South Carolina residents and $7.89 for the remainder of the U.S. These average willingness to pay values are significantly different from zero. However, it should be noted that 56% of all citizens surveyed indicated that they would be willing to pay $0[3] for restoration activities for the RCW.

[2] In the full survey, the contingent valuation question was asked using three different elicitation techniques: open-ended, payment card, and dichotomous choice. Results presented here are for the open-ended elicitation technique only.

[3] These zero valuations are included in the calculation of average willingness to pay.

As was expected, average values were higher for South Carolina than for the remainder of the U.S. However, since the U.S. subsample (many of whom may never expect to see an RCW or visit the FMNF) reported a positive average value as well, it can be concluded that a primary portion of the value that individuals place on the endangered RCW is existence value. Individuals all across the United States valued the restoration of the endangered RCW. Not only were U.S. citizens concerned about endangered species, but they expressed concern about ecosystems as well as reflected in the positive valuation for restoration of the FMNF even if the endangered RCW did not live there. This survey has indicated support for continued efforts for the RCW and its habitat.

SUMMARY

This paper has provided a discussion of the theory underlying the valuation of non-market goods, an outline of an empirical model for determining the value of a particular environmental good, and the results from a contingent valuation survey. These preliminary results suggest that individuals did hold some positive value for the endangered RCW and that they would be willing to forego part of their income to improve its chance of survival. Full survey results and a more detailed discussion of policy implications will be presented following the final analysis of the survey data.

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EFFECTIVENESS OF NEST BOXES FOR REDUCING USE OF RED-COCKADED WOODPECKER CAVITIES BY OTHER VERTEBRATES

Susan C. Loeb and Robert G. Hooper[1]

Abstract--The red-cockaded woodpecker (RCW; *Picoides borealis*) is highly dependent on the cavities it excavates in living pine trees. In September 1989 Hurricane Hugo destroyed 87 percent of the active red-cockaded woodpecker cavities on the Francis Marion National Forest (FMNF) in coastal South Carolina. Although over 1,000 artificial cavities have been constructed to replace some of the natural cavities that were destroyed, the number of cavities per colony site is still greatly reduced from pre-Hugo levels. As a result of the reduced number of cavities, interactions with other species appear to have increased. It is estimated that use of cavities by other species reduced the reproductive potential of RCW's during the nesting season following Hurricane Hugo by approximately 20 percent. One method suggested to reduce interspecific competition for RCW cavities is the provisioning of nest boxes in colony sites. The objectives of this study were to determine whether nest boxes in RCW colony sites effectively decrease use of RCW cavities by other species, and if so, whether lower use of cavities by other species increases the survival and reproductive success of the RCW's.

The study was conducted in 1991 and 1992 on the Francis Marion National Forest and included 116 colonies (61 Control colonies and 55 Experimental colonies) in 1991, and 121 colonies (63 Control colonies and 58 Experimental colonies) in 1992. Three blue bird nest boxes (NB's) were placed within each Experimental colony site. All NB's and cavities in Control and Experimental colonies were checked at least twice during the RCW breeding season.

NB's and cavities were used by a variety of vertebrate species but blue birds (BB's) and southern flying squirrels (SFS's) were the most common species. Both species showed a preference for NB's over cavities. Use of Control colonies by all species other than RCW's tended to be greater than those with NB's but this difference was not significant. However, in 1992 there were significantly fewer BB's and SFS's in Experimental colonies than in Control colonies. The presence of NB's had no effect on the reproductive success of the RCW's. Thus, although NB's can reduce the number of potential competitors in RCW cavities, this reduction is small and has little impact on the RCW's.

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CHARACTERISTICS OF TIMBER STANDS CONTAINING SUFFICIENT HEARTWOOD FOR CAVITY EXCAVATION BY RED-COCKADED WOODPECKER CLANS[1]

Alexander Clark, III[2]

Abstract--The relationship of heartwood development in loblolly (*Pinus taeda* L.) and longleaf (*P. palustris* Mill.) pine stands with site quality, stocking, stand age and average dbh of dominant and codominant trees is presented. This information is important to forest managers and biologists managing the recovery of the endangered red-cockaded woodpecker (*Picoides borealis*) (RCW). Twenty-nine loblolly and 22 longleaf pine stands representing a range of age classes (30 to 100 years) and site indexes (50 to 120 feet) were sampled in the Southeast for heartwood and sapwood content at 22 feet above the ground. Regression equations are presented for estimating average heartwood diameter and sapwood thickness at 22 feet using stand age and site index as independent variables. Results indicate that fast-growing loblolly and longleaf pine stands on the better sites will have the highest probability of developing sufficient heartwood for RCW cavity excavation at the earliest age.

INTRODUCTION

Information is available on foraging habitat and trees selected for cavity excavation by RCW clans (Lennartz and Henery, 1985) but little information is available on what timber stands have the highest potential for developing acceptable cavity trees at the earliest age.

The RCW requires a cross-section of at least 5 inches of heartwood at cavity height to envelope its nesting cavity. Cavities can be excavated into sapwood or a combination of heartwood and sapwood but it is rarely done. The RCW normally excavates cavities totally in heartwood and prefers redheart (*Phellinus pini*) heartwood infected trees for easier cavity excavation (Jackson 1977, Conner and Locke 1982, Hooper and others 1991).

Many of the changes that occur when sapwood converts to heartwood are known (Kramer and Kozlowski, 1979). Basically, extractives resulting from differentiation, respiration, synthesis, and degradation of starch are translocated along ray parenchyma cells toward the pith where they accumulate. With restricted respiration because of aspirated pits, starch grains hydrolize and disappear, phenols oxidize and polymerize to form pigments in cell voids and the ray parenchyma cells die in the transition zone between sapwood and heartwood to form heartwood. Thus, heartwood forms an irregular cylinder at the center of the bole and generally decreases with tree height.

Little research has been conducted on southern pine heartwood formation as influenced by environmental factors

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since the 1930's. The relative proportion of heartwood has been reported to vary directly with tree age and negatively with rate of growth (MacKinney and Chaiken 1935). Loblolly and longleaf pines with large crowns and rapid growth on good, moist sites are reported to contain a smaller proportion of heartwood than trees with small crowns from closely stocked stands on poor drier sites (Paul 1932, Bray and Paul 1934).

This paper discusses the relationship of site quality, stocking, stand age, tree dbh and total height with heartwood formation at 22 feet in loblolly and longleaf pine sampled in the Southeast. Linear equations are presented for predicting diameter of heartwood and sapwood thickness at 22 feet using stand characteristics as independent variables.

MATERIALS AND METHODS

A series of stands representing a range of age classes (30 to 100 years) and site indexes (50 to 120 feet) were sampled for heartwood and sapwood content. A total of 29 loblolly pine stands and 22 longleaf pine stands were sampled. Loblolly stands sampled were located on the Oconee National Forest in Georgia, the Francis Marion National Forest, and Belle W. Baruch Forest Science Institute Hobcaw Forest in South Carolina. Longleaf stands sampled were located on the Francis Marion NF and Hobcaw Forest in South Carolina and the Talladega and Conecuh National Forests in Alabama. Four to five dominant or codominant trees were randomly selected within each stand. Dbh, total height, height-to-base of full live crowns were recorded for each tree. A competitive index or point density measurement (ft^2/acre) was determined for each tree using a 10 BAF prism (Spurr 1962). A 12-mm increment core was extracted from each tree at breast height and a 5-mm increment core was removed from each tree at 22 feet.

Each increment core was dried, glued to a core holder, and sanded before staining with a benzidine-sodium nitrite solution to distinguish heartwood and sapwood (Kutscha and Sacks 1962). The age and length of heartwood and sapwood was recorded for each core. Age at 4.5 feet was converted to tree age at stump by adding 3 years for loblolly pine and 6 years for longleaf pine. The age and measurements collected for each tree within a stand were averaged to obtain average stand characteristics. Site index was determined using curves developed by the USDA Forest Service (1976).

Correlation coefficients (r) were developed to evaluate the relationship of heartwood diameter and sapwood thickness at 22 feet with site index, stand age, basal area, average dbh and total height of dominant and codominant trees, crown ratio, and growth rates. Linear equations were developed for each species to predict average diameter of heartwood and sapwood thickness at 22 feet. The following models were used:

$$Y = a + b\,(AGE) \qquad (1)$$
$$Y = a + b\,(AGE) + c\,(SI) \qquad (2)$$
$$Y = a + b\,(AGE) + c\,(THT) \qquad (3)$$
$$Y = a + b\,(AGE) + c\,(DBH) \qquad (4)$$

where:
Y = average diameter of heartwood or sapwood thickness at 22 feet in inches;
AGE = stand age in years;
SI = site index in feet;
THT = average total height of dominant and codominant trees in feet;
DBH = average dbh of dominant and codominant trees in inches.

RESULTS AND DISCUSSION

Average stand age of the two species sampled was 64 years for loblolly and 63 years for longleaf. Average site index of the longleaf stands was 76 feet compared to 86 feet for the loblolly stands (Table 1). The loblolly stands were growing at an average rate of 0.24 inches per year compared to 0.20 inches for the longleaf. The sampled loblolly pine averaged 15.7 inches dbh compared to 13.3 inches for the longleaf pine. There was little difference in the average diameter of heartwood between the two species; loblolly averaged 4.4 inches of heartwood compared to 4.3 inches for longleaf, but loblolly contained an average of 0.8 inches more sapwood at 22 feet than the longleaf.

Heartwood diameter at 22 feet was significantly correlated with stand age and dbh of dominant and codominant trees (Table 2). Diameter of heartwood was not significantly correlated with basal area of either species. Site index was not significantly related with heartwood diameter in the loblolly stands but was significantly correlated with heartwood diameter in the longleaf stands. This significant negative relationship occurred because no old longleaf stands on good sites were

Table 1--Average stand characteristics of the 29 loblolly and 22 longleaf pine stands sampled for heartwood content at 22 feet.[1]

Stand Characteristic	Loblolly Pine	Longleaf Pine
Age (yr)	64	63
Site index (ft)	86	76
Basal area (ft^2)	106	70
DBH (in)	15.7	13.3
Total height (ft)	87	74
Crown ratio (%)	37	20
Growth rate (in/yr)	0.24	0.20
Diameter heartwood at 22 feet (in)	4.4	4.3
Thickness of sapwood at 22 feet (in)	3.7	2.9

[1] Dominant and codominant trees.

Table 2--Correlation coefficients for diameter of heartwood and sapwood thickness at 22 feet with stand characteristics for loblolly and longleaf pine stands.[1,2]

	Diameter of heartwood		Sapwood thickness	
Stand Characteristic	Loblolly Pine	Longleaf Pine	Loblolly Pine	Longleaf Pine
Age	0.87**	0.88**	-0.46*	-0.23^{NS}
Site index	0.06^{NS}	-0.60**	0.51*	0.28^{NS}
Basal area	0.01^{NS}	-0.26^{NS}	-0.19^{NS}	-0.31^{NS}
DBH	0.78**	0.90**	0.26^{NS}	0.33^{NS}
Total height	0.79**	0.57**	0.04^{NS}	0.25^{NS}
Crown ratio	-0.42*	-0.25^{NS}	0.23^{NS}	0.07^{NS}
Growth rate	-0.66**	-0.68**	0.72**	0.41^{NS}

[1] Dominant and codominant trees
[2] Significant at P = .01 = **
Significant at P = .05 = *
Not significant = NS

sampled and the longleaf stands with the most heartwood were old stands growing on the poorest sites. Average annual diameter growth at dbh was negatively correlated with heartwood diameter at 22 feet because the sample trees with the most heartwood were the oldest and growing the slowest.

Sapwood thickness at 22 feet in the longleaf stands was not correlated with any of the stand characteristics measured (Table 2). However sapwood thickness was positively correlated with site index, negatively correlated with stand age and highly correlated with rate of growth in the loblolly stands. This indicates, as expected, that young, fast-growing stands contain more sapwood than older slow-growing stands.

A series of linear regression equations was developed to estimate diameter of heartwood at 22 feet using stand characteristics as independent variables (Table 3). Stand age and site index as independent variables accounted for 78 to 79 percent of the variation in heartwood diameter at 22 feet. The equation based on stand age and average dbh of dominant and codominant trees was the best predictor of heartwood diameter, accounting for 85 percent of the variation in loblolly pine and 93 percent in longleaf pine.

Average predicted diameter of heartwood at 22 feet increased with dbh and stand age (Table 4) and with increasing site index and stand age (Table 5). Thus, the youngest trees that contain sufficient heartwood for normal RCW cavity

Table 3--Regression coefficients for estimating average diameter of heartwood at 22 feet using stand age and age in combination with site index, average dbh and average total height of dominant and codominant trees as independent variables for loblolly and longleaf pine stands sampled in the Southeast.[1,2]

Equation/ Species	Regression parameters and coefficients: Intercept	Age	Site Index	DBH	Total Height	Standard error of estimate $S_{y.x}$	Coefficient of determination R^2	Coefficient of variation C.V.
						(Inch)		(Percent)
Equation 1								
Loblolly	-0.82375[NS]	0.08150**				1.1	0.75	24.4
Longleaf	-0.99334[NS]	0.08408**				1.0	0.77	22.6
Equation 2								
Loblolly	-3.56019*	0.08533**	0.02895*			1.0	0.79	22.8
Longleaf	-4.26668[NS]	0.10046**	0.02989[NS]			1.0	0.78	22.2
Equation 3								
Loblolly	-4.74120**	0.05748**		0.34677**		0.8	0.85	19.1
Longleaf	-5.33817**	0.03882**		0.54004**		0.6	0.93	12.7
Equation 4								
Loblolly	-3.42810**	0.05684**			0.04812**	0.9	0.84	19.5
Longleaf	-3.71733*	0.07402**			0.04556*	0.9	0.82	20.6

[1] Dominant and codominant trees
[2] Significant at P = .01 = **
Significant at P = .05 = *
Not significant = NS

Table 4--Average predicted diameter of heartwood at 22 feet by stand age and average dbh.[1]

Average dbh	Stand age (years): 50	60	70	80	90	100
(inches)	(inches)					
			Loblolly pine			
14	3.0	3.6	4.1	4.7	5.3	5.9
16	3.7	4.3	4.8	5.4	6.0	6.6
18	4.4	4.9	5.5	6.1	6.7	7.2
20	5.1	5.6	6.2	6.8	7.4	7.9
22	5.8	6.3	6.9	7.5	8.1	8.6
			Longleaf pine			
14	4.2	4.6	4.9	5.3	5.7	6.1
16		5.6	6.0	6.4	6.8	7.2
18		6.7	7.1	7.5	7.9	8.3
20			8.2	8.6	9.0	9.3

[1] Dominant and codominant trees

Table 5--Average predicted diameter of heartwood at 22 feet[1] by stand age and site index.

Site index	Stand age (years)					
	50	60	70	80	90	100
(feet)	(inches)					
	Loblolly pine					
70	2.7	3.6	4.4	5.3	6.1	7.0
80	3.0	3.9	4.7	5.6	6.4	7.3
90	3.3	4.2	5.0	5.9	6.7	7.6
100	3.6	4.5	5.3	6.2	7.0	7.9
110	3.9	4.7	5.6	6.4	7.3	8.2
	Longleaf pine					
50	2.3	3.2	4.2	5.3	6.3	7.3
60	2.5	3.6	4.6	5.6	6.6	7.6
70	2.8	3.9	4.9	5.9	6.9	7.9
80	3.1	4.2	5.2	6.2	7.2	8.2
90	3.4	4.4	5.5	6.5	7.5	8.5

[1] Dominant and codominant trees

excavation (≥5 inches) were the fastest growing trees on the best sites. Based on the values shown in Table 4, sufficient heartwood for RCW cavity activity does not occur in the average dominant on codominant tree until age 50 in loblolly pine and age 60 in longleaf pine and then only in the larger diameter trees. When diameter of heartwood is predicted using site index and stand age the equations show 70-year-old loblolly stands with a site index ≥90 and 70-year-old longleaf stand with a site index ≥80 will contain sufficient heartwood for RCW cavity activity.

The same stand characteristics used to estimate heartwood diameter were used to estimate sapwood thickness at 22 feet. However, the only variable combination which accounted for more than 36 percent of the variation in sapwood thickness was equation (4) which is shown below for each species:

LOBLOLLY PINE

$$SAP = 1.74006 - 0.02776\,(AGE) + 0.23516\,(DBH) \qquad (5)$$

LONGLEAF PINE

$$SAP = 1.40648 - 0.02487\,(AGE) + 0.23290\,(DBH) \qquad (6)$$

where

SAP = sapwood thickness at 22 feet in inches.

The sapwood thickness equation accounted for 79 percent of the variation in sapwood in loblolly pine and 73 percent of the variation in sapwood in longleaf pine. Predicted thickness of sapwood decreased with increasing stand age and increased with dbh.

CONCLUSIONS

Diameter of heartwood at 22 feet increases significantly with stand age and tree dbh. Fast-growing loblolly and longleaf pine stands on the better sites will have the highest probability of developing sufficient heartwood for RCW cavity excavation at the earliest age. At age 70, the average dominant or codominant tree in a loblolly stand with a site index ≥90 and in a longleaf stand with a site index ≥80 will contain sufficient heartwood (≥5 inches at 22 feet) for RCW cavity activity.

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RESTORATION OF THE RED-COCKADED WOODPECKER POPULATION ON THE FRANCIS MARION NATIONAL FOREST: THREE YEARS POST HUGO

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Abstract--The Francis Marion National Forest (FMNF) once supported the second largest and only documented naturally increasing population of red-cockaded woodpeckers (RCW). Prior to Hurricane Hugo, an estimated 477 RCW groups existed on the FMNF. Hugo destroyed 87% of the active red-cockaded woodpecker cavity trees on the Forest and killed 63% of the woodpeckers. In addition, 59% of the birds' foraging habitat, nesting habitat, and potential cavity trees were destroyed. By the nesting season of 1990, 537 artificial cavities had been installed and there were 249 groups. Forty-five percent of RCW nests were in artificial cavities and 302 young were fledged. In the 1991 breeding season, there were 306 groups, 483 young were fledged and 60% of the nests were in artificial cavities. In 1992, there were 332 groups, 500 young were fledged, and 61% of the nests were in artificial cavities. Following the catastrophic loss of woodpeckers and their habitat in 1989 from Hugo, the number of adult RCWs and the number of groups had increased 33% by 1992. This remarkable increase, despite the severe losses of nesting and foraging habitat, cavity trees, and individual birds, resulted primarily from installation of artificial cavities.

INTRODUCTION

The Francis Marion National Forest (FMNF) is unique in several respects in regard to the red-cockaded woodpecker (*Picoides borealis*). The RCW population on the FMNF was the second largest, one of the densest, and the only population known to be naturally increasing (Hooper et al. 1990); and it was one of the few populations near a recovered level. It was also the first population, following classification of the bird as endangered, to have been impacted by a major hurricane (Hooper et al., in press).

Hurricane Hugo, a Category IV hurricane at landfall, hit the FMNF on 21-22 September, 1989 (Townsend 1990). The center of the eye passed within 5 miles of the FMNF and the track of the hurricane was such that the FMNF received the strongest winds generated by the hurricane. Hurricane force winds occurred in a band greater than 50 miles wide and affected the entire FMNF (Hooper and McAdie 1994). As a result, catastrophic loss to RCW cavity trees, RCWs, and RCW foraging habitat occurred.

Hurricanes will be a continual threat to most recovery areas. Hooper and McAdie (1994) estimated there will be 4 recovery areas hit by major hurricanes

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every 100 years on average with 39 less intense hurricanes hitting the 11 most vulnerable recovery areas. The FMNF, recently impacted by a major hurricane, is one of these recovery areas. Clearly managers will be dealing with restoration efforts in the future because of the periodicity of hurricanes impacting RCW populations. Our experience following Hugo should be of value to managers because our efforts have led to a remarkable and unprecedented increase in an RCW population following a catastrophic event.

IMPACTS OF HURRICANE HUGO

Impacts to the Forest

Extensive damage to timber resources from hurricanes is not an unusual ocurrence (Van Hooser and Hedlund 1969, Hook et al. 1991, Hooper and McAdie 1994). In South Carolina, approximately 10.8 billion board feet (bf) of sawtimber on 4 million acres of forested lands were destroyed by Hurricane Hugo (Sheffield and Thompson 1992).

Destruction of pine trees on the FMNF that represented RCW habitat was catastrophic. Initial estimates of destroyed pine sawtimber on the FMNF were between 700 million and 1 billion bf or about 50-60% of pine sawtimber (Hooper et al. 1990). Data from the Forest Inventory and Analysis (FIA) Research Work Unit of the Forest Service's Southeastern Forest Experiment Station indicated a 56% loss of pine trees greater than or equal to 10" dbh with about 2.44 million stems surviving (Table 1). CISC (Continuous Inventory of Stand Condition) database information indicated a slightly higher loss of pine sawtimber with approximately 2.28 million pine trees greater than or equal to 10" dbh surviving Hugo (Table 1). This represents a 59% loss of pine sawtimber on the Forest.

Not all pine stands were equally damaged by winds of the same force (Hooper et al. 1990). Damage appeared to be a function of both tree age and basal area (ba). Sapling and young pole stands survived well with varying degrees of damage. Stands in the 30- to 40-year age class generally escaped with moderate damage (Figure 1). Most of these younger stands can be managed without regeneration. Mature pine stands with low to moderate basal areas (70 sq/ft ba) typically had less than 10 sq/ft ba after the hurricane.

Table 1--Number of pine stems in Francis Marion National Forest (x 1000)

Size	1936[1]	Pre-Hugo 1986[2]	Post-Hugo 1990[3]	Survival (%)
5-9" dbh	3,102	-----	6,681	44
>10" dbh	2,960	5,539	2,280 (2,442)[2]	41[2]

[1] Grumbine, A.A. 1936.
[2] Data are from inventories conducted in 1986 and 1990 by the Forest Inventory and Analysis Research Work Unit, Southeastern Forest Experiment Station, Asheville, NC.
[3] Data are from updated Continuous Inventory of Stand Condition (CISC) database from the Wambaw and Witherbee Ranger Districts of the FMNF after Hurricane Hugo.

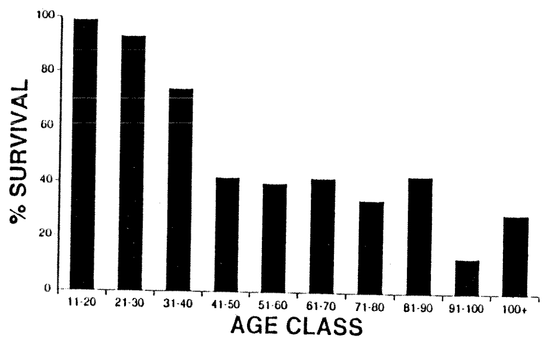

Figure 1--Percent survival of pine on the Francis Marion National Forest after Hurricane Hugo.

Most of the killed pine trees broke off at about 1/3 the height of the tree and the remaining were uprooted. Mature pine stands with high basal areas (90 sq/ft ba) escaped some of the strongest winds with moderate damage.

Hugo not only inflicted massive destruction to RCW nesting and foraging habitat in the form of broken and wind-thrown trees, but also created conditions for a continuing process of short-term habitat loss. Many pine trees that initially survived suffered root, bole, and crown damage that contributed to additional mortality. Remaining trees were subject to attack from engraver beetles (*Ips* spp.), turpentine beetles (*Dendroctonus terebrans*), and southern pine beetles (*Dendroctonus frontalis*).

Insect populations, suspected to be SPB, reached outbreak status within 9 months of Hugo's landfall and lasted through the summer of 1990. Through October 1990 there were 343 distinct infestations, mostly from Ips beetles in pine sapling stands on the FMNF. Long periods of hot dry weather during the summer of 1990 are thought to have considerably slowed down further spread of Ips infestations by making host material unsuitable to attack (P. Barry, pers. comm.). Basal area in sawtimber stands was so reduced from the storm that SPB outbreaks were limited and confined. Not all acres infested required control, but a total of 526 acres of potential and current RCW habitat was lost to insect infestations. Although not as dramatic as the loss of habitat from Hugo, the attrition of pine stems from these cumulative impacts is continuing to contribute to loss of RCW habitat.

Impacts to the Red-cockaded Woodpecker Cavity Trees

Impacts to the RCW from Hurricane Hugo were also catastrophic. Ligon (1971) suggests that the cavity tree is the single most important feature in the life of the RCW, and the lack of potential cavity trees for excavation was one reason cited for the species decline (USFWS 1985).

Hugo destroyed 87% of the estimated 1765 active cavity trees on the FMNF; only 229 RCW cavity trees remained standing after the storm. Most of the destroyed RCW cavity trees were broken at the cavity (52.8%) while loss of cavity trees from the tree being uprooted or being broken between the cavity entrance and stump was about equal (Table 2). A small percentage (9.9%) of RCW cavity trees died as a result of varying degrees of crown damage. Fifty percent (269/538) of all RCW clusters on the FMNF lost all cavity trees. Forty-six percent (218/477) of the active clusters lost all cavity trees (this included active, inactive, and incomplete cavities), and 57% (272/477) lost all active cavity trees. Only in 2% (12/538) of the clusters did all cavity trees survive. The average number of active cavities per cluster in a sample of 205 clusters surviving Hugo was 1.9 compared to 3.7 active cavities in 100 randomly selected clusters in 1988. Thus, the quality of the surviving clusters was greatly reduced.

Table 2--Type of damage to RCW cavity trees on the Francis Marion National Forest from Hurricane Hugo (n=1028).

Type of damage	# cavity trees damaged	Percent damage by category
Crown gone/cavity present	102	9.9
Broken at cavity	543	52.8
Broken below cavity	194	18.9
Cavity tree uprooted	189	18.4
Total	1028	100.0

Initially, non-lethal damage from Hugo was expected to cause continuing tree mortality (Sheffield and Thompson 1992). A stratified random sample of clusters indicated a net post-Hugo loss of cavity trees prior to the 1991 nesting season of 4.9% and 10.7% prior to the 1992 nesting season (Table 3). These losses included cavity trees that had natural or artificial cavities. Sixteen percent of the loss was attributable to lightning strikes and 14% was the result of Hugo-induced wind damage. Causes for the remainder of the losses were difficult to determine although most such trees showed signs of Ips beetle attack. Mortality was most likely a combination of crown and bole damage from Hugo and secondary attack by insects. Estimated mortality of cavity trees on the FMNF in 1991 was 65 trees and 137 in 1992.

Table 3--Percent mortality of RCW cavity trees by type of cavity on the FMNF after Hurricane Hugo.

	% natural cavities	% inserts	% drilled cavities	% drilled starts	% overall mortality
1991[1]	5.7	4.7	3.0	7.1	4.9[1]
1992[2]	16.2	4.9	7.7	7.7	10.7[2]

[1] 20 of 409 cavity trees sampled died.
[2] 43 of 406 cavity trees sampled died.

Mortality of RCW cavity trees in 1991 was highest for natural cavity trees and cavity trees with drilled starts, while cavity trees with inserts and drilled cavities experienced the least mortality (Table 3). Mortality of cavity trees with drilled starts and drilled cavities was about equal in 1992, while mortality of natural cavity trees was highest. Mortality of trees with inserts increased slightly (Table 3). Mortality for all types of cavity trees increased from 1991 to 1992, but it was apparent that natural cavity tree mortality exceeded that of trees with artificial cavities.

RCWs

When Hugo hit there were an estimated 1908 RCWs on the FMNF (Hooper et al. 1991). The mean number of RCWs per cluster on the FMNF in September prior to Hugo making landfall was 4.0 birds. Although only 12 dead red-cockaded woodpeckers were found in post-Hugo inventory efforts, the mean number of birds per cluster surviving Hurricane Hugo was 1.5 birds. Seven hundred six (706) RCWs were accounted for after Hugo which indicated a loss of 63% of individual RCWs on the FMNF (Hooper et al. 1990).

Seventy-two percent (344/477) of all formerly active clusters, 91% (227/248) of clusters with surviving cavity trees, and 47% (117/248) of those with no surviving cavity trees still supported one or more RCWs after the hurricane. Thus, there were 344 sites that still had one or more RCWs; 117 of these had no cavity trees and 227 had severely reduced numbers of cavity trees. Only 68% (233/344) of these had two or more RCWs, and thus a potential breeding group.

Further significant losses of RCWs most likely occurred from severe winter weather. Most RCWs that survived Hugo were roosting in the open. Temperature dropped to an average of 15.3°F during a 4-day period from 22-24 December 1991 with a low of 11°F on 24 December (NOAA 1989, temperature data obtained from the Santee Experimental Forest head-quarters on the Witherbee Ranger District). A stratified random sample indicated that 579 individual RCWs existed prior to the 1990 nesting season, representing a further loss of 18% of individual RCWs after Hugo hit. Thus, a 70% loss of RCWs occurred on the FMNF after Hurricane Hugo.

RECOVERY EFFORTS

Colony Damage Assessment and Prescriptions

Damage assessment was evaluated and management prescriptions were developed for each cluster. Biologists visited all known clusters within 4 months after Hugo. The number of surviving RCWs and cavity trees were determined and an account was made of the trees suitable for natural and artificial cavities. The extent of foraging habitat for each cluster was also determined. This data provided a basis for our prescription of each cluster's potential for restoration. Prescriptions provided information for the priority of artificial cavity installation, placement of restrictors, removal of slash and debris from around cavity trees, needed midstory treatments, and silvicultural and timber management needs.

Priority for rehabilitation of RCW clusters with artificial cavities (given adequate foraging habitat being available) was where:

1) 2 or more birds survived with no surviving cavity trees,
2) 1 bird survived with no surviving cavity trees,
3) 2 or more birds survived with one functional cavity present, and
4) 1 bird survived with one functional cavity. Care was taken not to force the process of recovery by rehabilitating colonies where suitable habitat did not exist.

Artificial Cavity Program

Prior to Hugo, three experimental techniques for constructing artificial RCW cavities had been introduced (Copeyon 1990, Allen 1991). These techniques were a major technological breakthrough in RCW management. Copeyon's techniques (drilled cavities and drilled starts) had been tested in North Carolina and were successful in providing cavities that were used for nesting by RCWs (Copeyon 1991). Allen's technique (inserts) had not been tested during an RCW nesting season prior to Hugo. Copeyon and Allen came to the FMNF after Hugo to teach us how to construct artificial cavities for RCWs.

Our immediate goal prior to the 1990 nesting season was to ensure at least 2 functional cavities per cluster where at least 1 RCW survived and where minimal or adequate foraging habitat existed. The long-term goal is to have at least 4 functional cavities (natural or artificial) per cluster. These actions should contribute to the overall survival of RCWs, provide functional cavities necessary for nesting, and provide sufficient cavities for dispersing RCWs.

As of this writing, 989 artificial cavities of the three types have been constructed in 328 clusters. A major effort prior to the 1990 nesting season resulted in the installation of 537 artificial cavities in 246 clusters, of which 117 clusters did not have any surviving cavity trees. A total of 428 inserts, 319 drilled cavities, and 242 drilled starts have been installed since Hugo, with the number of artificial cavities installed being about equal each of the following nesting years after 1990 (Table 4). The average number of potential roosting cavities per cluster, as of the 1992 nesting season (including natural and artificial cavities), is now 3.6 and essentially the same as the number of active cavities per cluster (3.7) before Hugo hit.

Table 4--Number of artificial RCW cavities installed on the Francis Marion National Forest since Hurricane Hugo prior to each nesting season (nesting season year here is defined as occurring from April 1 of each year to March 31 of the following year).

	1990	1991	1992	1993[1]	Total
Inserts	277	52	27	72	428
Drilled cavities	126	65	89	39	319
Start cavities	134	34	24	50	242
Total	537	151	140	161	989[2]

[1] Number of artificial cavities installed from April 1, 1992, to September 30, 1992.
[2] An additional 70 artificial cavities are projected to be installed prior to the 1993 nesting season for a total of 1,059.

Initial monitoring of artificial cavities to determine use was intensive. At this writing, greater than 90% of all artificial cavities were estimated to be used to some extent by RCWs (maintenance of resin wells, chipping of the entrance tunnel or cavity, roosting, or nesting). As the utilization rate of artificial cavities and the average number of cavities per cluster increased, monitoring activities were reduced. The elapsed time for cavities to be used varied, dependent upon the number of available cavities in the cluster and the number of birds in the group. Some cavities were utilized the same day of construction and approximately 30 are not being used three years after installation. Those not utilized may not have sufficient habitat in those sites to support RCWs. We expect nearly all artificial cavities installed in suitable habitat to be utilized eventually. Time till first use of an artificial cavity also appeared to be related to the degree of simulation of a natural cavity tree. Trees with artificial cavities that simulated the copious resin flow of natural cavity trees were utilized quicker than trees with artificial cavities that were not treated with artificial resin wells (Taylor and Hooper 1991, Copeyon 1990, Allen 1991). Some artificial cavity trees that are now active have enough resin flow developed to be indistinguishable from natural cavity trees. Many of the drilled starts were excavated to complete cavities within 2 months.

Approximately 540 artificial cavities were constructed prior to the 1990 nesting season by Copeyon's and Allen's technique. A modification of Copeyon's technique by Taylor and Hooper (1991) has reduced training time, safety hazards, and improved mobility of work crews. Allen's technique was modified by increasing the depth of the cavity, primarily to reduce competition from secondary cavity nesters. Artificial cavities constructed after the 1990 RCW nesting season utilized the modified techniques. These changes improved already successful techniques, allowed increased efficiency of construction, and resulted in higher utilization of artificial cavities.

Restrictors

Since Hugo, 306 cavity restrictors have been installed. Traditional restrictors recommended by Carter et al. (1989) were installed where cavity enlargement was observed. Full plate restrictors similar to Type A restrictors described by Carter et al. (1989) were placed on inserts when enlargement occurred. Approximately half of the inserts installed have been outfitted with restrictors. The width of the restrictor entrance was increased to 1.75" to allow easy entry and exit by RCWs, and to reduce monitoring efforts. Although no quantitative data are available, we feel that restrictors have most likely contributed to the successful nesting efforts of RCWs since Hugo. Data from the stratified random sample indicates that 25%, 21%, and 20% of RCW nests were in cavities with restrictors in 1990, 1991, and 1992, respectively.

Reproductive Attainment and Population Trend

For the first three nesting seasons following Hugo a stratified random sample of RCW clusters (n=90) was used to estimate reproductive attainment and population trend. The sample was stratified by the level of damage to the clusters: high, medium, and low (this is the same stratified random sample mentioned throughout the text to estimate other parameters of population condition). Clutch size, number of eggs hatching, and the number of nestlings reaching fledgling age was determined. An additional 30 clusters were examined throughout the nesting season for the same nesting activity. Data on competition was also collected in these 120 clusters, 60 of which had 3 bluebird boxes erected in the cluster. The purpose of the bluebird boxes was in part to reduce competition from secondary cavity nesters. Although data on competition has yet to be analyzed, juvenile RCW's were observed using bluebird boxes for roosting in clusters where the number of RCWs in a group was greater than the number of available cavities.

Three years after Hurricane Hugo, all evidence supports the conclusion of a continued improvement in the FMNF RCW population size. An estimated 250 groups with two or more adults were present in the 1990 nesting season (Table 5). The number of groups with 2 or more adults increased each of the first three years since Hugo. Between 1990-91, the number of 2-bird groups increased 23.0%, from 249 to 306. The rate of increase between 1991-92 slowed, but was still 8.5%. Overall, increase in 2-bird groups from 1990 to 1992 was 33.0%, from 249 to 332.

Table 5--Estimated values for RCW population in the Francis Marion National Forest after Hurricane Hugo, based on a stratified random sample of 90 clusters.

	1990	1991	1992
# of clusters	384	384	391[1]
# of adults	607	729	806
Clusters with 2+ birds	249	306	332
Clusters with 1 bird	83	30	27
Clusters with no birds	52	48	31

[1] The increase in the number of clusters from 1991 to 1992 is due to artificial cavities being installed in seven recruitment stands and being managed as clusters.

The increase came mostly from either single birds that successfully attracted a mate or from colonization of vacant clusters (Table 5). The number of clusters with 1 bird decreased by 67% from 1990-92, while the number of clusters with 0 birds decreased by 40% for the same period (Table 5). Relatively large numbers of dispersing RCWs (302, 483, and 500 RCWs fledged in 1990, 1991, and 1992 respectively, Table 6) and the presence of suitable cavities (mostly artificial cavities) has resulted in the occupation of clusters that formerly had 0-1 birds. Additional population increases resulted from an increase in the mean number of birds per group for the three-year period since Hugo. The mean number of adult birds per group during the nesting season has increased each year from 1.5 in 1990, and to 1.9 and 2.1 birds in 1991 and 1992, respectively.

In 1990, 1991, and 1992, respectively, 45,60, and 61% of RCW nests were in artificial cavities (Table 6). Without the use of artificial cavities by RCWs, the current population would most likely be 100-125 groups.

Table 6--Estimated nesting attainment of RCW population on the Francis Marion National Forest after Hurricane Hugo, based on a stratified random sample of 90 clusters.

	1990	1991	1992
# of young fledged	302	483	500
Mean young fledged/group with 2+ birds	1.21	1.58	1.50
% of groups with 2+ birds nesting successfully	72	81	81
% of nesting artificial cavities	45	60	61

Recruitment Stands

Further evidence of the excellent nesting attainment, dispersal of RCWs, and the utility of artificial cavities, has been the colonization of recruitment stands provisioned with artificial cavities. Two kinds of recruitment stands were designated. The first was the traditional recruitment stand with no history of occupation by RCWs (USFS 1985). The second type of recruitment stand designated were clusters totally destroyed by Hugo having suitable habitat available to support a group and not having birds two years after Hugo. Utilizing CISC database information and Geographical Information System (GIS) maps displaying RCW habitat elements, the most likely locations for recruitment stands were determined. Criteria used to delineate recruitment stands were:

1) stands with greater than 40 sq/ft basal area (preferably higher),
2) pine trees> 14" dbh and,
3) the presence of suitable foraging habitat within .5 mile of the proposed site.

The value of this criteria was verified as one recruitment stand, identified through use of GIS, was found to have an active cluster (not previously known) when the stand was visited. Since the 1991 nesting season artificial cavities were installed in 9 recruitment stands; six were in previously unoccupied habitat and two were formerly active, but now destroyed cluster sites. The remaining recruitment stand was a shift of a formerly inactive cluster where all cavity trees had died. The new cluster, approximately .2 mile away from the original site, contained larger trees suitable for artificial cavity excavation. Seven of the 9 recruitment stands were created prior to the 1992 nesting season. Of these 7, 5 successfully fledged young in 1992 (including the inactive cluster we shifted). Of the remaining 2, one is inactive and the other had 1 RCW in 1992. The cluster with 1 bird attracted a second bird after the 1992 nesting season. Two recruitment stands were created after the 1992 nesting season; both are active, with 1 bird at one cluster and 2 birds at the other. The mean period for colonization was 49 days, and all recruitment stands outfitted with artificial cavities are expected to be occupied by functional groups in time. All recruitment stands were located within .75 mile of an active cluster except one that was located 1.25 miles from an active cluster; it became active in 30 days.

Augmentation

Due to the excellent dispersal of RCWs into unoccupied and single bird clusters since Hugo, augmentation efforts were minimal. Three female RCWs were moved from the FMNF to the Savannah River Site after Hugo because these solitary birds had little chance of surviving. Four translocations were conducted within the FMNF similar to those described by DeFazio et al. (1987); two resulted in group formation and successful nests. Because natural RCW dispersal appears to be contributing to the overall growth and health of the population, intensive augmentation efforts within the FMNF are not anticipated.

HABITAT MANAGEMENT

As critical as the artificial cavity program has been in the stabilization and recovery of the RCW on the FMNF, other successful management efforts have played an important role. Salvage of downed timber, fire suppression, and prescribed burning, have been an integral part of the short-term recovery of the RCW. Habitat restoration and timber management efforts will no doubt play an integral role in the long-term recovery of the RCW by establishing much needed RCW habitat.

Salvage Efforts

Post-Hugo, the greatest risks to the remaining pine resource on the FMNF were fire and insect attack. Normal fuel loads in coastal plain forests prior to Hugo were between 1.7-7.1 tons/acre (Hook et al. 1991). Fuel loads after Hugo were in excess of 60 tons/acre, increasing the chances of catastrophic wildfires (and difficulty of suppression) and insect attacks. Salvage guidelines were designed to protect the RCW and facilitate removal of downed timber. Guidelines included surveying proposed salvage areas for RCW clusters before salvage, leaving trees that were leaning less than 45° for RCW foraging, leaving 5 snags/acre for secondary cavity nesters, restrictions on salvage activities during the RCW nesting season, and penalties for damaging cavity trees and potential cavity trees during salvage operations. Following these guidelines resulted in the protection of RCW habitat, reduced fuel loads, and reduced dead and dying wood that attracted insects.

Efforts to salvage the estimated 1 billion bf of downed timber began immediately, and by the end of 1992 approximately 290 million bf of timber had been salvaged, representing about 30% of the downed volume (Table 7). The largest effort was in 1990 with 250 million bf salvaged. In addition, debris was removed and scattered from within 50 feet of existing cavity trees to further reduce the threat of insect attack and damaging wildfires.

Table 7--Timber salvage and thinning volumes in MBF on the Francis Marion National Forest since Hurricane Hugo (MBF=thousand board feet).

	1990	1991	1992	1993
Net salvage volume	249,235	37,805	11,850	298,980
Green volume cut	13,149	------	------	13,149
Thinning volume	2,786[1]	793	1,663	5,242
Total volume cut	265,170	38,598	13,513	317,281

[1] Volume cut before Hurricane Hugo struck the FMNF.

Fire Suppression

Efforts for fire suppression after Hugo included an intensive fire prevention program by the South Carolina Forestry Commission and the Forest Service, and the rapid detection and suppression of wildfires. One hundred ninety miles of fuel breaks were constructed between private lands and Forest Service lands to minimize wildfire hazards to all landholders. Prior to January 1993, 242 wildfires had started on the FMNF. They were rapidly suppressed and only 3,308 acres were burned. No wildfires have resulted in the mortality of cavity trees or RCWs. Many of the wildfires suppressed were determined to be roadside arson, thus salvage efforts played a major role in prevention of catastrophic wildfires by reducing fuel loads near roadsides.

Prescribed Burning

The importance of prescribed fire to the RCW can not be over stated. The RCW does not tolerate hardwood encroachment into the colony site (Val Balen and Doerr 1978, Locke et al. 1983, Loeb et al. 1991, Hooper et al. 1991). Prescribed fire is the most cost effective and ecologically sound method of controlling unwanted hardwoods. No prescribed burning was conducted on the FMNF the first year after Hugo. However, prescribed burning resumed the second year after Hugo with 21,000 acres burned in 1991 and 31,000 acres burned in 1992. In a five-year period (1985-1989) prior to Hugo, an average of 37,600 acres were burned annually on the FMNF, and this level of burning is expected to resume in the near future. Growing season burns, thought to be more efficient in controlling encroachment of hardwoods into clusters, were conducted on approximately 4000 acres in 1992. To further control encroaching hardwoods in clusters after Hugo, 1900 acres were treated with a combination of chainsaws and herbicide.

Reforestation Efforts

Prescribed burning is also playing a key role in reforestation efforts necessary to reestablish suitable RCW habitat, particularly in the recovery of longleaf pine (*Pinus palustris*) stands. Approximately 9,000 acres of longleaf stands have been burned for seedbed preparation and/or brown spot needle blight (*Scirrhia acicola*) control. An additional 6,000 acres have been site prepared and planted to longleaf pine since Hugo.

Efforts to manage loblolly pine (*Pinus taeda*) have also been intensive with 13,700 acres of loblolly pine seedlings fertilized. An additional 12,500 acres of naturally regenerating loblolly pine stands were site prepared by injecting hardwoods with herbicide. Approximately 32,000 acres on the FMNF have regenerated naturally to loblolly pine without any post-Hugo silvicultural treatments (J. Dupre, A. Kiser, pers. comm.).

Timber Management

Timber management practices that promote the growth of pine stands will also have a profound positive effect on future RCW habitat. Hooper et al. (1991) reported that 36% of the pine stands on the FMNF were regenerated from 1957-1987. These stands are now 6-36 years old. Although only 2,224 acres have been pre-commercially thinned since Hugo, the potential for these thinnings is enormous, as is the potential to thin loblolly pine stands naturally regenerating after Hugo. Thinned stands should be suitable as foraging habitat sooner than unthinned stands (Hooper and Harlow 1986). Except for salvage, all timber harvested since Hugo has been from first-time thinning operations (Table 7). Projected thinning volume for the next three years is 38.3 million bf (Table 8), all in pine poletimber 20-30 years old. These young stands suffered little damage and because of the amount of pine stands in younger age classes present when Hugo hit, a relatively large number of young pine stands are available for management.

Table 8--Projected salvage and thinning volumes for the Francis Marion National Forest in MBF for 1993-1995 (MBF=thousand board feet)

	1993	1994	1995	Total
Salvage volume	3,211	----[1]	----[1]	3,211[1]
Thinning volume	18,939	16,022	3,408	38,369[2]
Total	22,150	16,022	3,408	41,580

[1] No projected salvage volume although salvage volume will most likely occur.
[2] Additional volume is being proposed on the Wambaw Ranger District in this three-year period.

DISCUSSION

Three years after Hurricane Hugo destroyed 87% of the active cavity trees and 63% of the RCWs on the FMNF, the RCW population has recovered remarkably. Popular opinion and current literature would have suggested that a continued and severe decline of the RCW population could be expected. Losses from Hugo were thought to be insurmountable: loss of birds, disruption of group composition, loss of cavity trees, the tremendous loss of foraging habitat, and fragmentation of the forest. Instead, the population is at 333 groups, instead of perhaps 100-125 groups or less had there been no restoration efforts. This recovery is primarily due to the implementation of an artificial cavity program and the efficacy of artificial cavities. Forty-five, 60, and 61% of RCW nests were in artificial cavities in 1990, 1991, and 1992, respectively.

Excellent reproductive attainment (Table 6) and dispersal of RCWs produced during the past three nesting seasons has led to this increase. New groups are being formed by RCWs occupying recruitment clusters or by single birds attracting mates. We estimate 1285 RCWs successfully fledged in the three years since Hugo, and these birds have taken advantage of the opportunities provided by single-bird clusters and vacant recruitment clusters. Although no quantitative data on the number of floaters in the population exists, they are present and likely responsible for the quick occupation of recruitment stands with artificial cavities. The number of 2-bird groups has increased annually, but has slowed (8.5% increase in 1992 as compared to 23.0% in 1991). It is unlikely that future increases will be this high because not enough suitable habitat exists at this time to sustain this continued rate of growth.

Currently we see the biggest threats to the population to be:

1) the desire by some individuals, agencies, and organizations for more hardwoods throughout the FMNF;
2) encroachment of both pine and hardwood midstory into RCW clusters;
3) the general lack of potential cavity trees and increased cavity tree mortality;
4) another hurricane.

If successfully implemented, management programs designed to grow more hardwoods throughout the FMNF would have a negative effect on the RCW. Significant increases of hardwood in RCW habitat and potentially suitable habitat would not only most likely cause a loss of groups, but also decrease the potential for growth and expansion of the existing population.

Midstory problems on the FMNF are compounded by the flush of new growth in clusters, in the wake of Hugo opening the forest canopy and stimulating growth of shade intolerant species. It is hoped that an aggressive prescribed burning program combined with mechanical treatments and the application of herbicide can control most of this growth.

Another management challenge includes controlling loblolly pine regeneration in clusters with low basal areas. Our goal is to reestablish foraging and nesting habitat as quickly as possible for long-term recovery of the RCW. However, with loblolly pine regenerating in clusters, fire may be excluded to protect the seedlings and saplings, creating a pine midstory in clusters. Pine encroachment will also cause abandonment of clusters if not controlled (Loeb et al. 1991).

No doubt we will have to develop a strategy that both controls pine midstory and encroaching hardwoods, and facilitates pine regeneration for improvement of RCW habitat.

An important factor that became apparent during the last two years was the increasing mortality of cavity trees. RCWs are making cavities on their own, but the general lack of potential cavity trees and increased mortality of cavity trees may affect some groups. It is likely that some groups can not locate or construct enough cavity trees to offset the mortality of existing cavity trees. A shortage of trees suitable for artificial cavities is anticipated, but the extent of this shortage is unknown. Hopefully, in most cases it will be possible to shift the cluster to another stand. There is no doubt that the current RCW population would be a fraction of what it is now without the use of artificial cavities, and we doubt that the current population can maintain its current level without the continued construction of artificial cavities. However, the rapid development of nesting habitat and the potential for provisioning recruitment stands with artificial cavities will hopefully provide suitable habitat and clusters necessary to recover the population.

Ironically, the amount of sawtimber surviving Hugo is similar to the amount of pine sawtimber that existed when the FMNF was acquired, and the number of pine stems 5-9" dbh on the FMNF now is twice what it was in 1936 (Table 1) (Grumbine 1936). Pine stands 40 years old and younger survived well (Figure 1). Stands that survived Hugo with less than 30 sq. ft. ba were considered sparse or destroyed and were placed into the 0-10 year age class, although some stands categorized as such support RCW clusters and residual trees that represent potential RCW cavity trees. In addition, the number of pine stems ≥ 10" dbh is only slightly less than what was present in 1936 (Table 1) (Grumbine 1936). The FMNF's RCW population recovered largely on its own from the conditions that existed in 1936, despite the fact that the first 30 years of management included cutting of cavity trees and entire clusters in thinnings and regeneration harvests (Hooper et al. in press). By 1989 the population was essentially recovered. Presently, conditions are similar to those in 1936. The number of potential cavity trees surviving Hugo, the potential for developing foraging and nesting habitat quickly, and the amount of pine in regeneration will contribute greatly to the long-term recovery of the RCW on the FMNF. The more foraging habitat and potential cavity trees, the more probable the recovery of the population.

Considering the potential for managing future RCW habitat, it is likely that the RCW population on the FMNF can reach a recovered level (500 active groups or 250 effective groups) in time, assuming another hurricane causing catastrophic losses does not impact the FMNF. Hurricanes hitting the FMNF within the next 50 years would be capable of destroying most of the trees with artificial cavities and many of the trees without cavities that were injured by Hugo. In the next 100 years, 45 hurricanes are expected to make direct hits on the 11 most vulnerable recovery areas (Hooper and McAdie 1994). Four of these hurricanes will bring category III winds to 4 of the recovery areas, 2 of the 4 getting hit twice by such winds. Perhaps the most vulnerable recovery area is the FMNF (Hooper and McAdie 1994). Fortunately, not all of the RCW population and habitat was destroyed, although 3 of 4 major concentrations of RCWs on the FMNF were severely impacted by Hugo. A more uniform spatial distribution of clusters on the FMNF would have resulted in less impacts to the entire population and would be desirable so that concentrations of RCWs would not be severely impacted.

The big lesson from Hurricane Hugo is that an RCW population suffering catastrophic losses can be stabilized and increased, at least over the short term, given that integrated management efforts strive for common goals. This is important considering the expected number of hurricanes to hit recovery areas in the next 100 years (Hooper and McAdie 1994). A myriad of management efforts led to an increase of the RCW population on the FMNF before Hugo, and the continuation of these efforts will no doubt contribute to the eventual recovery of the RCW on the FMNF after Hurricane Hugo. In only three years, the population of RCWs on the FMNF has increased greatly; breeding groups fledged 1285 young, much of this recruitment coming from artificial cavities. Given the enormous impacts to the RCW population on the FMNF in 1989 and its apparent subsequent recovery, it is highly probable and technologically possible that similar results could be achieved on other recovery areas not impacted by hurricanes.

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HURRICANES AND THE LONG-TERM MANAGEMENT OF THE RED-COCKADED WOODPECKER

Robert G. Hooper and Colin J. McAdie[1]

Abstract--Hurricanes will play a major role in the long-term management of the red-cockaded woodpecker (*Picoides borealis*) [RCW]. Historical evidence indicates that hurricanes can destroy extensive areas of forests. Forests are helpless in the face of catastrophic winds, but such winds are limited in extent in hurricanes. Most damage is caused by lesser winds interacting with tree and site factors. It may be possible to enhance tree survival silviculturally by modifying tree factors. The vulnerability of RCW recovery areas to hurricanes is largely determined by their distance from the coast. The 4 most inland of the 15 recovery areas are essentially immune from severe hurricane-induced winds. The mean time between category I and III force winds occurring over 1 or more of the 11 most vulnerable recovery areas is 2 and 16 years, respectively. On average in 100 years, 45 hurricanes are expected to deliver at least category I force winds to 10 of the 11 most vulnerable recovery areas. Six of these hurricanes are expected to bring very destructive winds of at least category III force to 4 of the recovery areas. Repeated hits to the same areas could extirpate their RCW populations. It seems certain that at least 1 recovery area will always be in the process of restoration from hurricane damage. Currently, at least 2 recovery areas are in that process.

INTRODUCTION

Hurricanes have the potential to instantly destroy the habitat of red-cockaded woodpecker [RCW] over large areas. A hurricane's effects can be long lasting, and some probability exists that an area will get hit again before it has had time to recover from its last hurricane.

From 1970 when the RCW was listed as endangered, through 1991, there had been only 0.68 hurricanes per year making landfall within the range of the RCW (from Galveston, TX to the NC-VA border). This is the lowest frequency of hurricanes for any period of similar length since 1899, and is half the frequency from 1899 through 1969 (Neumann et al. 1987). Thus, the first 2 decades of recovery of the RCW were conducted during a lull in hurricane occurrence. During this lull, 5 recovery areas were impacted by hurricanes, and the populations on 2 of these areas suffered significantly. We can probably expect an increase in frequency of hurricanes in the coming decades (Gray 1990). In addition, there is some concern that global climate changes may significantly increase the frequency and intensity of future hurricanes (Walker et al. 1991). It seems evident that hurricanes will have some role in the long-term management of RCW recovery areas (Figure 1). Our paper explores this role.

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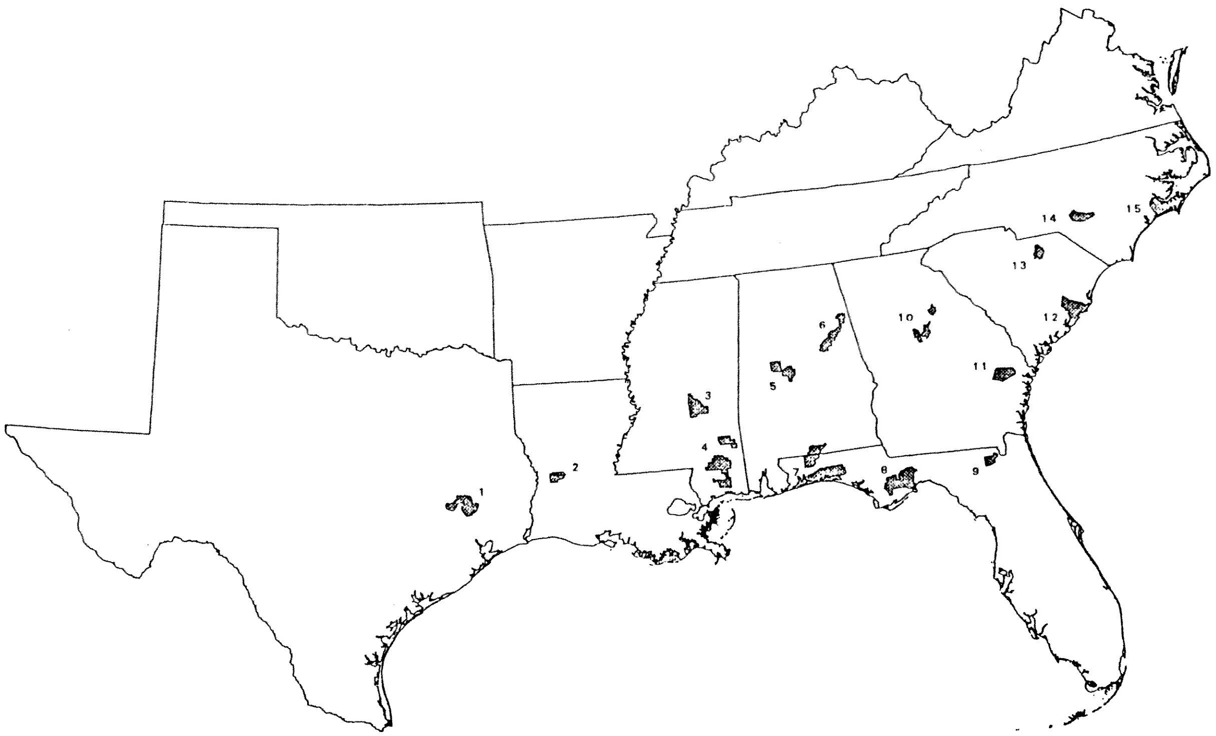

Figure 1--Location of red-cockaded woodpecker recovery sites: (1) Sam Houston National Forest [NF]; (2) Ft. Polk-Vernon District, Kisatchie NF; (3) Bienville NF; (4) DeSoto NF; (5) Oakmulge District, Talladega NF; (6) Talladega-Shoal Creek Districts, Talladega NF; (7) Eglin Air Force Base-Blackwater State Forest-Conecuh NF; (8) Apalachicola NF; (9) Osceola NF; (10) Piedmont National Wildlife Refuge-Oconee NF; (11) Ft. Stewart; (12) Francis Marion NF; (13) Carolina Sandhills National Wildlife Refuge-Sandhills State Forest; (14) Ft. Bragg; (15) Croatan NF (from Lennartz and Henry 1985).

THE HISTORICAL RECORD

Damage to the southern pine forest

In assessing the risk to RCW recovery areas from future hurricanes, it is important to understand the damage these storms can cause to pine forests. One approach is to examine the damage inflicted by past hurricanes (Table 1). Given the human tragedy associated with hurricanes, we suspect that forest damage has frequently gone unreported. Some evidence exists for hurricane damage to forests prior to 1875 (Ludlum 1963), but it is not quantitative either in the extent or degree of damage. Nonetheless, it appears that earlier hurricanes were very destructive to the virgin forests of the time.

By 1900, there was increased economic interest in forest resources in the South (Walker 1991:97-101), and foresters and lumbermen were making quantitative reference to hurricane damage. But we suspect that hurricanes that hit after the old-growth forests had been cut (1885-1930 depending upon region) had relatively little to destroy until fairly recently (say after 1960). Thus, it is difficult to get a clear picture of potential hurricane damage to forests from the historical record alone.

The hurricanes of 1875 and 1900 in Texas did impressive damage to large areas of forests, as did the 1906 hurricane in Mississippi (Table 1). The 1906 hurricane may have done more damage than Hugo. There seems to be a pattern of increasing damage over time beginning with Hazel in 1954 and continuing with Audrey in 1957, Gracie in 1959, Camille in 1969, Federick in 1979 and Hugo in 1989. This trend may be due in part to the increasing age of the southern forest. Hugo was 5 times more destructive to forests in the South than any previous hurricane in the past 4 decades. There can be little doubt

Table 1--Hurricanes that occurred within the range of the red-cockaded woodpecker since 1875 for which forest damage was reported.

Year	State	Damage	Reference
1875	TX	Almost completely destroyed old-growth loblolly in 20X100 mile area.	Bray 1901
1896	FL	Enormous damage to pine in 50-mile-wide strip.	Henry 1896
1900	TX	50% of oak and pine timber in 2000-square-mile area blown down. Nearly 100% of trees down on thousands of acres.	Bray 1901
1906	MS	30-90% of timber in 50X150-mile area blown down.	Dunston 1910
1909	LA	10% of timber in 2 parishes lost. 65% of virgin longleaf blown down.	Foster 1912
1911	AL	Extensive areas of even-aged longleaf established following hurricane.	Boyer 1991
1928	FL, GA	10% of turpentine trees killed.	Annon. 1928
1935	FL	50-75 million board feet of pine blown over in 30-mile wide strip.	Annon. 1935
1947	GA	Many pines and hardwoods in 50X50-mile area were destroyed.	Bradwell 1947
1954	NC	Hazel: widespread but unquantified damage.	Camey and Hardy 1962 Seamon 1954
1957	LA	Audrey: 212 million board feet of merchantable timber killed. 90 miles inland 10 million board feet of virgin loblolly killed.	Derr and Enghardt 1957
1959	SC	Gracie: 580 million board feet of timber damaged.	Flory 1960
1964	LA	Hilda: about 4 million board feet expected to be salvaged.	Hurst 1965
1965	LA	Betsy: 200 million board feet of timber killed.	Robinson 1965 Annon. 1965
1969	MS, LA	Camille: 1.2 billion board feet of sawtimber and 1.3 million cords of pulpwood on 115-mile strip 20-60 miles wide damaged.	Van Sickle and Hedlund 1969; Touliatos and Roth 1971
1975	FL	Eloise: 400,000 cords of pine and 270,000 cords of hardwood damaged.	Wilkinson et al. 1978
1979	MS, AL	Frederick: 3.4 billion board feet of sawtimber (68% pine), plus 881,000 cords of pulpwood damaged.	MFC 1979
1983	TX	Alicia: 56 million board feet damaged in Sam Houston National Forest.	L. J. Carmical, pers. commun.
1985	FL	Kate: 80,000 mostly older longleaf pines destroyed on Apalachicola NF. 100 miles inland, 10% of old-growth longleaf killed.	Bodie 1985; Platt et al. 1988
1989	SC, NC	Hugo: In SC 10.8 billion board feet killed, plus 9.6 billion in critical condition. In NC, 1 billion board feet destroyed.	Sheffield and Thompson 1992; Doggett 1989

that much of the damage resulted from the extensive areas of pine sawtimber in Hugo's path (Sheffield and Thompson 1992). Bray (1901), Foster (1912), and Derr and Enghardt (1957) made special note of hurricane destruction to the old-growth pine forest (Table 1).

Damage to RCW Cavity Trees and Recovery Areas

Note that the references to hurricane strength in the following section are hourly interpolations of maximum sustained winds (1-minute average) near the storm center using estimates of such winds that had previously been made at 6-hour intervals. These data were obtained as part of the printout from the HURISK model (Neumann 1987) we used to estimate average time between hurricane occurrences. The threshold maximum sustained winds for Saffir-Simpson category I, II, III, IV, and V hurricanes are 74,96, 111, 131, 155 mph, respectively (Saffir 1977).

Hurricane Hugo. The Francis Marion National Forest (NF) (Figure 1) suffered catastrophic loss to its RCW population, cavity trees and foraging habitat from Hugo. The storm destroyed 87% of the cavity trees, killed 63% of the birds, and destroyed 70% of the foraging habitat (Hooper et al. 1990). Overnight, the population was reduced from 477 groups down to 239 groups. The 239 groups reflected a response to installation of 537 artificial cavities prior to the first nesting season following Hugo. Without the artificial cavities the number of groups may have been as low as 100 (Watson et al. 1994).

Hugo was a category IV hurricane at landfall, and a category III and then II as it passed over the Francis Marion. The Carolina Sandhills National Wildife Refuge (Figure 1) lost 10% of its cavity trees from Hugo (David H. Robinson, pers. commun.). Had Hugo turned more northerly, loss of cavity trees on the refuge could have been substantial. Severe loss of cavity trees occurred over an area >50 miles wide 15 miles from the coast, to at least 10 miles wide 110 miles inland (Figure 2).

Hooper et al. (1990) thought RCW cavity trees were 2-4 times more vulnerable to wind than trees without cavities. Lipscomb and Williams (1994) found that cavity trees 45 miles from the center of Hugo's storm track were 4 times more vulnerable to wind damage than trees without cavities. Eighty-six percent of the heavily damaged cavity trees broke at the cavity (Lipscomb and Williams 1994).

The hypothesis that RCW cavities weaken trees is supported by Watson et al. (1994), who found 53% of the cavity trees lost in Francis Marion NF broke at the cavity; 10% broke above the cavity and 19% below the cavity, and the remaining 18% were uprooted. Engstrom and Evans (1990) reported 6 of 8 wind-killed cavity trees broke at the cavity and 2 snapped below the cavity.

Other hurricanes. Kate passed over the western edge of the Apalachicola NF (Figure 1) in 1985 with category I force winds. About 80,000 trees, mostly older longleaf pines, were blown down or broken (Bodie 1985). Balboni (1985) estimated more than 80 cavity trees were killed. This number was only about 4% of the cavity trees on the western half of the Apalachicola (Susan M. Fitzgerald, pers. commun.).

Alicia, damaged about 56 million board feet of timber in the Sam Houston NF (Figure 1) in 1983 (L.J. Carmical, pers. commun.). The storm did not have maximum sustained winds of hurricane force by the time it was abreast of the center of the Sam Houston. Wind damage exacerbated a southern pine beetle (*Dendroctonus frontalis*) epidemic which eventually destroyed more timber than Alicia. Conner et al. (1991) reported about 3% of the RCW cavity trees were killed outright by Alicia, but that during the 5 years after Alicia 26% of the cavity trees were lost.

Eloise passed over Eglin Air Force Base (Figure 1) in 1975 as a category III and II hurricane. Significant forest damage occurred on 55-60% of the 400,000-acre area (Wilkinson et al. 1978). Most of this damage was to sand pine (*Pinus clausa*) (Stephen M. Seiber, pers. commun.), a species of little or no value to RCW. Seiber stated that little damage was done to RCW cavity trees because most were west of the storm track.

The DeSoto NF (Figure 1) suffered significant damage from 3 hurricanes starting with Camille in 1969 (Wayne H. Stone, pers. commun.). Camille was a category V hurricane at landfall but had decayed to a category II when

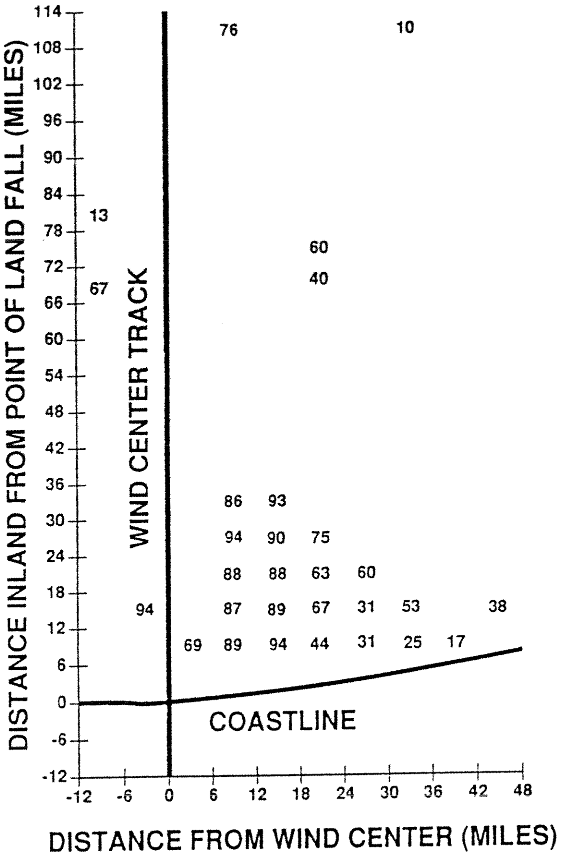

Figure 2--Percentages of red-cockaded woodpecker cavity trees in 6 by 6 mile areas that were destroyed by Hurricane Hugo, relative to the distances from the wind center tract and the coast. Data are from Cely (1991); Lipscomb and Williams (1994); D.L. Carlson, J.E. Cely, C.J. Townsend, D.H. Robinson, J.C. Watson (pers. communications).

abreast of the west side of the DeSoto. Ninety million board feet of timber were salvaged from the DeSoto and it was estimated that at least 12 clusters of RCW cavity trees were destroyed by Camille. In 1975, Frederick passed on the east side of the DeSoto as a category II hurricane when abreast of the DeSoto. After Frederick, 110 million board feet were salvaged from the DeSoto and 9 clusters of RCW cavity trees were destroyed or heavily damaged.

In 1985, Elena passed to the southwest of the DeSoto as a category II hurricane. After Elena, 8 million board feet of timber were salvaged from the DeSoto, and 4 RCW clusters were destroyed or heavily impacted. The DeSoto had only 18 active clusters in 1989 (Dennis L. Krusac, pers. commun.).

FACTORS AFFECTING FOREST DAMAGE

Conceptual forest damage model

Damage to forests varies greatly within the path of a hurricane. A better understanding of this variation might help in derivation of a strategy for dealing with future hurricanes. We can think of the total damage from a hurricane as simply the sum of the damage to individual stands of trees. Stand damage is a function of the hurricane wind field parameters, the position of the stand in the wind field, rainfall, tree factors, and site factors (Figure 3).

Hurricane wind field parameters affecting the potential for forest damage are maximum sustained winds, horizontal wind profile, forward speed of the storm, decay rate as the hurricane progresses inland, associated rainfall, and the frequency, intensity and aerial extent of down bursts. The damage potential of a hurricane is filtered through site and tree factors, which either exacerbate or ameliorate the actual damage that occurs. With catastrophic winds (probably category V force winds), site and tree factors are overridden; any stand subjected to such winds will be destroyed (Hook et al. 1991). However, such winds over land usually occur over a relatively small portion of the area affected by most hurricanes. Thus, most forest damage occurs from an interaction of wind field parameters, tree factors and site factors (Figure 3).

Wind Field Parameters

Horizontal wind profiles. In the northern hemisphere the highest maximum sustained winds usually occur on the right side (facing the direction of forward motion) of hurricanes. The high velocity of wind near the eyewall is supplemented by the hurricane's forward speed (Simpson and Riehl 1981). Thus, forest damage tends to be more severe on the right than on the left side of hurricane tracks. This skewed effect was prominent in Hugo (Sheffield and Thompson 1992, Doggett 1989) and was seen to a lesser extent in Camille (Touliatos and Roth 1971). An exception to this rule occurred with Hazel. More forest damage occurred on the left side of the track because the heaviest rainfall occurred there (Trousdell 1955).

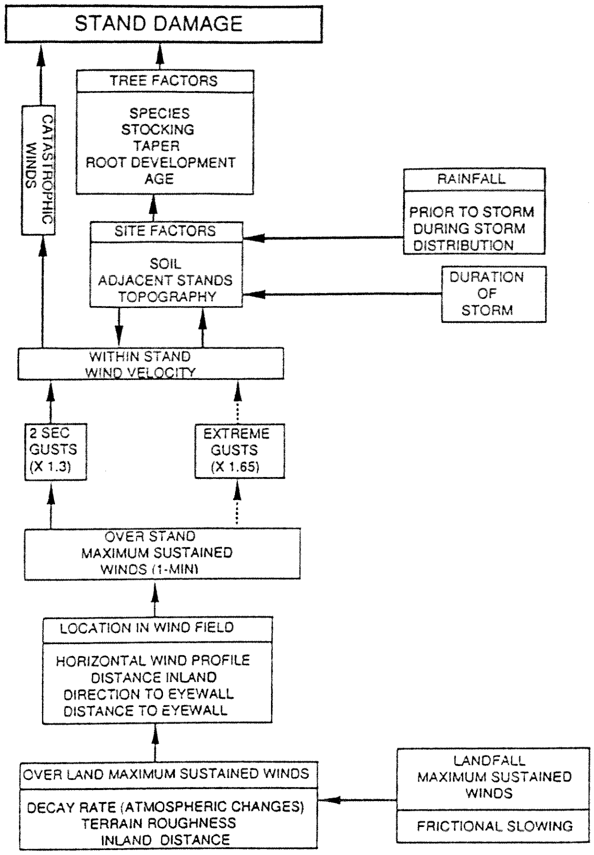

Figure 3--Major factors that affect hurricane damage to an individual forest stand. The total damage to a region from a hurricane is the sum of the damages to individual stands. Because of the relationships shown here, forest damage tends to be patchy.

The radius of maximum winds (RMW) is the "radial distance outward from the center of the eye where the winds reach a maximum value. This typically occurs a few miles radially outward from the eyewall" (Neumann 1987). On average, the RMW varies directly with latitude and inversely with storm intensity, with latitude having the greatest effect. The difference in latitude between the southern-most and northern-most recovery areas is about 5 degrees, resulting in an average increase in RMW of 5 miles (Neumann 1987). Beyond the RMW, wind velocity decreases with distance from the center of circulation. Wind damage follows this same pattern: damage is greatest near the RMW and decreases as one moves away from the hurricane center.

Gusts. Much of the damage to forests may be caused by short-duration gusts (2-4 seconds) resulting from turbulence (Savill 1983); and from extreme gusts associated with extremely convective rainbands, both within and external to the eyewall (Hook et al. 1991, Powell et al. 1991). These gusts may partially explain the patchy occurrence of damage to forests from hurricanes (Bray 1901, Curtis 1943, Derr and Enghardt 1957, Flory 1960, Robinson 1965, Hurst 1965, Wilkinson et al. 1978, Doggett 1989, Hook et al. 1991, Sheffield and Thompson 1992). Damage caused by extreme gusts is probably mistaken for tornadic damage. Tornadoes are associated with about 25% of the hurricanes making landfall in the United States. Typically, when they do occur, tornadoes are found in the right front quadrant of large hurricanes (Anthes 1982:62).

Decay rate. Barometric pressure increases and wind velocity decreases after hurricanes make landfall. The decay rate strongly affects potential damage from a hurricane. Three major physical effects are responsible for the decay of hurricanes over land (Anthes 1982:62). The most important factor may be the sudden reduction in evaporation as the storm leaves the ocean. A second factor is that during the hurricane season, the land is cooler than the ocean and the low-level air is cooled rather than heated by the underlying surface. Lastly, the rougher surface of the land causes more friction than the ocean.

Rainfall

The amount of rain prior to and during hurricanes interacts with soils to greatly increase damage to forests, especially damage from less intense storms. Saturated soils can behave as a liquid, greatly reducing the holding ability of tree roots (Day 1950, Derr and Enghardt 1957, Trousdell et al. 1965).

Damage from Hurricane Hazel was probably lessened considerably by a dry summer and by the rainfall distribution resulting from the hurricane (Trousdell 1955). Heavy rainfall for the 9 months preceding the 1900 Galveston Hurricane was credited with contributing to the enormous forest damage from that storm (Bray 1901). Others have also implicated rainfall as a major factor in wind-related forest damage (Curtis 1943, Grano 1953, Croker

1958, Hurst 1965, Trousdell et al. 1965).

Influence of Tree Factors on Stand Damage

Species. Derr and Enghard (1957) thought slash pine (*Pinus elliottii*) plantations on wet, shallow soils, were more susceptible to windthrow during Hurricane Audrey than loblolly (*P. taeda*) plantations on similar soils. Grano (1953) found loblolly to be many times more wind resistant than shortleaf pine (*P. echinata*) on soils with poor internal drainage. From their experience with Hurricane Camille, Touliatos and Roth (1971) ranked longleaf (*P. palustris*), slash, and loblolly in that decreasing order of resistance to breakage, uprooting, insects and disease.

Hook et al. (1991) found no difference in the loss of longleaf (89%) and loblolly (91%) pines that were subjected to eyewall winds during Hugo. However, in an area 45 miles to the right of the storm track, only 27% of the longleaf was damaged, compared to 52% of the loblolly. In the same area, there was little difference in the percentages of longleaf and loblolly that suffered fatal damage (7.8 vs 9.0%, respectively) (Gresham et al. 1991). Loblolly, however, was much more susceptible to defoliation and top breakage than longleaf (17.5 vs 4.5%, respectively). Some 26.7 percent of the pond pine (*P. serotina*) suffered fatal damage.

Sheffield and Thompson (1992) saw no difference in resistance to wind damage among loblolly, longleaf, slash and pond pine throughout South Carolina from Hugo. But in the Francis Marion NF, where some of the strongest winds occurred, 56% of the longleaf ≥ 10 inches DBH survived, compared to 40% of the loblolly (comparison based on inventories made in 1986 and 1990 by the Forest Inventory and Analysis Work Unit, Southeastern Forest Experiment Station, Asheville, NC).

Pond pine seems highly vulnerable to wind damage. Pond pines often have heartrot and grow on unstable soils (Bramlett 1990). These factors probably account for its vulnerability. Among the other pine species, none seems to have a major advantage over the others in the ability to survive hurricanes. Loblolly may be more windfirm than slash on wetter sites. Longleaf seems to be more resistant to fatal wind damage than loblolly. But, because site and tree factors have not been accounted for in the assessment of vulnerability among species, we are not certain these apparent advantages are real. Comparisons among species are also confounded by the patchy distribution of hurricane damage caused by extreme gusts and downbursts.

Tree age and size. Age and size affect tree survivability in strong winds. Typically, the older and larger trees are more susceptible to fatal wind damage than younger and smaller trees. In what is now the Francis Marion NF, Chapman (1905) reported that windfalls were common in over-mature loblolly (some of the windfall was due to earlier fire damage). In Louisiana, the major causes of tree loss over a 5-year period in a virgin longleaf stand with trees 175-240 years old were windthrow (not of hurricane origin) and bark beetles (Chapman 1923). Windthrow usually occurred after heavy rains (implicating soils) and usually involved the larger, older trees. The major sources of mortality among longleaf > 11 inches DBH in a virgin stand in Georgia over a 4-year period were lightning and wind (54 and 31% of the mortality, respectively) (Platt et al. 1988). Later, Hurricane Kate killed 10% of the larger trees in the stand, about 2.5 times the mortality observed during the 4 years of study. Chapman (1923) stated that hurricanes (as evidenced by the orientation of windthrow mounds) had created even-aged stands in former old-growth longleaf. This statement suggests that the vast majority of canopy trees had been destroyed.

Trousdell (1955) reported that young stands suffered minor damage while older stands, especially those that were recently thinned or had low stocking, sustained significant damage during Hazel. In a 1,365-acre area 50 miles east of the storm track and 70 miles after landfall, Hazel destroyed 6.1% of the pines > 10 inches DBH. Derr and Enghardt (1957) found that Audrey damaged older stands more than younger ones. Stands below merchantable size and 30- to 40-year-old longleaf were not seriously damaged. Managed stands of intermediate age were damaged to varying degrees, and virgin stands of loblolly were heavily damaged. Much of the bole breakage in large loblolly pines was thought to be associated with heartrot.

Pulpwood-sized stands suffered less damage from Betsy than sawtimber stands (Robinson 1965). Touliatos and Roth (1971) reported that older stands suffered the most damage from Camille. Bodie (1985) stated that the majority of longleaf pines uprooted and broken during Kate were older trees.

In an area 45 miles to the right of Hugo's track, mean DBH's of undamaged longleaf, loblolly and pond pine were 11, 7, and 6 inches, respectively; means for trees with fatal damage were 15, 11, and 13 inches, respectively (Gresham et al. 1991). In the Francis Marion NF, loss of pines from Hugo increased as DBH increased (Figure 4). Hooper et al. (1990) reported that sapling and pole stands were frequently heavily damaged but that enough trees survived to make a manageable stand. Many 30- to 40-year-old pine stands in the Francis Marion were moderately damaged and many mature stands suffered very heavy damage. In Congaree Swamp, 90 miles inland, Hugo killed 71% of the loblolly pines 24-30 inches DBH, 45% of those 32-38 inches DBH, and 24% of those more than 40 inches DBH (Putz and Sharitz 1991). It is not clear why those results are contrary to the other studies cited in this section.

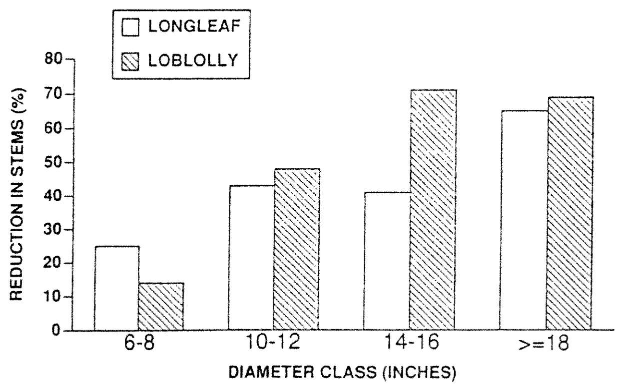

Figure 4--Reduction in the number of longleaf and loblolly pines by diameter classes in Francis Marion National Forest as a result of Hurricane Hugo. Under normal conditions, the percentage change in any diameter class would have been < 5%. Data are from inventories conducted in 1986 and 1990 by the Forest Inventory and Analysis Research Unit, Southeastern Forest Experiment Station, Asheville, NC.

Stand density. Stand damage is inversely related to stand density (stocking), with denser stands surviving better than more sparsely stocked ones. Closed canopies tend to keep wind out of stands (Curtis 1943, Alexander 1964, Gorden 1973, Wilson 1984, Foster 1988). Trees also gain mutual support from adjacent crowns. Recently thinned stands are especially vulnerable to winds if the individual trees have not had sufficient time to develop strong roots and boles, but such trees gradually become less vulnerable as they respond to the increased exposure to wind and the temporary reduction in competition (Mergen 1954, Savill 1983, Kozlowski et al. 1991:491). Hooper et al. (1990) observed that 100-year-old longleaf stands with 110 square feet of basal area were reduced to about 70 square feet of basal area by Hugo. Similar stands thinned to 70 square feet 3 years before Hugo were reduced to less than 10 square feet of basal area. Seed tree and shelterwood stands are vulnerable to windthrow for a long time (Trousdell 1955, Robinson 1965, Savill 1983).

The effect of stand density may be misleading in that trees grown in stands where competition is less intense throughout their life, tend to develop superior wind resistance. Thus, we do not mean to imply here that growing trees in dense stands would necessarily be the best long-term approach to reducing hurricane damage.

Taper. Open-grown conifers with pronounced stem taper are much more resistant to wind breakage from wind than trees grown in dense stands (Curtis 1943, Mergen 1954, Gratkowski 1956, Larson 1963, Assmann 1970:60, Savill 1983, Smith 1986:398). Increased tree taper may be partially a response to swaying caused by the wind; this effect is inhibited in stands with closed canopies (Mergen 1954, Savill 1983, Burton and Smith 1972, Wilson and Archer 1979).

Curtis (1943) found a direct relationship between crown development and resistance to windthrow and breakage. He thought the longer crowns had their geometric centers lower down the bole, which reduced the leverage affect of the wind on the bole. More likely, the trees with longer crowns had more taper and stronger boles (Assmann 1970:60, Smith 1986:100, Farrar and Murphy 1987, Oliver and Larson 1990:83, Nix and Ruckelshaus 1990).

Root development. Mergen (1954) thought that windthrow resulted from compression failure of roots on the leeward side of trees and that roots could be strengthened by exposure to wind during their development. Resistance to uprooting increases as the overall size of the root system increases (Frazer 1962, Coutts 1983). It is generally thought that open-grown trees or at least trees with well developed crowns, have stronger root systems than trees grown in dense stands, and that thinning of stands can improve root development, especially if done when the stands are young, and continued into older age (Mergen 1954, Zahner and Whitmore 1960, Larson 1963, Smith 1986:399, Oliver and Larson 1990, Kuiper and Coutts 1992).

Influence of Site Factors on Stand Damage

Soil. Hardpans and other restrictive layers can halt the development of a taproot in the pines important to the RCW (Boyer 1990, Baker and Langdon 1990, Lohrey and Kossuth 1990, Lawson 1990). Pulling studies have shown that relatively small reductions in root development result in significant loss of wind firmness (Frazer 1962). Thus, it is not surprising that soils have frequently been cited as a primary factor in wind damage to stands, especially when the storms were accompanied by heavy rainfall (Bray 1901, Foster 1912, Pessin 1933, Grano 1953, Croker 1958, Trousdell et al. 1965, Foster 1988). The same restrictive layers that retard root development can also inhibit internal soil drainage. Water-logged soils behave essentially as a fluid with greatly reduced root holding properties (Day 1950, Derr and Enghardt 1957, Trousdell et al. 1965).

Soil texture can also affect wind firmness (Mergen 1954). Trousdell et al. (1965) observed that stands on moderately coarse-textured soils lost 30% of their trees, compared to 5% loss in stands on medium- and fine-textured soils, and 51% loss on soils with restrictive layers.

The effects of soils on root development and wind firmness are important because relatively low velocity winds can cause major forest damage to stands on shallow, coarse or restrictive soils (Bray 1901, Foster 1912, Trousdell 1955, Foster 1988). Thus, if a recovery area has such soils it will be at great risk from even a category I hurricane and category III force winds would cause catastrophic damage.

Topography. Topography strongly influences wind damage to trees (Curtis 1943, Gratkowski 1956, Alexander 1964, DeWalle 1983, Foster 1988, Bellingham 1991). Ridges and valleys accelerate winds in some areas and create protected zones in others. On the lower coastal plain, where hurricane-induced winds are strongest, however, topography is not very pronounced. Topographic influences on hurricane damage to forests, are probably greater in the more inland recovery areas.

Adjacent stands. The more uniform a canopy, the less the damage from wind (Curtis 1943). Gaps in the canopy allow wind to enter the stand and cause damage (Curtis 1943, Gratkowski 1956). In addition, an uneven canopy causes turbulence, a principal factor in gusting. The rougher the canopy and the faster the wind velocity, the greater the turbulence (Savill 1983). In some areas, partial cuts that created small gaps, have led to more wind damage than clearcuts that created large gaps (Alexander 1964). Several studies outside the range of the RCW suggested that overall wind loss decreases as gap size increases (Alexander 1964, Neustein 1965, Gorden 1973).

Two additional studies found no relationship between gap size and damage to adjacent stands (Ruth and Yoder 1953, Gratkowski 1956). The shape of adjacent stand boundaries can funnel and accelerate winds, multiplying damage (Gratkowski 1956 Alexander 1964, Gorden 1973, DeWalle 1983, Conner et al. 1991). The effect of gaps on wind damage decreases if residual trees have time to respond to increased growing space and become more windfirm.

EXPECTED FREQUENCY OF FUTURE HURRICANES

The HURISK Model

No one can predict when a hurricane will hit a recovery area, however, it is possible to estimate the mean elapsed time between hurricanes (return period). Neumann (1987) developed a model, HURISK, for estimating return periods for tropical cyclones with sustained winds of at least some threshold strength at specified locations within the Atlantic tropical cyclone basin. HURISK fits site-specific historical information for tropical cyclones to probability distributions or functions. The primary parameters in the model are storm distance from the site, maximum winds, radius of maximum winds, effects of latitude, horizontal wind profile, and frictional effects. The model uses a Monte Carlo simulation to select sequentially from the distributions of 10,000 tropical cyclones within a 150-nautical mile radius of a site. The number of years that it would take for the 10,000 storms to occur is based on the observed frequency of tropical cyclones within the 150-mile radius. For example, with 2.00 storms per year, it would take 5,000 years to have 10,000 cyclones.

Return periods (mean time between events) are then calculated from the simulated frequencies for specified winds occurring at the site (e.g. the center of each recovery area, based on the number of years it would take to have 10,000 storms. For example, out of the 10,000 simulated storms, 25 might have caused category III force winds to occur over the site. Thus, 5,000 years divided by 25 equals a return period of 200 years for category III force winds over the site.

HURISK uses a Weibull distribution of maximum wind velocities associated with tropical cyclones within 75 nautical miles of a site and a storm count-distance function, to create a family of lines representing return periods for specified winds at different distances from the site. The combination of the site and areal return periods allows one to determine the return periods for winds having at least the specified strength occurring anywhere over an area of specified size and stated location within the Atlantic tropical cyclone basin. The data in Tables 2 and 3 were derived with these procedures.

Based on comparisons to actual events, the estimated return periods generated by HURISK are considered to be reasonably valid for periods up to 100 years. While the validity of the estimates beyond 100 years are less certain, they are still the best available (Neumann 1987).

Relative Vulnerability of Recovery Areas

We used HURISK to estimate return periods for hurricane-induced winds of a specified or greater force (category I-IV, Saffir 1977) occurring within the boundaries of a specified RCW recovery area (Figure 1, Table 2). For application in HURISK, we defined the recovery area boundary as the area of a circle equal to the area of the irregular convex polygon that enclosed the recovery area. The area of any private lands enclosed by the polygon was included as part of the circle.

The threshold maximum sustained wind (1-minute average) expected to occur within the boundary of each recovery area on average in 100 years as a result of tropical cyclones (Table 3), was used as an index of the relative vulnerability of each recovery area to hurricanes. The 100-year expected winds were regressed against distance from the center of the recovery areas to the coast. Distance from the coast accounted for most of the variation in the relative vulnerability among the 15 recovery areas (Figure 5). The closer a recovery area is to the coast, the more frequently it will experience hurricane-induced winds and the more intense those winds are likely to be.

The least vulnerable. Least vulnerable to hurricanes are the Bienville NF, Piedmont National Wildlife Refuge --Oconee NF, and the Oakmulgee and Talladega Ranger Districts of the Talladega NF. For these areas, estimated return periods for hurricane-induced winds of at least category I strength were ≥ 170 years (Table 2). HURISK output indicates the return periods for hurricane-induced maximum sustained winds of at least category III force are more than 5,000 years for these 4 recovery areas. These values greatly exceed the model in several respects, but do suggest that the 4 most inland recovery areas may be essentially immune to the more destructive category III force winds.

The 2 least likely recovery areas to be subjected to hurricane force winds are the Oakmulgee and Talladega Ranger Districts with return periods of 350 and more than 500 years, respectively, for winds of category I force or greater (Table 2). Because of the paucity of observed hurricanes near these two areas, and the fact that HURISK does not take into account the physical constraints imposed by sites located well inland, our estimated return periods for the 2 areas are questionable. Nonetheless, tropical

Table 2--Return periods for hurricane-induced winds of at least the specified force (Saffir-Simpson Category I-IV[1]) occurring within the boundaries of red-cockaded woodpecker recovery areas. Return periods were estimated by HURISK.

Recovery Area	Miles From Coast[2]	Category of Wind[1] I	II	III	IV
		Return Periods (years)			
Francis Marion NF	15	14	43	90	260
Croatan NF	15	15	55	130	400
Apalachicola NF	20	16	50	100	325
Eglin-Blackwater-Conecuh[3]	25	20	52	99	250
DeSoto NF	50	21	55	105	260
Ft. Stewart	35	25	110	280	>500
Osceola NF	60	27	140	240	>500
Ft. Bragg	105	38	120	270	>500
Sam Houston NF	90	48	290	>500	>500
Carolina Sandhills NWR-SF	105	50	210	>500	>500
Ft. Polk-Vernon RD[4]	90	90	420	>500	>500
Bienville NF	140	170	>500	>500	>500
Piedmont NWR-Oconee NF	180	200	>500	>500	>500
Oakulgee RD[5]	175	350	>500	>500	>500
Talladega-Shoal Cr. RD[5]	200	>500	>500	>500	>500

[1] Maximum sustained winds (1-minute average) Saffir-Simpson Category I: 74-95 mph. Category II: 96-110 mph. Category III: 111-130 mph. Category IV: 131-155 mph.
[2] Miles from center of recovery areas to the coast.
[3] Eglin Air Force Base - Blackwater State Forest - Conecuh NF.
[4] Ft. Polk and Vernon Ranger District of the Kisatchie NF.
[5] Talladega NF.

Table 3--Threshold maximum sustained winds[1] expected to occur within the borders of red-cockaded woodpecker recovery areas in N-years, on average, as a result of tropical cyclones. Expected values were estimated by HURISK.

Recovery Area	N-Year Event 10	25	50	100	200
	Maximum Sustained Winds (mph)[1]				
Francis Marion NF	68	86	101	116	131
Croatan NF	66	83	95	109	115
Apalachicola NF	66	84	98	112	125
Eglin-Blackwater-Conecuh[2]	60	83	99	115	132
DeSota NF	59	82	95	112	135
Ft. Stewart	59	74	84	95	106
Osceola NF	59	71	86	97	110
Ft. Bragg	48	65	77	90	106
Sam Houston NF	53	66	76	84	94
Carolina Sandhills NWR-SF	49	62	77	84	95
Ft. Polk-Vernon RD[3]	44	55	66	76	84
Bienville NF	41	52	61	69	76
Piedmont NWR-Oconee NF	<40	49	58	66	73
Oakmulgee RD[4]	<40	46	53	60	68
Talladega-Shoal Cr. RD[4]	<40	43	54	56	64

[1] Maximum sustained winds averaged over 1 minute.
[2] Eglin Air Force Base - Blackwater State Forest - Conecuh NF.
[3] Ft. Polk and Vernon Ranger District of the Kisatchie NF.
[4] Talladega NF.

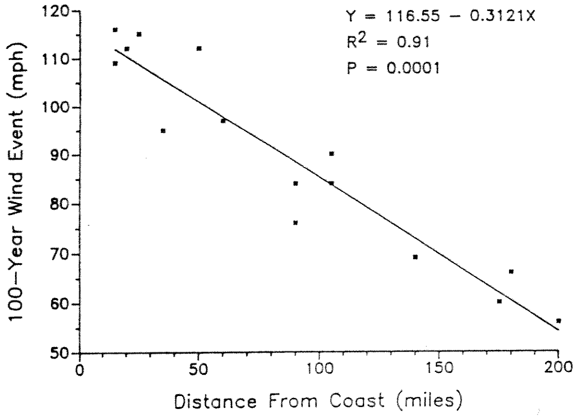

Figure 5--Relationship between tropical cyclone-induced 100-year wind events that are expected to occur within the borders of red-cockaded woodpecker recovery areas, and the distance from the center of recovery areas to the coast. The 100-year wind events are the average threshold maximum sustained winds (1-minute average) expected in 100 years. Expected values were estimated by HURISK.

cyclones can still have hurricane force winds that far inland in the southern United States, and given the uncertainties involved, the Oakmulgee and Talladega Ranger Districts should not be thought of as being totally immune to minimum hurricane force winds.

The most vulnerable. The 11 most vulnerable recovery areas represent a wide range of return periods: 14 to 90 years for category I force winds, and 90 to more than 500 for category III force winds of hurricane origin (Table 2). Compared to say the Francis Marion NF, Ft. Polk-Vernon Ranger District is not very vulnerable to hurricanes. HURISK indicates the return period for category III force winds occurring over Ft. Polk - Vernon RD and Sam Houston NF may be more than 1,000 years. Nonetheless, those 2 recovery areas are relatively vulnerable to category I force winds. The 5 most vulnerable recovery areas are Francis Marion, Croatan, Apalachicola NF, DeSoto NF, and Eglin AFB--Blackwater SF--Conecuh NF (Table 2). These areas have return periods of ≤ 130 years for category III force winds of hurricane origin, and ≤ 55 years for category II force winds. Osceola NF, Ft. Stewart and Ft. Bragg have relatively short return periods for category I hurricanes 38 years), but relatively long ones (≥ 240 years) for category III force winds.

The shorter the return period, the more likely a recovery area will be hit by another hurricane before its forests can recover from previous hurricane damage. For example, it may take the Francis Marion NF more than 50 years to recovery to its pre-Hugo condition (Hooper et al. 1990, Watson et al. 1994).

The return time for hurricane-induced winds of at least category I force for the Francis Marion is only 14 years (Table 2). Such a storm would be capable of destroying most of the trees with artificial cavities and many of the trees without cavities that were injured by Hugo. Thus, RCW populations on the 5 most vulnerable recovery areas are at considerably greater risk of extirpation from hurricanes than any of the other recovery areas.

N-year Events

A useful question to ask for a given recovery area is what intensity of wind on average, can be expected in a specified number of years? N-year events for each recovery area were determined from the same HURISK output as return periods (Table 3). The threshold maximum sustained wind that the Francis Marion NF, Croatan NF, Apalachicola NF, Eglin AFB--Black-water SF--Conecuh NF, and DeSoto NF will experience on average in 25 years as the result of tropical cyclones is ≥ 82 mph, sufficient to destroy a significant number of cavity trees. The seven most vulnerable recovery areas can expect at least 95 mph maximum sustained winds every 100 years on average. Winds of that velocity can be expected to cause serious loss of both cavity trees and foraging habitat. In comparison, the four least vulnerable recovery areas would expect to experience winds of 76 mph in 200 years on average.

N-year events and return periods are averages from a distribution of events. Therefore, a 100-year event will not happen every 100-years, nor will a 25-year event happen every 25 years, etc. The frequency of N-year events occurring through time can be described by the binomial distribution, from which one can determine the probability of an event of any N-years occurring one or more times in any number of years (Formula 4, Appendix I). The relationship of the probabilities of several N-year events to elapsed time is shown in Figure 6. This figure essentially describes the recurrence of hurricanes over a recovery area. For example, to be nearly certain that a 100-year event will occur at least once, one would have to wait 500 years. Stated another way, every time a 100-year event occurs, it will almost certainly have been less than 500 years since the last such event occurred and it will almost certainly be less than 500 years before such an event occurs again. But six out of ten times a 100-year event will occur, on average, within 100 years of the last such event. And two times out of ten, a 100-year event will occur within 22 years of the last event. There are numerous examples of several hurricanes making landfall near the same location in a relatively few years, but then many years elapsing before the same location is again visited (Neumann et al. 1987).

Likelihood of Hurricanes Among Recovery Areas

There are 15 recovery areas (Figure 1) with varying degrees of risk from hurricanes (Figure 5). The 4 most inland recovery areas have such a low probability of hurricane force winds occurring over them, we excluded them from the following analyses. The chance of any one or more of the 11 most vulnerable recovery areas experiencing hurricane force winds is much greater than for a specified recovery area. For example, the probability of the Francis Marion NF experiencing hurricane-induced winds of category I and III or greater, in a year is 0.069 and 0.011, respectively (Formula 1, Appendix I). In contrast, the probability of at least 1 of the 11 most vulnerable recovery areas experiencing hurricane-induced winds of category I and III force in a year, is 0.319 and 0.060, respectively (Formula 2, Appendix I).

Similarly, the return period for any 1 or more of the 11 most vulnerable recovery areas experiencing hurricane-induced winds of at least a specified intensity, is much less than for a given recovery area. The return period for category III force winds occurring over any 1 or more of the 11 recovery areas is only 16 years (Formula 3, Appendix I), compared to a return period of 90 years for the Francis Marion NF (Table 2). The

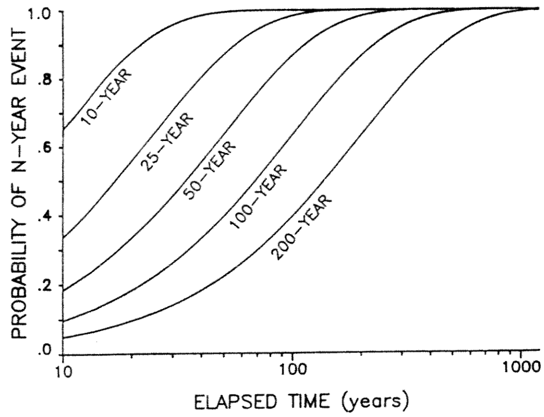

Figure 6--Probabilities of N-year events occurring over time. Values are calculated from the binomial distribution using Formula 4, Appendix I.

return period for category I force winds occurring over any 1 or more of the 11 most vulnerable recovery populations is only 2 years. Again this is much shorter than the 14-year return period for category I force winds occurring over the Francis Marion.

Expected Number of Hurricanes

We used the Poisson distribution (Formula 5, Appendix I) to estimate the total number of recovery areas that can be expected to be affected by at least 1 hurricane-induced wind event of designated intensity over t-years (Figure 7). For example, it will on average take about 500 years for all 11 of the most vulnerable recovery areas to experience at least category 1 force winds within their boundaries. However, 8 recovery areas will on average experience at least 1 such event in only 50 years, and 10 of the 11 areas will do so in 80 years (Figure 7). Similarly, 4 of the recovery areas are expected to have at least category III force winds occur over them in 100 years on average (Figure 7).

While we wait for all 11 of the most vulnerable recovery areas to experience hurricane-induced winds of a given intensity, some of the 11 areas will have numerous such events. In other words, more than 11 hurricanes will occur among the 11 recovery areas before all 11 areas experience winds of specified intensity at least once. This relationship (Figure 8) was estimated by Formula 6, Appendix I. For example, in the 500-year period

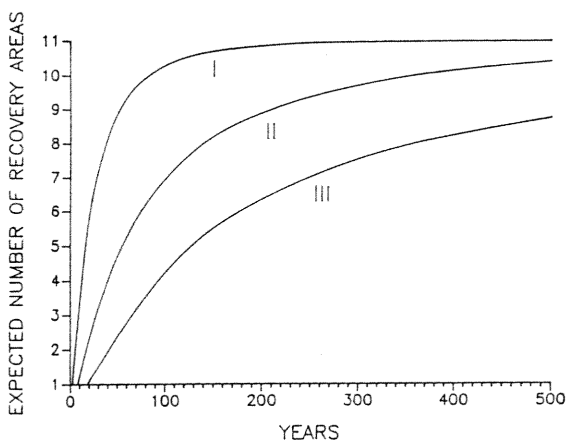

Figure 7--Expected number of red-cockaded woodpecker recovery areas from among the 11 most vulnerable, that will experience at least once over time, a hurricane-induced wind event within their respective boundaries of at least the specified Saffir-Simpson category (I, II, or III). Expected numbers of areas were calculated by Formula 5, Appendix I, using return periods estimated by HURISK (Table 1).

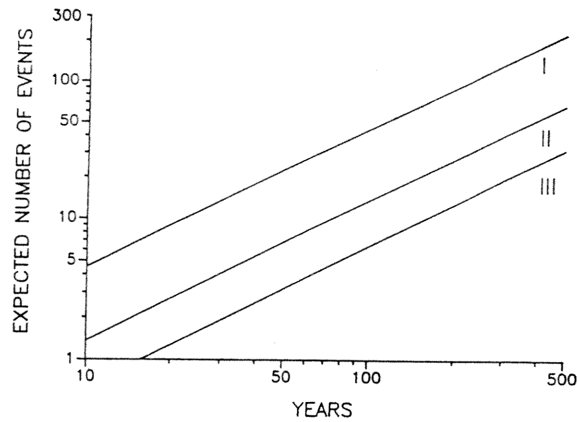

Figure 8--Expected number of events in which hurricane-induced winds of at least the specified Saffir-Simpson category (I, II or III), will occur within the boundaries of any of the 11 most vulnerable red-cockaded woodpecker recovery areas. Expected numbers of events were calculated by Formula 6, Appendix I, using return periods that were estimated by HURISK (Table 1).

that it takes for all 11 recovery areas to experience at least 1 event with category I force winds (Figure 7), 226 such events are expected among the 11 recovery areas (Figure 8). Obviously, some of the 11 areas will experience many hurricanes before all the areas have experienced at least 1. Similarly, while category III or greater winds are expected to occur over 4 recovery areas in 100 years on average (Figure 7), 2 of those 4 areas are expected to have 2 such events in that time (Figure 8).

DISCUSSION

Uncertainty

The stochastic nature of tropical cyclones adds considerable uncertainty to the long-term recovery and management of the RCW. We presented estimated average return times (Tables 2, 3) and average numbers of recovery areas expected to be hit by hurricanes (Figures 7, 8). Because our estimates are averages, recovery areas could be impacted fewer times by hurricanes in say the next 100 years than our data suggest, or just as likely, they could be impacted more times than we estimate. However, the longer the period of time that we define as "long-term", the less effect stochasticity has and in that sense, the more closely our estimates may predict the future.

The Average Worst Case Scenario

Hurricane-induced maximum sustained winds of category I force can destroy a significant number of cavity trees. Most recovery populations have demographic problems and suffer from a paucity of trees suitable for cavities (Costa and Escano 1989). A significant loss of cavity trees can have major impact on these floundering populations. Category I force winds can have a devastating effect on a recovery area that has recently been hit by a major hurricane. Trees with artificial cavities are probably more susceptible to breakage from winds than trees with natural RCW cavities (Allen 1991, Taylor and Hooper 1991). Also, trees that have survived major winds frequently have compression and root damage that render them more susceptible to breakage in future winds (Mergen 1954, Trousdell 1955, Watson et al. 1994). Recovery areas with soil limitations can suffer major damage from category I force winds. Finally, catastrophic loss of trees can occur when soils are waterlogged.

We expect that hurricane-induced maximum sustained winds of category III or greater force occurring over a recovery area will cause tremendous damage to cavity trees, potential cavity trees and foraging habitat. Such an event in 1 of the floundering populations can cause extirpation. Major hurricanes passing over large and relatively healthy populations can greatly reduce the population and create isolated sub-populations.

In 100 years, on average, we expect 4 recovery areas to suffer the effects of maximum sustained winds of category III or greater force (Figure 7). Two of those areas will probably be affected twice (Figure 8). In addition, 39 instances of category I or II force winds are expected to occur among the 11 most vulnerable recovery areas. Some of those could as likely hit a recovery area following a category III hurricane as anywhere else. Thus, even in 100 years we can expect major hurricane-induced problems in recovery populations. Clearly, future managers of 1 or more RCW recovery areas will be dealing with the effects of hurricanes on a continuing basis. Currently, at least 2 recovery areas are suffering from past hurricanes. Hugo devastated the Francis Marion NF. The RCW population on the DeSoto NF is small and has suffered a decline, partially at least, as a result of Camille, Frederick and Elena.

What Can We Do?

The inclusion of inland populations as part of the recovery of the species was wise (Lennartz and Henry 1985). The 4 most inland recovery areas are essentially immune from major hurricanes and are at low risk from minor ones. These inland areas should receive renewed emphasis. Establishment of additional inland recovery areas has considerable merit; several opportunities exist for doing that on public lands.

Catastrophic hurricane damage is fairly limited geographically and overall damage is typically patchy. Thus, anything that can be done to increase the geographic extent of a population associated with a recovery area will enhance its potential for surviving hurricanes and its ability to recover from them. Probably the worst management decision that could be made would be to concentrate a population into a portion of a recovery area. In our opinion, it is better to have a given number of groups at a lower density on a larger area, than to have the same number of groups concentrated at a higher density in a smaller area.

Recovery areas under even-aged management have an advantage of having stands of different age classes spatially distributed. In general, the younger age classes survive better than the older ones. Recovery from hurricanes is enhanced by having stands surviving that are 10-50 years old (Watson et al. 1994). Some reasons to think that net tree survival may not be as great under uneven-aged management are the extended periods of growth suppression for younger trees (Farrar and Boyer 1990) and the increased turbulence from an uneven canopy (Curtis 1943, Savill 1983).

There is general agreement that nothing can be done to protect trees from catastrophic winds. However, much of the damage from hurricanes comes from lesser winds interacting with tree characteristics (Figure 3). Considerable interest has been shown in wind-silvicultural relationships in other regions, but almost none has been shown within the range of the RCW. One reason for this lack of interest has been the typically short rotations (ca. 30 years) used to grow the southern pines. Given that recovery of the RCW will require extended rotations (ca. 80-120 years) in order to provide old trees for cavities, we think an analysis of the best way to grow stronger and more windfirm trees would be worthwhile. There is much literature that suggests it is possible to grow more wind-resistant trees. Basically trees need to be grown throughout their lives in stands that are not overcrowded in order to enhance crown development, root development, taper, and bole strength. This approach to growing trees in recovery areas would also reduce the threat of southern pine beetle epidemics (Thatcher et al. 1986, Belanger et al. 1988), another very serious threat to long-term management of the RCW (Rudolph and Conner 1994).

The importance of recent technological advances that can now be used to counter the effects of hurricanes can not be overstated. The artificial cavities developed by Copeyon (1990) and Allen (1991) have provided an effective response to the loss of RCW cavity trees. The use of artificial cavities, along with augmentation of populations (Allen et al. 1993) when necessary, can reduce the effects of hurricanes on healthy RCW populations.

This prediction assumes:
(1) the responsible agency can respond to the crisis,
(2) enough trees for foraging and artificial cavities survive to support a population, and
(3) that the recovery area is not soon hit by other hurricanes. We may very well lose some populations from repeated hits by hurricanes. Also at great risk are smaller populations that are already struggling.

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APPENDIX I

Formulae used to calculate the probabilities and expected values for hurricanes that were used in the text and figures.

Our basic data were the return periods for category I-V hurricanes passing near the center of the 15 red-cockaded woodpecker recovery areas (Table 1). Those return periods were generated by HURISK (Neumann 1987). A brief description of HURISK is provided in the text.

The mean number of hurricanes of a given category per year, m_i, is the reciprocal of the return periods in Table 1.

The yearly probability of 1 or more hurricanes of a specified intensity passing over the center of a specified recovery area is equal to,

$$1-e^{-m_i} \qquad (1)$$

The yearly probability of 1 or more hurricanes of a specified intensity passing over the center of any 1 or more of the 15 recovery areas is equal to,

$$1-\prod_{i=1}^{15} e^{-m_i} \qquad (2)$$

The return period for 1 or more hurricanes of specified intensity passing near the center of any 1 or more of the 15 recovery areas is equal to,

$$1/\sum_{i=1}^{15} m_i \qquad (3)$$

The probability of having 1 or more N-year events in t years is equal to,

$$1-(e^{-m_i})^t \qquad (4)$$

The expected number of recovery areas, from among the 8 most vulnerable, that will be hit by 1 or more hurricanes of specified intensity over t years is equal to,

$$\sum_{i=1}^{8} (1-e^{-m_i t}) \qquad (5)$$

The expected number of hurricanes of specified intensity passing near the center of any of the 8 most vulnerable recovery areas over t years is equal to,

$$\sum_{i=1}^{8} (m_i t) \qquad (6)$$

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IMPACT OF HURRICANE HUGO ON CAVITY TREES OF A RED-COCKADED WOODPECKER POPULATION AND NATURAL RECOVERY AFTER TWO AND A HALF YEARS[1]

Donald J. Lipscomb and Thomas M. Williams[2]

Abstract--The impact of hurricane Hugo on a relatively isolated population of red-cockaded woodpeckers (*Picoides borealis*) was evaluated by the loss of cavity trees to wind, saltwater, and bark beetles. The population is located 90 km northeast of Charleston, South Carolina, on a peninsula between Winyah Bay and the Atlantic Ocean. Damage to red-cockaded woodpecker cavity trees was significantly more severe than damage to the surrounding forest and 45 of 127 active cavity trees were destroyed. New cavities were begun in 47 trees and 38 cavities completed two and a half years after the storm. However, additional cavity tree mortality from salt intrusion and bark beetles resulted in an eighteen-month delay before a net gain in active cavity trees occurred. Dynamics of cavity activation, deactivation, and tree mortality show the complexity of cavity tree replacement in a red-cockaded woodpecker population after a catastrophic event.

INTRODUCTION

Hobcaw Barony is located on the South Carolina coast approximately 90 kilometers northeast of Charleston and 4 km east of Georgetown. Hobcaw forest is approximately 3077 hectares surrounded by 3800 hectares of non-forested marshes and islands between Winyah Bay and the Atlantic Ocean. The forest is 80 percent pine and pine-hardwood types. Age class distribution of the pine types was skewed heavily toward the over 100-year class before Hurricane Hugo (Figure 1). Less than four percent of the longleaf area was under 80 years old. Hobcaw forest was prescribe burned regularly since the mid 1970's. Thus there was an abundance of open old pine stands on the forest. Red-cockaded woodpeckers (RCW) have been reported on Hobcaw for more than 20 years. Dennis (1971) reported 138 cavity trees (active and inactive combined) on Hobcaw in the early 1970's. Grimes (1977) studied 77 active cavity trees in the late 1970's. A geographic information system (GIS) red-cockaded woodpecker data base, initiated in 1988 and completed before August 1989, recorded 194 active and inactive cavity trees. The cutting on Hobcaw between 1955 and 1965 (Williams and Lipscomb 1983) combined with the burning program of the 1970's and 1980's resulted in a density of approximately 1 cavity tree per 13 hectares of pine type.

On September 22, 1989, Hurricane Hugo crossed the South Carolina coast 20 kilometers east of Charleston with maximum sustained winds of 222 km/hr (Purvis and others 1990). However, winds at Georgetown were lower at 87 km/h and gusts to 138 km/h. Hobcaw forest was still significantly impacted by the wind with 27 percent of the trees receiving moderate to heavy damage (Gresham and others 1991). In addition, the storm surge inundated roughly 600 hectares on the east and south portions of the forest. The combination of salt water in the soil and bark beetles killed more trees than were killed by wind. Latter mortality

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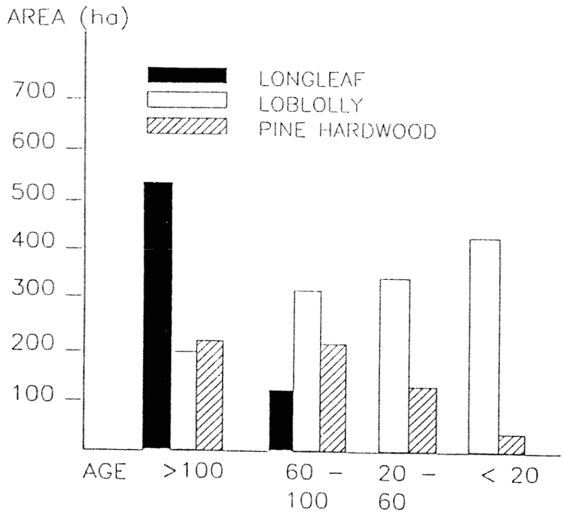

Figure 1--Age-class distribution of pine types on Hobcaw Forest, South Carolina, before Hurricane Hugo.

occurred primarily during 1990 but has continued until 1993. These combined forces killed trees accounting for 40 percent of the merchantable volume on the forest.

We observed the effect of Hurricane Hugo on RCW cavity trees and the dynamics of cavity tree replacement by the surviving RCW population on Hobcaw. Our objective was to observe the interaction of forest condition, storm impact, and nesting recovery with a goal of defining forest conditions that allow recovery of RCW cavity trees without resorting to artificial cavities. We chose this goal rather than artificial cavity construction because the area studied had a surviving woodpecker population and extensive nesting habitat remaining after the storm.

METHODS

Maps of RCW cavity trees were created by RCW research in the early 1970's. Annual inventories of Hobcaw Forest were conducted in 1976 and 1986. In each inventory all stands in the forest were surveyed. RCW cavities found during these surveys were also added to the maps. In 1988 and the early part of 1989 all known red-cockaded woodpecker cavity trees were visited and evaluated. Information recorded included the height and activity of the cavity or cavities; the species of the cavity tree and its dbh, total height, and crown class. Information about the surrounding vegetation included basal area of pines 10 inches dbh and larger and basal area of mid-story pine and hardwoods.

This data and mapped locations were put in the Hobcaw GIS (Williams and Lipscomb 1988) which was established in 1986. The RCW data layer could then be overlain on existing stand, soil, and other information already in the data base (Lipscomb and Williams 1990). All known RCW cavity trees were entered into the data base before Hurricane Hugo.

A 1.08 percent sample of the forest was taken during the winter of 1989-90 to evaluate damage to all species on the forest. Over 16,000 trees were measured and placed into one of eight wind-damage categories (Gresham and others 1991). All 194 cavity trees were visited, examined for cavity activity, and placed into one of the same damage categories immediately after Hugo in November 1989.

We re-evaluated the surviving trees in April 1991 and again in April 1992. Areas likely to have new cavities (based on either distance from a known active or inactive colony or stand characteristics) were searched for new cavities from December through March prior to each evaluation. The same parameters were measured on new trees as on previously known cavity trees and the new trees were added to the permanent record.

RESULTS

RCW cavities occurred in three pine species on Hobcaw: loblolly pine (*Pinus taeda* L.), pond pine (*Pinus serotina* Michx.) and longleaf pine (*Pinus palustris* Mill.). For each species three data sets were prepared; one containing the cavity trees, one containing all trees in the damage survey, and one from the damage survey with tree diameter distributions matched to the cavity trees. The eight damage classes of Gresham and others (1991) were grouped into light (undamaged, bent, branches broken), medium (defoliated, top broken), and heavy (bole broken, uprooted, downed) and the three data sets compared. Heavy damage in cavity trees was four times the damage of all trees of the same species, and at least twice as high as in trees matched by diameter (Figure 2). RCW excavate cavities in old, large pines (Conner and O'Halloran 1987, Jackson and others 1979). Larger trees were subject to greater wind

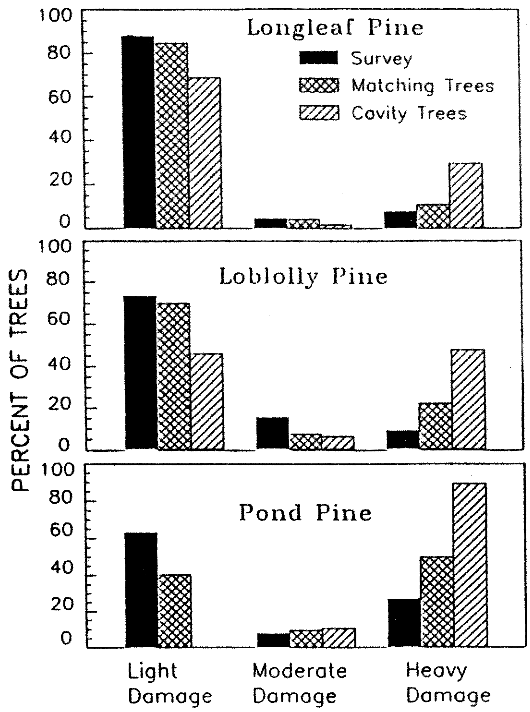

Figure 2--Wind damage to pines on Hobcaw Forest following Hurricane Hugo. Survey was a 1.08 percent sample of the entire forest. Matching was a subset of the survey with the same diameter distribution as the cavity trees. Light damage: none, bent, or broken branches; Moderate damage: defoliated or top broken; Heavy damage: bole broken, or uprooted and leaning, or uprooted and down.

stress and were more heavily damaged as shown by the matched data set in Figure 2. Note that there is little difference in longleaf pine since 96 percent of the longleaf on the forest was over 80 years old. In addition, 69 of the 80 cavity trees heavily damaged by the wind, broke at the cavity. For the general forest trees matched by diameter the greatest damage was by uprooting. Not only were the cavities in large trees which were likely to be uprooted but apparently the cavity weakened the tree to the point that it broke at the cavity.

While 80 of the 194 cavity trees were severely damaged by wind, six were still alive in November 1989. Of the 120 surviving cavity trees 83 were active. Since wind mortality in the forest in general was less than 20 percent and more than 87 percent of the longleaf pine survived (Gresham and others 1991), there was an abundant supply of potential cavity trees available.

Forty-five active cavity trees were lost during Hurricane Hugo, 20 new cavity trees (including starts) were found by April 1991, and 27 more during the following year for a total of 47 by April 1992. Of these 47 new cavity trees 38 had completed cavities 30 months after the hurricane. However, the number of active cavity trees did not reach pre-hurricane level since normal mortality, saltwater intrusion, and bark beetles continued to take a toll (Figure 3).

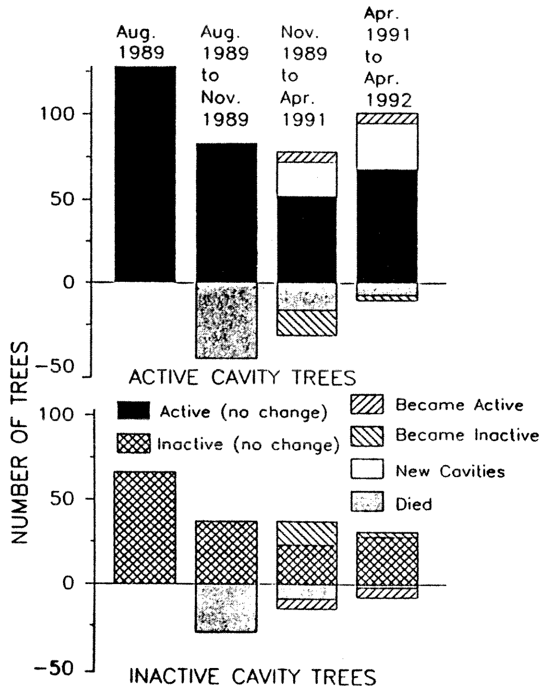

Figure 3--Net changes in red-cockaded woodpecker cavity trees on Hobcaw Forest from August 1989 to April 1992. Active cavities includes 6 starts in April 1991 and 9 starts in April 1992.

Between November 1989 and April 1991,20 new cavity trees were found (14 completed cavities) and 16 active cavity trees died. Fifteen active cavity trees became inactive while 6 previously inactive cavity trees (some having been inactive for more than three years) were reactivated. These changes in activity affected more than one third of the total remaining active cavity trees. However, the number of active cavity trees declined by five.

Between April 1991 and April 1992, 27 new cavities (for a total of 47 new cavities with 38 completed) were found and seven active cavity trees died. Again six previously inactive cavities became active, but only three previously active trees became inactive. Less than thirteen percent of active cavities was subject to change during 1991-1992. One might surmise that the large number of trees becoming inactive in the first time period compared with the second, were a result of bird mortality during the storm. The combination of lower mortality and lower deactivation allowed a 29 percent net increase of active cavity trees during this time period. By April 1991 the woodpeckers had completed 38 new cavities and had nine starts. If this rate were to continue the number of active cavity trees would reach pre-hurricane levels in a few years. However, by 1991 the hurricane effects killed 40 percent of the pine foraging habitat as well as 97 active cavity trees.

CONCLUSIONS

There was significant damage to RCW cavity trees on Hobcaw forest located 70 kilometers from the center of the path of Hurricane Hugo's eye. Damage to the RCW cavity trees was significantly greater than the damage to similar trees in the surrounding forest. Within two and a half years the birds had constructed more new active cavity trees (and had 38 of 47 new cavities completed) than were initially lost to hurricane winds. However, additional losses of cavity trees occurred after Hugo from salt intrusion and bark beetles. Thus, thirty months after the hurricane there were still 21 percent fewer active cavity trees than before the hurricane.

Hurricanes are a frequent episodic event throughout the red-cockaded range (Hooper and McAdie 1994). We found RCW cavity trees are especially vulnerable to wind damage. Over 40 percent of the cavities were lost 70 km from the eye with wind gusts under 140 km/h. Old, large pines are both preferred for cavities and subject to strong wind stress. Cavity trees are more likely to break at the cavity probably due to weakness caused by either the cavity itself or red heart fungus often associated with the cavity.

The RCW population on Hobcaw forest was able to establish new active cavity trees in a relatively short time period because there were abundant old pines that survived. With sufficient nesting habitat the birds were able to complete a large number of cavities in a short period of time. Artificial cavity placement (Copeyon 1990, Allen 1991) is an important strategy, but it was unnecessary for this population. The criteria we used to choose natural recovery was presence of a surviving cavity tree in each colony and survival of 87 percent of the longleaf which was over 80 years old.

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TECHNOLOGY AND INNOVATION...KEY TO HUGO RECOVERY[1]

D. W. Gerhardt[2]

ABSTRACT--Westvaco forest managers utilized advanced logging methods, technology, and research to recover from forest damage done by Hurricane Hugo. Hugo affected more than 175,000 acres of Westvaco woodland and 21,000 acres of private woodland in the company's Cooperative Forest Management program. Westvaco used a computer-based Forest Resources Information System (FRIS), the National Aerial Photography Program (NAPP), and aerial reconnaissance to assess the damage and plan the salvage operation. A variety of logging methods, including horse logging, helicopter logging, and logging crews from Oregon and Sweden, allowed Westvaco and its CFM participants' salvage success rate to be almost double the statewide rate. Intensive site preparation techniques helped reestablish pine plantations with little or no loss of production. Westvaco Forest Research established a long-term study to determine response of plantation loblolly to hurricane damage.

What I'd like to do is explain the damage done to Westvaco lands, the planning for recovery, recovery methods and technology employed, and our forest research results since Hugo.

Unlike many others, I had the pleasure of not being here when Hugo actually hit. My wife and family will tell you that I fled inland, not to the safety of Charlotte, but clear to the west coast. In some ways this qualifies me as an expert--I was out of state when Hugo hit!

When I returned, I was faced with the prospect of salvaging storm-damaged timber from Westvaco's forest land. Recovery from Hugo occupied our work lives, personal lives, and impacted our community for over one year. I'm only one of many Westvaco foresters who could share this learning experience with you.

[1] A paper presented at the 72nd Annual Meeting of the Appalachian Society of American Foresters held at Greenville, S.C., on January 20-22, 1993.
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For those who may not be familiar with Westvaco, let me give you a brief description of our South Carolina operations. Westvaco is South Carolina's largest private landowner, with over 500,000 acres of forest land, most of it located in the Coastal Plain or Low country. Through our Cooperative Forest Management, or CFM program, we assist private landowners in managing another 420,000 acres of forest land in the state. Our management objective is to provide a stable supply of wood fiber to our paper mill in North Charleston. About 2,200 Westvaco employees in South Carolina are involved in a range of activities from forest management to paper, chemical, and lumber production.

Much of Westvaco's forest land was in the direct path of the hurricane. More than 175,000 acres of company land were affected; roughly 50,000 acres were severely damaged. Another 21,000 acres of CFM properties were also severely damaged.

A "team spirit" grew quickly at Westvaco among our Kraft, Chemical, Lumber, Real Estate, and Timberlands units, plus private landowners in our CFM program. In the days immediately following the storm, the state forestry commission, U.S. Forest Service, Westvaco, and other landowners began to assess the damage to our state's forests.

Westvaco's initial efforts following Hurricane Hugo focused on identifying and assessing the extent of damage and prioritizing salvage efforts based on potential loss and loggability for company and CFM lands. Our Forest Resources Information System (FRIS) was invaluable in providing pre-storm stand statistics and provided much of the information needed to prioritize salvage efforts. The National Aerial Photography Program (NAPP), a commonly used tool in the forest industry, provided accurate aerial information for forest planning purposes. Coincidently, the last NAPP photos were flown in 1989 just prior to Hugo.

Westvaco management wanted as quick an assessment of damages as possible. Aerial reconnaissance, using contract aircraft, provided information on overall woodlands damage and was essential for setting initial salvage priorities. We contracted a special aerial photography flight using NAPP specifications to obtain new pictures corresponding exactly to pre-hurricane images. Using color infrared photography, Westvaco employees were able to identify the areas and extent of damage, differentiate forest types, and note areas of saturated soils.

This information, combined with the information from our FRIS system, provided a complete overview of damage, including timber stand descriptions, soil types, and soil moisture necessary to plan the most effective and efficient salvage operation across the woodlands.

Our recovery goals were to maximize salvage volume, protect the damaged woodlands from debris-fed wildfire, and to clear salvage areas for reforestation where feasible. We set out to develop a salvage plan for recovering millions of board feet of sawtimber and millions more tons of pulpwood. There were two major challenges. The first was time (estimated six months salvage for sawtimber, 18 months for pulpwood) and the second was ground conditions, which were extremely wet (10" of rainfall and broken/fallen trees). Conventional shears and skidders could not work in these conditions and we did not have the luxury to wait for dryer times to salvage our higher value products.

In the first six months after the storm, every conceivable approach to logging was considered and, over the course of the salvage period, most were tried--big tires, crawlers, shovels, cable systems, and horses--all of which required new thinking. Based on these and our salvage goals, we made an early commitment to helicopter logging for salvaging our highest grade sawtimber. Finding no local contractors, we began to assemble our own. We contracted with Heli-Jet out of Eugene, OR, which provided the flying and choker setters, and matched the helicopter with one of the best local loggers.

In our highly mechanized area of the world, a man with a chain saw became a valuable commodity. We had to look outside the local area for well-trained and experienced chain saw operators. We brought in a cutting contractor out of Eugene, OR; a typical western logging crew (with the tin hard hats, suspenders, and long saw bars).

At the same time, we called a long-time Westvaco advisor and friend, Soren Erikkson, a world class chain saw expert and instructor. Within two weeks, we had professional Swedish chain saw cutters, all decked out in the latest safety gear, running high performance saws. Most importantly, they had the knowledge and training to safely cut the wood to stringent specifications at remarkably high production rates.

It was a precise operation, with the helicopter removing one or more logs every 1 1/2 minutes. On the average, we ran about 40 turns/hour, 6-8 hours/day, 15 loads/day, 6 days/week. We completed the project in four months.

Our venture into helicopter logging was very successful. We even added a second helicopter to accelerate completion on our own land. By March 1, we had met all expectations, salvaging several million board feet of high quality sawtimber.

Let me take a few minutes to put some of our salvage results in perspective. First, don't allow my enthusiasm for the helicopter salvage operation to cloud the fact that helicopters, horses, and other specialized systems were but a part of the overall salvage effort, albeit a strategic part. Once the wet ground conditions improved, the majority of the salvage on Westvaco land (and other private land) was accomplished by the hard work of the local conventional loggers, primarily the independent loggers who had been cutting and hauling to industry mills before the storm.

One factor in the salvage success was water storage. More than 150,000 tons of recovered wood were stored under sprinklers during the summer of 1990. We stored this wood at two locations and metered it into our mill's wood flow over an 18-month period.

Through almost a year of round-the-clock teamwork, Westvaco salvaged more than 600,000 tons of hurricane-damaged timber from company lands. Another 500,000 tons of downed timber was recovered from CFM lands. At Westvaco's Southern Woodlands, we set a salvage goal of 50 percent of the severely damaged timber volume. We reached 25 percent in the first six months, and late in 1990, we met the 50 percent goal. Thus, the salvage success rate for Westvaco and its CFM participants was approximately double the statewide rate.

Concurrent with our efforts to salvage damaged timber, we started looking at the short and long-term impacts on Westvaco's fiber supply. Our harvesting plans include a steady increase in pine pulpwood production to our Charleston mill. Hugo gave us a surge of pulpwood, as damaged trees were fed into the system. By mid-1994, however, the impact of Hugo on Westvaco's pine pulpwood production will disappear. This is largely due to improved practices and technology that have occurred over the last decade.

Genetics, site preparation, fertilization, and competition control are just some of these practices. Combined, they effectively increase our plantation growth to replace the volume lost to Hugo. The advantages of genetics and fertilization were unaffected by Hugo. However, site prep prescriptions in Hugo areas involved several considerations.

1. Was the broken timber salvaged?
2. How much debris is on the ground?
3. Quantity of standing snags (volume, size) and uprooted stumps.

On any given site there could be a wide range of salvage (from 0 to 100 percent) and an equally wide range of site conditions. There are a few key factors about site preparation that helped us maintain production with little or no loss of long-term productivity.

Traditionally, our intensive site prep in the Lowcountry has used a combination of shearing, raking, brush drumming, burning, bedding, and herbicides. Following Hugo, we combined these more effectively, plus took advantage of some recent technology improvements. Time and patience became our best tools. On many post-Hugo sites we sheared the sites and let the debris decompose from one to two and even three years. This minimized the amount of land occupied by piles and windrows, thus more of our land base is in production. In a two-year layout scenario, we can grow more volume in 23 years with 10 percent windrows than in 25 years with 20 percent windrows.

There have been some equipment and herbicide innovations that assisted us in site preparation. One is the relief or "stump-jump" plow used to construct beds. The advantage of the relief plow is that each disk works independently of the others. This allows an individual blade to ride over a stump or debris while the other blades continue to form the bed. We have also used herbicides to our advantage in post-Hugo site prep. Some additional items we found useful in site preparation and planting were hoedads. We also used a machine called a slashbuster.

You now have a good overview of how we prioritized our salvage operations using the most up-to-date technology, and how we tackled the additional twists Hugo threw us on site preparation. But what about the stands that were too young to salvage? One of the big questions confronting our operations people was what to do with young stands that were only marginally merchantable or really young plantations. Do we plow them under and start over? Do we let them go? If we do, will the trees survive, and if they survive, what will they look like at rotation?

The published literature wasn't much help. The vast majority of hurricane-related articles dealt with damage assessment rather than recovery. We could find only one research note dealing with plantation-pine recovery, and the results were limited.

Looking for the silver lining, our Research Director pushed for the establishment of a long-term study to determine response of plantation loblolly to hurricane damage. We decided to concentrate our efforts in damaged stands of mid-rotation age and younger. Older stands would be salvaged, either immediately or in due time, depending on the extent of the damage.

We installed the study in the early spring of 1990 at nine locations, using existing research plots to give us an accurate history and pre-storm measurements. Most of the locations are in the age 2- to 5-year range. We are following three older stands, primarily for survival information.

In addition to the traditional forestry measurements, we are collecting several other objective and subjective measures. Because most of the damage in the young stands was stem lean, we want to quantify the degree of recovery. On all trees we are measuring the vertical and horizontal distances to eight feet of stem length, base of live crown, and the tip.

We need to get a handle on where in the stem the recovery occurs, so on a 10 percent subsample of the trees ages 2 to 4, we are also measuring the vertical and horizontal distances to dbh, to one-half the original stem length, and to the original tip. These three points are permanently marked on the stem with paint. After one year we think we have a viable stem-angle measuring system.

One of our subjective measures involves tree form. Some of these may not be applicable immediately but can be used later. Other subjective measures include root damage, percent foliage and branch loss, and stem-damage codes. In addition, we are also documenting recovery at each location by photographing subject trees at each remeasurement.

Now I want to briefly go over some preliminary first-year results. Even with a rather severe drought the summer following Hugo, mortality was rather light. Only about six percent of the trees leaning at study installations died. The average angle of the dead trees was approximately 60 degrees from vertical. There is a small negative correlation between initial age and the one-year change in stem lean. For example, this tree, age two in 1990 at study establishment, had an average stem lean of 65 degrees. One year later, at age three, it grew 0.1" in diameter, 1.2′ in stem length, and improved 28 degrees.

In 1990, the tree with the orange paint was five years old and had an average lean of 26 degrees. After one year, the tree grew 0.6" in diameter, 3.2′ in stem length, and had an average lean of 5.6 degrees. The first-year results indicate that severely leaning trees got worse the following year. There is also a positive correlation between age and mortality, with younger trees exhibiting better recovery from storm damage. We will continue this study through the eleventh year following the storm.

We hope this study, which will be published, will assist other forest managers in recovery planning from future disasters. Of course, we hope they never have occasion to use it!

To say that Hugo presented us with some management opportunities would be to liken it to a summer squall. There were limitless combinations of damage severity, site conditions, accessibility factors, safety concerns, and subjective value judgements which challenged us beyond our normal duties. Hugo recovery was to a forester what war is to a soldier.

We had numerous tools at our disposal, from heavy machinery to horse logging to herbicides. Technology and innovation provided the edge. NAPP aerial photos gave us a quick overview of damage severity, and FRIS provided instant information on volumes, site characteristics, and loggability. Combined, they enabled us to make effective, informed decisions. Our recent experience with site preparation studies and techniques also gave us some insight on how to approach our recovery goals. Without these tools, we would have lost much of our efficiency in salvage efforts and resource renewal and recovery. But, the most important factor was the individual efforts put forth by many dedicated people.

I've mentioned very little about the impacts on families, homes, and communities. As resource managers, we were concerned about the resource, but our first overriding concerns were for the safety and well-being of our employees and neighbors where we live. In the first crucial weeks following the storm, Westvaco resources and personnel were actively engaged in assisting others. For example, portable generators were loaned to local communities and refrigerated seedling vans were provided for food storage.

One of the most crucial lessons learned from Hugo was the need for teamwork, compassion, and support among all groups. State, local, and federal government worked hand-in-hand with individuals, corporations, community, and church efforts. The result was a feeling of camaraderie, belonging, and cooperation, which allowed the completion of an enormous amount of work in a relatively short time period.

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EASING THE TRANSITION: REDUCING THE COST OF REFORESTING LANDS DAMAGED BY HURRICANE HUGO

Stephen K. Nodine[1]

In September of 1989, many forest landowners in South Carolina learned first-hand how vulnerable forests are to storm damage. In a few short hours, Hurricane Hugo ripped a path of destruction across the state. It left in its wake more than four million acres of devastated forest land. No one's land was immune, and some of the best and most beautiful stands were hit hardest.

If you are a landowner affected by Hurricane Hugo, you probably still remember the shock of seeing what happened to your trees. Even now, you may still be trying to decide if your forests can ever recover. Well, the good news is "Yes, there is life for a forest after Hugo." The bad news is that it takes some careful planning to rebuild the forests in a way that is effective and efficient for you. But maybe this need for planning is not all bad news, because the effect of a good plan is a good outcome.

There have been many questions for both landowners and foresters about how to best recover the damaged forests. Some of the techniques we have relied on just don't seem adequate to meet the needs. And, frankly, we have never really faced a situation with so many unknowns.

This brochure can't address all the questions that have been raised by Hugo. It does try to answer the question "How can I get the best forest regeneration in a way that I can afford?" There are several cost-sharing programs that can help reduce your out-of-pocket costs. Income tax incentives also are available to help recover some of those investment dollars within a few years. And there are several reforestation techniques that may accomplish the task without the high cost of some traditional high-intensity methods.

START WITH A PLAN

Under normal circumstances, it is helpful to have a plan before undertaking forest management activities. Under the conditions created by Hurricane Hugo, planning is essential! Without careful planning, at best you may end up paying more to reforest your land than might have been necessary. At worst, you might end up spending a lot of money and still have a forest that is not much better off than it was right after the hurricane.

A professional forester can help you develop a plan that will meet your objectives on your land. Each forest and each landowner is different, so no one plan will work for everyone.

While planning with a forester, you can consider:

- the condition of your land,
- possible methods of reforesting your land,
- your ability to afford the possible actions, and
- your short and long-term goals.

If you talk about these factors with a professional forester, you can find a plan of action that is suited to you and your land. And remember, a management plan is required if you plan to apply for federal and state cost-sharing assistance.

Foresters from the S.C. Forestry Commission, private consulting

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[1] Extension Forester, Clemson University, Clemson, SC. Reprinted from a brochure (EC677) produced by the Clemson Cooperative Extension Service, Department of Forest Resources in cooperation with the South Carolina Forestry Commission. This work was supported by a grant under the Dire Emergency Supplemental Appropriations Act, providing federal funds through the Forestry Commission.

foresters, and landowner assistance foresters from some forest products firms are available to help you. For a list of names of foresters offering management plan assistance in your area, contact one of the offices listed on the back of this brochure.

COST-SHARING ASSISTANCE

Sometimes a landowner cannot afford to pay the full cost of reforesting his land. For such cases, there are several programs in which the government will share the costs. You can receive 50 to 75 percent of the average costs of reforesting if you apply for assistance. You will need to carry out the work under an approved forest management plan.

There are several requirements that are basic to most cost-share programs. A private, non-industrial landowner must own less than 1,000 acres of woodland to qualify for federal funds. State programs do not include a limit on total acreage owned, but a 100-acre limit is placed on the amount of land that can be cost-shared with a landowner each year. The land to be reforested must be able to produce at least 50 cubic feet of wood per acre per year.

The Forestry Incentives Program (FIP) has helped to plant trees on more than 235,000 acres in South Carolina since 1975. FIP pays 50 percent of the costs of reforesting cut-over land, planting open land, and improving your woodlands. Reforestation practices include various combinations of mechanical, chemical, and prescribed burning site preparation and tree planting. Assistance with woodland improvement activities is also available.

Designed to promote conservation of soil and water, the Agricultural Conservation Program (ACP) also can help reforest your land. ACP supports the same practices and cost schedules as FIP. Both FIP and ACP are administered by the Agricultural Stabilization and Conservation Service (ASCS) in cooperation with the S.C. Forestry Commission.

The Forest Renewal Program (FRP) is sponsored by the state of South Carolina and is administered directly by the Forestry Commission. FRP supports reforestation practices similar to those funded by FIP except timber stand improvement.

The newest cost-share program is the Stewardship Incentives Program (SIP). This program is designed to support reforestation and management practices that are a part of a landowner's stewardship forest management plan. SIP includes the basic activities of reforestation and stand improvement, but also helps manage for wildlife, recreation, and soil and water conservation.

A special cost-share program was created following Hurricane Hugo. The Hugo Incentives Program (HIP) can pay 75 percent of reforestation costs. HIP is restricted to land that was forested before Hurricane Hugo and was damaged by the storm. Funds for HIP are provided annually by the federal government, so it is unknown how long this program will be available.

Because of the wide-ranging damage caused by Hugo, all these programs are in great demand. Some delays are likely in receiving cost-share funds, but these programs can make a critical difference for many landowners. Remember that you need a forest management plan under these programs. And try to identify (with the help of a forester) the lowest-cost practices that can get the job done. This can help speed your approval under most programs.

REFORESTATION TAX INCENTIVES

To encourage reforestation, the federal government offers two significant income tax incentives. The first of these is a tax credit that you subtract from your income taxes paid during the year you reforest your land. You can subtract ten percent of your reforestation costs, up to a maximum credit of $1,000. Second, you can amortize (deduct) 95 percent of your reforestation costs over a seven-year period, rather than waiting to deduct them from timber harvest revenues. For example, if you spent $4,000 to reforest 25 acres of land, you could receive a credit of $400 when you file your income taxes the next spring. In addition, you could claim deductions totaling $3,800 over seven years' tax returns. This would effectively reduce your reforestation costs from $160 per acre to $115. If you received 50 percent cost sharing, you would further reduce your effective cost to $57 per acre.

Most landowners don't realize they are eligible for these helpful tax incentives, and as a result don't claim them. But there is no waiting line, and most private landowners can qualify. So be sure to claim this important benefit. (Incidentally, these tax incentives are available for all land, not just that damaged by Hugo!)

LOW-COST REFORESTATION METHODS

As a part of developing your reforestation plan with your forester, make sure that you have found the lowest-cost method for reforesting your woodland. Many times we do things the way we always have, but if you do you may be missing out on the benefits of newly-developed reforestation techniques. Each site has its own special set of conditions that may make it well-suited to one method, while ruling out others all together. With the tangle of debris that Hugo left in most forests, you may need all the help you can get to reduce the total cost of preparing and regenerating the site. Briefly, here are several techniques that may work especially well on Hugo-damaged sites.

NATURAL REGENERATION

If there was a bright side to forestry after Hurricane Hugo, it was that the storm hit after seeds in pine cones had ripened. This provided many sites with a new potential crop of trees already in place. You will need to have a forester check your land to see if such natural restocking took place. If so, and if there are enough seedlings, the major part of your work may be complete. You do need to see if there needs to be any control of competing vegetation, any need for thinning seedlings that are too closely spaced, and any spot planting that may be needed in areas which did not receive a good seed fall.

VEGETATION CONTROL WITH HERBICIDES

If your site does appear to have a good crop of natural seedlings, you may be able to improve their growth by controlling competing vegetation while the seedlings are getting started. You also may need to do this if you planted seedlings without heavy mechanical clearing of the site. Chemical control is the only practical method of releasing pines. Chemical control combined with careful prescribed fires can also be a very effective yet very economical site preparation system.

STAND REHABILITATION

Some timber stands were damaged but not completely destroyed. If enough healthy trees remain that can grow to acceptable stocking levels, you may be able to manage the remaining trees until they are mature. In the meantime, you may be able to develop natural regeneration of your next stand. This allows you to both delay and reduce the eventual costs of artificially reforesting the area.

STRIP CLEARING

Many stands of trees that could not be salvage harvested still contain so many downed trees and brush that it is difficult to even enter the area. Clearing the entire area with heavy machinery may be too expensive to be justifiable. A method called strip clearing pushes corridors through the tangle. Seedlings then are planted along the sides of these corridors. Although the trees may not be perfectly spaced across the entire area, an acceptable stand of trees can be established at much less expense.

OTHER IDEAS--THE ART OF FORESTRY

These are just a few of the possible ways that your forest stands could be reforested at reasonable costs. Since each site is different, not every method will work for you. But by working with a forester, you can draw upon his experience to find other possibilities. It may be that only brute force will work, but you owe it to yourself to investigate all possibilities before opening your checkbook.

IN CONCLUSION...

Even though the prospects for the restoration of our forests seemed bleak after Hurricane Hugo, the ability of the forest to adapt and recover is one of its great strengths. In many cases the potential for starting a new forest stand lies just below the surface, waiting for a nudge to break through. As a forest landowner, you can be an important part of the recovery. And even if the task is large and your financial resources are limited, there are some things that you can do. Talk with a forester, develop a plan that will work for both you and your land, and start the healing process on your land.

MANAGEMENT ALTERNATIVES COSTS FOR STORM-DAMAGED TIMBER IN THE SOUTHERN UNITED STATES[1]

C. D. Egbert, T. J. Straka, and A. P. Marsinko[2]

Abstract--Hurricane Hugo devastated over one-third of South Carolina's forest land. Much of the damage was so severe that site preparation is necessary for adequate forest regeneration. This paper describes the standard site preparation treatments and contrasts the costs in South Carolina for storm-damaged and non-damaged areas. Low-cost management alternatives are also described.

INTRODUCTION

On September 21, 1989, Hurricane Hugo devastated over one-third of South Carolina's forest land. Eleven counties suffered extensive or moderate forest damage and thirteen counties lesser, but significant, levels of forest damage. More than 4 million acres of trees, about 36 percent of the state's forest area, suffered severe damage, (meaning that 50 percent or more of the tree stems per acre are either broken or blown down). An estimated 1,331,785 acres of forest land require reforestation following Hurricane Hugo. In many cases the damage was so severe that management alternatives are quite limited. However, fortunately, wide-ranging management alternatives exist for most of the damaged area.

SITE PREPARATION TREATMENTS

Four site preparation treatments are in common use. The first can be described as standard heavy mechanical site preparation, consisting of shearing, raking, piling, and bedding or disking. The remaining three alternatives consist of V-bladed strips with light, medium, or heavy herbicide application. As might be expected the treatments in the hurricane-damaged area are more costly than those in the non-damaged area (Table 1). Even with an extensive salvage effort that removed much of the timber, site preparation costs were roughly 20 to 40 percent more costly in the storm-damaged area.

Table 1--Preliminary cost trends for site preparation in the Hurricane Hugo damage area, compared to normal site preparation costs in South Carolina.

Site Preparation Treatment	Cost Per Acre	
	Non-Hugo Area	Hugo Area
Straight three-pass practice (Shear, rake, pile, and bed or disk)	$168	$208
V-bladed strips with light herbicides	86	122
V-bladed strips with medium herbicides	116	152
V-bladed strips with heavy herbicides	156	182

In both the Hurricane Hugo area and the non-Hugo area the costs of tree planting are identical. This is expected because the site preparation operations create nearly identical planting sites. Total regeneration costs can be obtained by adding planting costs to site preparation costs (planting costs are $52 per acre for loblolly pine and $66 per acre for longleaf pine).

[1] A paper presented at the SAF National Convention poster session held at San Francisco, CA, on August 4-7, 1991.

[2] Charles D. Egbert, Thomas J. Straka, and Allan P. Marsinko, Department of Forest Resources, Clemson University, Clemson, SC 29634-1003.

Low-Cost Alternative

Over half the acres damaged by Hurricane Hugo are owned by nonindustrial private forest (NIPF) landowners, those landowners who often do not have the capital to finance regeneration efforts. Note that total regeneration costs ranged from $174 to $260 per acre in the storm-damaged area. Even with federal assistance many NIPF landowners will require low-cost management alternatives.

Straka and Baker (1991) identified two low-cost alternatives: (1) selection management, with 25-30 percent initial stocking and (2) natural even-aged management resulting from chemical release of suppressed pine seedlings. These two alternatives were contrasted with a standard loblolly pine plantation management regime with a $250 per acre establishment cost.

The selection management alternative assumes a stand that was initially 30 percent stocked, on site index 90 (base age 50) land, and a seven-year cutting cycle beginning at year 18. Competing hardwoods were controlled initially with herbicide at a cost of $45.00 per acre. A supplemental management cost of $13.00 per acre (for inventory and marking) was incurred every seven years prior to the harvest cut. Timber stand improvement was done every 10 years at a cost of $45.00 per acre.

The natural even-aged management alternative incurred an initial cost of $45.00 per acre to chemically release a stand originating from natural reproduction (at least 100 percent stocked) using herbicide. Timber stand improvement was done at age 5 at a cost of $45.00 per acre. Prescribed burning was done every 5 years, beginning at age 15, at a cost of $5.00 per acre. A supplemental management cost of $13.00 per acre (for inventory and marking) was incurred every 5 years prior to harvest.

The two low-cost alternatives were compared to the loblolly pine plantation alternative. Ignoring land cost the selection management alternative earned an internal rate of return (IRR) of 9.9 percent, the chemical release 8.6 percent, and the plantation 6.2 percent. When land cost is considered, all the alternatives earn roughly the same IRR (between 4.0 to 4.5 percent).

The landowner's management objective and treatment of land cost will determine the optimal alternative. Availability of federal assistance will also be a determining factor.

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PROBLEMS WITH NATURAL REGENERATION ON HUGO-DAMAGED LANDS

Joe Hamilton, Jim Adkins, Jaime Teel, David Nagel and Patrick Lee[1]

After the initial shock over the extensive devastation of Hurricane Hugo in 1989, questions surfaced about how the damaged forest lands would he restored to a productive state. Many professional foresters speculated over the possibilities of natural regeneration due to an abundant loblolly pine cone crop present when Hugo hit.

Stone Container, one of the forest products companies operating in the Hugo-damaged area, undertook a study on nonindustrial private landowner tracts in their Landowner Assistance Program (LOA) to determine if pine reproduction was sufficient to restore damaged stands. This undertaking was done on behalf of the LOA clients to assist in determining natural regeneration results and was not intended to be a statistical research project.

In the fall of the year following Hugo, the study was conducted in a ten-county area which was some of the hardest hit. The study area involved 77 LOA clients and consisted of 5,477 acres. All timber types were sampled to determine the success of natural pine and hardwood reproduction.

Individual LOA tracts were randomly sampled in the study area. Due to the natural regeneration ability of hardwood stands more emphasis was placed on sampling of pine stands. Stands that were only slightly damaged were not sampled because a manageable residual stand existed. The sampling procedure first consisted of a cursory inspection to determine if there was evidence of natural regeneration. If a significant amount of regeneration was found, then a systematic sample was taken using mil-acre plots to obtain total coverage of the stand on a grid spacing. A minimum of 50 plots were taken per stand. Regardless of the total number of pine seedlings found within the plot, only a maximum of two seedlings four feet apart were counted. These two seedlings would express dominance over the remaining pine seedlings within the plot. Pine seedlings were also evaluated based on hardwood competition which could affect their growth. If a hardwood sapling overtopped the pine seedling, then the pine seedling was considered as not free-to-grow.

All hardwood stands were evaluated based on a cursory observation to determine the number, quality and species of natural regeneration.

RESULTS

Based on the field study, the majority of the sampled acreage contained very little pine regeneration approximately one year after Hugo.

Stocking categories were selected based on the number of trees per acre. The data listed in Table 1 is based on total pine regeneration per acre. Understocked stands (0-300 trees/acre) totaled 3,374 acres or approximately 75 percent of the sampled area. Well stocked stands (300-1000 trees/acre) consisted of 1,068 acres or 24 percent of the sampled area. The balance of the sampled area consisted of 43 acres or 1 percent of overstocked regeneration (1000+ trees/acre).

Stocking categories which contain free-to-grow (FTG) seedlings per acre can be found in Table 2. Well stocked stands, when considering only free-to-grow trees per acre, actually consist of 551 acres or 12 percent of the sampled area.

The cursory examination of the hardwood stands revealed that these areas were regenerating back to hardwood.

[1] Woodlands Foresters, Stone Container Corporation.

Table 1--Acres of Total Natural Pine Regeneration by Stock Levels.

COUNTY	0 to 300	300 to 1000	1000+	TOTAL ACRES
Berkeley	699	577	0	1,276
Charleston	50	0	0	50
Dorchester	282	115	0	397
Orangeburg	71	73	0	144
Clarendon	319	45	14	378
Williamsburg	74	88	29	191
Kershaw	490	66	0	556
Lancaster	130	0	0	130
Lee	515	38	0	553
Sumter	744	66	0	810
	3,374	1,068	43	4,485

Table 2--Acres of Natural Pine Regeneration Categorized as Free-to-Grow by Stocking Levels.

COUNTY	0 to 300	300 to 1000	TOTAL ACRES
Berkeley	807	469	1,276
Charleston	50	0	50
Dorchester	367	30	397
Orangeburg	144	0	144
Clarendon	364	14	378
Williamsburg	191	0	191
Kershaw	556	0	556
Lancaster	130	0	130
Lee	515	38	553
Sumter	810	0	810
	3,934	551	4,485

Based on these results, the conclusion can be drawn that very little pine acreage (12 percent) was classified as adequately stocked with free-to-grow seedlings. This poor natural regeneration is believed to be attributable to the following factors:

· Evidence indicated that the majority of the pine cones did not release their pine seeds.

· Dense litter layers prevented available pine seed from contacting mineral soil.

· Dry conditions in the spring and summer of 1990 contributed to the poor survival of the pine seedlings on well drained to upland sites.

It is also clear that adequate natural pine regeneration is not guaranteed in the aftermath of a major hurricane simply because an abundant loblolly pine cone crop exists. Successful regeneration is dependent on many factors such as proper seed dispersal, contact with mineral soil, adequate moisture conditions and competition.

RECOMMENDATIONS TO LANDOWNERS IN HUGO AREA

If you are a landowner whose timberlands were damaged by Hurricane Hugo, the following steps should be taken to ensure adequate restocking of your timberlands:

· Natural regeneration on damaged forest land should be checked to determine stocking level, species composition and growth potential.

· Acceptability of natural regeneration should be determined on a stand-by-stand basis, thereby avoiding fragmentation into unmanageable units.

· Consider pine-release utilizing forestry chemicals if adequate regeneration is present but stagnated by hardwood competition.

· Both chemical and mechanical site preparation methods should be considered as alternatives if inadequate stocking is found.

· Inquire about cost-share possibilities from state, federal and private sources for stand restoration if stocking is found to be inadequate.

· Based on individual goals and objectives, seek professional advice to restore timberlands to a productive state.

· Always remember that properly managed lands offer the landowner the most options under normal conditions as well as when catastrophy strikes.

This study in the aftermath of Hugo will hopefully serve as useful reference material on natural pine regeneration when another hurricane strikes. The success of natural regeneration will vary with all of the many conditions present at the time of the hurricane. These pine regeneration results will not necessarily be the same with future hurricanes but do serve as realistic documentation with Hugo.

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CYPRESS RESTORATION IN SALT-KILLED WETLAND SYSTEMS (SOUTH CAROLINA)

William H. Conner and George Askew[1]

There are over 1.2 million hectares (2.7 million acres) of forested wetland in South Carolina (Dahl, 1990), including extensive swamps along the lower coastal plain. Unlike the coastal forests of Louisiana (Allen, 1992), South Carolina's forests are not subject to rapid water level rise (Stevenson and others, 1986) or nutria predation (Platt and Brantley, 1990; Allen and Boykin, 1991). Tropical cyclones, however, seriously affect the coastal forests of South Carolina. For instance, when Hurricane Hugo struck the South Carolina coast in September 1989, Hobcaw Forest was hit with a three-meter tidal surge, which flooded and killed the poorly drained bottomland forests and baldcypress (*Taxodium distichum*) with its saline waters (Hook and others, 1991).

Our preliminary plantings of locally-obtained baldcypress seedlings at Hobcaw Forest show that problems due to high salinity remain three years after the storm (Conner, in press; Williams, in press). As a result, we now want to determine whether some populations of baldcypress may be more tolerant to saline water than others. Our experiment is being coordinated with James Allen at the USFWS National Wetlands Research Center, who is working on the same subject using seedlings he germinated from locally-collected baldcypress growing in high-salinity areas in Louisiana (see R&MN 10(2):155). If we are successful in finding and reproducing a salt-tolerant strain of baldcypress then we can restore areas damaged by rising sea levels or storms.

During November 1992, we collected baldcypress seed from 5 trees from each of 9 tidal areas in South Carolina, Georgia, Alabama, and Louisiana. Salinity during collection averaged 2 parts per thousand (ppt), although locals said levels were higher during other parts of the year. We moist-stratified the seed for 90 days at 4-8 degrees C (39-46 degrees F) and then planted 44 seeds from each of the 45 parent trees. After the first growing season, we plan to measure the diameter and height of the nursery-grown seedlings prior to outplanting them for further testing at Hobcaw Forest and the Savannah River National Wildlife Refuge.

We also planted seed from each source in 5 cm by 25 cm Deepots, which we will expose to one of the following treatments: 0, 2, 4, 6, 8, or 10 ppt saltwater. After one growing season, we will measure the weight of stems, leaves and roots to determine if there are differences in growth among sources. We have plans for a second test that will use a single seed source to produce seedlings that will be subjected to 5 ppt saltwater. We will harvest these seedlings every three days throughout the growing season in order to analyze the leaves, stems, and roots for chloride content. In the third part of the experiment, we will perform electrophoresis on all the seed sources to examine patterns of genetic diversity across the coastal portion of the species range using the phosphoglucose isomerase enzyme (PGI).

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Impact of Saltwater Flooding on Red Maple, Redbay, and Chinese Tallow Seedlings

William H. Conner and George R. Askew[1]

Abstract--Potted seedlings of red maple (*Acer rubrum* L.), redbay (*Persea borbonia* (L.) Spreng.), and Chinese tallow (*Sapium sebiferum* (L.) Roxb.) were subjected to flooding with saltwater for 0 to 5 days. Red maple and redbay seedlings were very susceptible to saltwater flooding and were unable to tolerate more than 1 day of flooding. Chinese tallow seedlings, on the other hand, were able to tolerate saltwater well (60% survival after 5 days of flooding). Height growth of red maple and redbay seedlings was low (0.6 and 3.4 cm, respectively) during the eight-week study even for those seedlings not exposed to saltwater. Unflooded Chinese tallow seedlings, however, grew 20.7 cm during the eight-week observation period. Diameter growth of flooded seedlings along with biomass of shoot, leaf, and root components in all three species was significantly reduced by saltwater flooding. Biomass partitioning of surviving seedlings was not appreciably affected by saltwater flooding. Chinese tallow seems to be able to tolerate salinity fairly well and may become a dominant species of southern coastal forests.

INTRODUCTION

Forested wetlands in the lower coastal plain region of the southern United States are subjected to saltwater flooding by hurricane storm surges and extreme high tide events. Global warming and resulting rising sea level of 0.25 to 2.0 m by the year 2100 (Smith and Tirpak 1989, Houghton and others 1990) indicate that these forests will be subjected to increased flooding and salinity in the future. While some research has been conducted on the response of major canopy species to salinity (see Pezeshki and others 1990 for a review), there are no published studies which describe the response of the understory species to saltwater intrusion.

Red maple (*Acer rubrum* L.) and redbay (*Persea borbonia* [L.] Spreng.) are both common species in lowland forests of the Atlantic coastal plain (Jones and Gresham 1985). Chinese tallow (*Sapium sebiferum* [L.] Roxb.) has successfully invaded some forested wetland areas of the southern United States (Jones and McLeod 1990). All of these species are shade tolerant (Walters and Yawney 1990, Brendemuehl 1990, Jones and McLeod 1989). Redbay is commonly found growing on the borders of swampy areas, while red maple and Chinese tallow can grow in areas ranging from very dry to very wet. Both of the latter species can form pure to nearly pure stands in poorly drained areas (Helm and others 1991, Walters and Yawney 1990). Because Chinese tallow can tolerate some salt (Huoran and Pengxin 1991) as well as flooding and shade (Jones and McLeod 1989, 1990), it may become more common in coastal forests in the future.

The scarcity of information on the impact of saltwater flooding on understory components of coastal forests led

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to the development of this project. Although it is not a large-scale experiment, it can provide us with preliminary data as to what to expect when these species are flooded with saltwater and point us in the proper direction for future studies. The specific objective of this study was to determine survival, stem diameter and height growth, and biomass accumulation of seedling plants of the three species when subjected to saltwater flooding such as would occur during passage of a hurricane or an extreme high tide event.

METHODS

Red maple, redbay, and Chinese tallow seeds were collected from Hobcaw Barony near Georgetown, South Carolina. Chinese tallow and redbay seeds were collected from a variety of trees in the fall of 1990 and stratified according to Schopmeyer (1974). Red maple seeds were collected in the spring of 1991. All seeds were planted in seed beds at the Baruch Forest Science nursery in the spring of 1991. After the production of several fully expanded leaves, seedlings were transferred to Deepots™ (2.54 cm diameter and 25 cm deep) filled with a commercial potting mix and a slow release fertilizer (Osmocote 14-14-14). Potted seedlings were placed in an outdoor facility and allowed to grow for four months before treatment. Seedlings were irrigated daily and fertilized weekly with a water soluble fertilizer (Miracle Gro 15-30-15).

In July 1991, ten seedlings of each species were randomly assigned to 0, 1, 2, 3, 4, or 5 days of saltwater flooding. After recording height and basal diameter, all of the seedlings were placed in a plastic pool (1.5 m diameter, 0.3 m deep) filled with water collected from a tidal creek (27 ppt). One treatment was removed from the pool each day. Flooding was maintained at approximately 5 cm above the soil surface by adding salt water as needed. The pool was under shade cloth (50% reduction) to prevent the water from becoming too hot. Water temperature varied from 27-30°C and tracked air temperature by 1°C. Salinity in the pool declined from 27 ppt to 20 ppt by day 5.

Seedlings were flushed with fresh water after they were removed from the pool and then placed in the outdoor facility, watered daily with freshwater, and fertilized weekly (Miracle Gro 15-30-15). Flushing with fresh water simulated rainfall that occurred after passage of the hurricane. Seedlings were allowed to grow for 8 weeks after the flooding treatment, and their status was recorded weekly. After eight weeks, all seedlings were harvested and separated into root, stem, and foliage (if still alive) components, dried to a constant weight at 65°C, and weighed.

RESULTS

Red maple and redbay seedlings were extremely susceptible to saltwater flooding (Figure 1). Within 2 weeks of flooding, 80% of the red maple seedlings were dead. Redbay seedlings seemed to be more tolerant than red maple seedlings at first, but after 3 weeks they began to die rapidly. None of the red maple and redbay seedlings were capable of withstanding more than 1 day of flooding. Chinese tallow seedlings were very tolerant of saltwater, with 60% surviving 5 days of flooding (Figure 1). Up to 2 days of flooding had very little impact upon survival, and mortality of seedlings flooded for more than 2 days did not occur until 3 weeks after flooding.

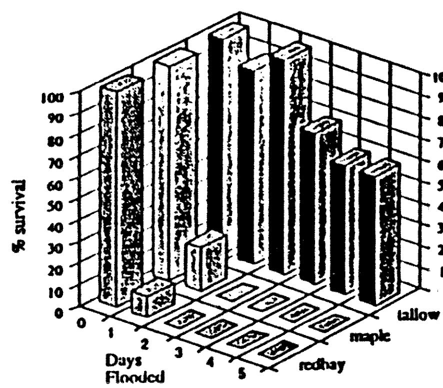

Figure 1--Percent survival for red maple, redbay, and Chinese tallow seedlings flooded for 0 to 5 days with saltwater.

Height growth of red maple and redbay seedlings was low (0.6 and 3.4 cm, respectively) during the eight-week study even for those seedlings not exposed to saltwater. Final height of red maple (6.5 cm) and redbay (28.0 cm) seedlings surviving saltwater flooding was less than the average height at the beginning of the experiment because the stems tended to die and new growth emerged from the base of the seedling. Unflooded Chinese tallow seedlings grew 20.7 cm during the 8-week observation period. Average height of flooded seedlings declined with increasing exposure to saltwater (Table 1) with a sharp decrease after 3 days of flooding. Interestingly, average height of the 5-day flooded seedlings was greater than the 4-day flooded seedlings.

Average diameter growth of unflooded seedlings was 1.2, 1.6, and 2.4 cm for redbay, red maple, and Chinese tallow seedlings, respectively. After 1 day of flooding, the surviving redbay seedling only increased 0.5 cm during the 8-week post flood period while red maple seedling diameter only increased 0.2 cm. Diameter growth of Chinese tallow decreased with each additional day of flooding until there was no positive change in diameter at 3 days and beyond (Table 1).

Just 1 day of saltwater flooding significantly reduced the biomass of shoot, leaf, and root components in all three species (Figure 2). Red maple and redbay biomass values tended to stabilize after 1 day of flooding, but Chinese tallow biomass values continued to decline with up to 4 days of flooding. Both Chinese tallow and redbay root and stem biomass showed a slight increase in dry weight for seedlings flooded for 5 days. Root: shoot (stem + leaves) ratios of unflooded seedlings were fairly consistent (0.45-0.49) for all three species. Although the Chinese tallow root:shoot ratio declined to 0.34 with 3 days of flooding, the ratio for 5-day flooded seedlings was nearly identical to unflooded seedlings.

Biomass partitioning of surviving seedlings was not appreciably affected by saltwater flooding.

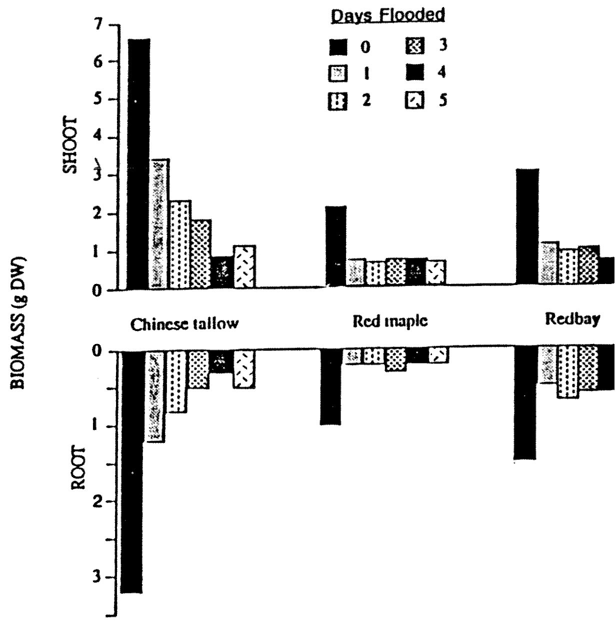

Figure 2--Biomass partitioned into shoot (stem + leaf) and root dry weights (DW) for seedlings flooded for 0 to 5 days with saltwater.

DISCUSSION

Although there have been no previous studies detailing the response of these understory species to salinity, there have been a limited number of studies describing the effects of freshwater flooding on red maple (Day 1987, Jones and others 1989) and Chinese tallow (Jones and Sharitz 1990) and the effects of light intensity on Chinese tallow growth (Jones and McLeod 1989, 1990). Day (1987) and Jones and others (1989) both reported that red maple

Table 1--Height and diameter data for Chinese tallow seedlings flooded with saltwater. Standard deviation is in parentheses. Numbers in the same column followed by identical letters are not statistically different (alpha = 0.05, Fisher PLSD).

Days flooded	Initial ht. (cm)	Initial dia. (cm)	Final ht. (cm)	Final dia. (cm)
0	53.0 (6.5)a	5.1 (0.3)a	73.7 (7.3)a	7.5 (1.0)a
1	52.1 (3.8)a	5.1 (0.4)a	63.3 (4.4)a	6.1 (0.9)a
2	50.4 (4.2)a	5.1 (0.4)a	47.0 (14.2)b	5.3 (0.6)b
3	51.2 (4.1)a	5.1 (0.4)a	43.1 (29.8)b	5.1 (0.6)b
4	49.7 (6.4)a	5.4 (0.4)b	11.3 (4.8)c	4.8 (1.0)b
5	49.7 (3.4)a	5.3 (0.6)a	22.7 (8.3)c	4.8 (0.5)b

seedlings survive flooded conditions but total dry weight, height, and diameter were reduced. Day (1987) hypothesized that lower root:shoot ratios are probably the result of root die-off and is similar to flooding results of other forested wetland species (Dickson and Broyer 1972, Keeley 1979, Sena Gomes and Kozlowski 1980, Kane 1981). Chinese tallow has a high shade tolerance (Jones and McLeod 1989, 1990) and high flood tolerance (Jones and Sharitz 1990).

In the present study, all three of the species exhibited greatly reduced growth and vigor as a result of increased flooding with saltwater. Chinese tallow seedlings were the most tolerant and were able to survive up to 5 days of flooding. Red maple and redbay seedlings were very susceptible to saltwater flooding, with significant mortality and growth reductions after 1 day of flooding. These results are consistent with field observations of areas on Hobcaw that were flooded by Hurricane Hugo's storm surge. More study is needed to determine successional patterns in coastal forested wetlands that are, or will be in the future, subject to saltwater intrusion. Chinese tallow seems to be able to tolerate shade (Jones and McLeod 1989), flooding (Jones and others 1989), and salinity (this study) fairly well and may become a dominant species of southern coastal forests. Because of Chinese tallow's tolerance to a wide range of environmental conditions, it is successfully becoming established and thriving in coastal wetlands of the southeastern United States. It has the potential to outcompete native vegetation and may become a serious pest species in the future.

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ARTIFICIAL REGENERATION OF BALDCYPRESS IN THREE SOUTH CAROLINA FORESTED WETLAND AREAS AFTER HURRICANE HUGO[1]

William H. Conner[2]

Abstract--Permanent plots were established in three forested wetlands on Hobcaw Barony, South Carolina, during the spring of 1990 to monitor recovery of the wetlands following Hurricane Hugo. Plots were located in (1) an area that retained saltwater for several days following the hurricane storm surge, (2) an area flushed with saltwater, and (3) an area that received no saltwater. Because of the lack of natural regeneration occurring in the three areas, baldcypress seedlings were planted to help restock the stands. Tubex treeshelters were placed on one-half of the seedlings to determine if they improved survival and height growth. After two growing seasons, survival was greatest in the area that received no saltwater. The treeshelters seemed to increase survival of seedlings in the two storm surge areas. Height growth was greatest in the area that retained saltwater, and seedlings averaged over 10 inches taller than seedlings in the other two areas. Whereas the treeshelters seemed to have a beneficial effect on height growth during the first growing season, growth differences were not as pronounced during year two. Available light and salinity levels may be the two most important factors controlling survival and growth in the stands. More detailed research needs to be conducted to develop sound silvicultural plans.

INTRODUCTION

Hurricanes are an episodic, but normal, part of the climatic regime of the southeastern United States. Current evidence indicates that between 160,000 and 320,000 hurricanes have occurred in the Florida Keys during the past 2 million years (Ball and others 1967). What coastal ecosystems would be like without hurricanes is unknown, but they would probably be different, both morphologically and ecologically (Conner and others 1989). Hurricane disturbance can result from both wind and flooding effects. High winds can defoliate, break, or topple trees, with the severity of damage related to storm intensity, forest structure, species, and soil conditions (Weaver 1989, Gresham and others 1991). Little attention has been given to storm surge effects since heavy rains accompanying the hurricane usually saturate soils to protect them from saltwater intrusion (Gardner and others 1991, Hook and others 1991).

Hurricane Hugo struck the South Carolina coast in September 1989 causing timber damage on nearly 4.5 million acres (Hook and others 1991). Hobcaw Forest, 4 miles east of Georgetown and 56 miles northeast of where the eye of the hurricane came ashore, was hit with winds estimated to be 54 mi/hr gusting to 86 mi/hr (Purvis

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and others 1990). Although heavy damage was sustained in pine forests and poorly drained bottomland forests, baldcypress (*Taxodium distichum* (L.) Rich.) forests suffered little wind damage (Gresham and others 1991, Hook and others 1991). The greatest damage to forested wetlands on Hobcaw was caused by saltwater flooding from the 10-foot storm surge.

OBJECTIVES

The objectives of this research were to initially document the effects of Hurricane Hugo on Hobcaw forested wetlands and natural recovery of the forest. However, the lack of natural regeneration during the first growing season after Hugo necessitated the establishment of long-term study plots to monitor regeneration patterns and to examine the feasibility of planting seedlings in the affected stands. This paper describes the damage done to three forested wetland stands, the lack of natural regeneration, and the initial success of underplanting baldcypress seedlings.

METHODS

Study plots were established during March 1991, 18 months after Hurricane Hugo, in three forested wetland stands on Hobcaw Forest. The first stand (hereafter referred to as Marsh Road) was a baldcypress/swamp blackgum (*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.) forest that lies between two old beach ridges on the eastern edge of Hobcaw Forest. Saltwater from the storm surge was retained in the forest for several days. The second area (Boardwalk) was flushed by saltwater, and the third area (Crabhaul) received no saltwater but did receive minor wind damage.

Within each stand, five 0.12 acre plots were installed during the spring of 1990 to inventory trees larger than 4.0 inches diameter at breast height (dbh). Each tree was tagged, dbh measured, and condition or cause of death recorded. Natural regeneration was monitored in ten 3.3 ft X 3.3 ft subplots within each of the larger plots. Regeneration was inventoried in June and September 1990 and in January and May 1991. Seed banks were sampled by randomly collecting twenty 12 in X 12 in X 2 in sections of forest floor from each stand in July 1990. The soil samples were mixed, placed in trays, put in a greenhouse, kept moist, and inventoried weekly for three months. After three months, tree seeds were collected by sieving and tested for viability using Tetrazolium (Shuel 1948).

When it became evident that little natural regeneration was occurring in the stands, 80 one-year-old baldcypress seedlings (obtained from the South Carolina Forestry Commission) were planted adjacent to each tree measurement plot in March 1991. The planting design consisted of 20 equally spaced planting spokes radiating from a center point. Four seedlings were planted on each spoke at a 6.6 ft spacing. Two-foot tall Tubex treeshelters were used on seedlings in every other row to determine if they increased survival and growth of newly planted seedlings in wetland conditions.

RESULTS AND DISCUSSION

Tree Damage

Very few tops were broken out of trees in the wetland stands (Table 1), although 84% of baldcypress trees and 88% of swamp blackgum trees did suffer some limb breakage (Gresham and others 1991). Major damage was caused by the 10-foot storm surge that struck the eastern edge of the forest. Runoff was impeded in the Marsh Road stand by old logging roads at each end of the low-lying area that the forest is in. Saltwater was retained for several days until water levels stabilized at pre-storm heights. Salinity levels of 2 ppt were still being measured two years after the hurricane. Over one-half of the canopy trees were killed during the first few weeks following flooding. Saltwater also flooded the Boardwalk area, killing the mainly waxmyrtle (*Myrica cerifera* L.) understory. Only 28% of the canopy trees died immediately after the saltwater surge. Additional mortality occurred, however, during the summer following the storm surge. It is unknown why this delay in mortality occurred in the Boardwalk area. Canopy trees are still dying in the two saltwater areas, indicating that there are still residual effects of the salt.

Natural Regeneration

There was very little natural regeneration of woody species during the two growing seasons following Hurricane Hugo. The greatest number of baldcypress and water tupelo seedlings came up in the Crabhaul stand, but they failed to grow tall enough to survive subsequent flooding. In the Marsh Road

Table 1--Variation in Hurricane Hugo damage to three forested wetland stands in South Carolina. All values are given as percentages.

Area	Top Breakage	Dead	
		1990	1991
Crabhaul	2.7	0	0
Boardwalk	3.8	28.0	40.8
Marsh Road	1.8	57.1	65.5

and Boardwalk stands, some redbay (*Persea borbonia* (l.) Spreng.), wax-myrtle, fetterbush (*Lyonia lucida* (Lam.) Koch), and red maple (*Acer rubrum* L.) became established on old stumps, cypress knees and buttresses, and other raised areas that kept them out of the water. Overall, only 3 water tupelo seedlings survived in the Crabhaul stand, along with 5 bald-cypress in the Boardwalk stand and 2 baldcypress in the Marsh Road stand.

The soil seed banks were surprisingly devoid of seeds from the canopy species. A total of 7 baldcypress and 13 swamp blackgum seeds germinated from the soil sections taken from Crabhaul. This was much better than the Boardwalk stand (no germination) or the Marsh Road stand (3 bald-cypress). Although a number of seeds were sieved from the soil samples at the end of three months, none tested viable with Tetrazolium. This pool of dead seeds is similar to that observed by Schneider and Sharitz (1986) for another forested wetland site in South Carolina. They suggested that too much flooding may result in nonviable seeds. Saltwater may have also had an impact in this study. Additional work needs to be done examining the seed longevity and viability in relation to flooding and salinity.

Planted Seedlings

Survival of baldcypress seedlings during the first growing season was greatest in the Crabhaul stand and least in the Boardwalk stand (Table 2). Tubex treeshelters seemed to greatly increase survival in the Boardwalk area, while there were no differences in survival of Tubex and non-Tubex seedlings in the Crabhaul stand. Survival was greater with treeshelters in the Marsh Road stand, but not significantly. Survival percentages after two growing seasons

Table 2--Survival of planted bald-cypress seedlings in three South Carolina wetland stands.

Area	First-year survival		Second-year survival	
	Tubex	non-Tubex	Tubex	non-Tubex
Crabhaul	100	100	100	99
Boardwalk	79	48	72	38
Marsh Road	94	82	92	80

were similar to first year survival in the Crabhaul and Marsh Road stands, but the Boardwalk stand continued to lose seedlings. Saltwater in the Marsh Road and Boardwalk areas may still be affecting survival. Examination of Cl^- levels in seedling leaves revealed 71 ppm in the Boardwalk area and 57 ppm in the Marsh Road area compared to 17 ppm in the Marsh Road area. Whereas chloride is an essential micronutrient, excess chloride can be detrimental (Ghosh and Drew 1991). Pezeshki and others (1988) found that salinity causes accumulation of several ions in baldcypress leaf tissue significantly decreasing photosynthesis levels.

Height growth was best in the Marsh Road area during both growing seasons (Table 3). Average height of seedlings in the Marsh Road stand were 3 inches greater than seedlings in the other two areas after one growing season and 10 inches greater after two growing seasons. The Tubex treeshelters seemed to have a beneficial effect on height growth during the first growing season but not as clear an effect during the second year. Non-Tubex seedlings grew slightly more than Tubex seedlings in Crabhaul during the second growing season and slightly less than Tubex seedlings in Marsh Road. The Boardwalk was the only area that exhibited significantly greater height growth of Tubex seedlings during the second growing season. Most of the seedlings grew out of the 2-foot treeshelters during the first year. Therefore, the treeshelters did not offer much of an advantage over non-Tubex seedlings during the second year. Taller treeshelters should be tested to see if they remain beneficial for longer than one growing season.

One factor that probably influenced growth rates at the Crabhaul and Boardwalk stands was the amount of sunlight reaching the forest floor. Only 4% of available light reached the

Table 3--Average height growth (inches) of planted baldcypress seedlings in three South Carolina wetland stands.

Area	First-year growth		Second-year growth	
	Tubex	non-Tubex	Tubex	non-Tubex
Crabhaul	3.5	3.0	4.6	5.0
Boardwalk	3.4	1.3	5.0	0.9
Marsh Road	7.0	4.2	11.6	10.7

Crabhaul forest floor during the summer months. Even though 38% of available light reached the floor at Boardwalk, this may not have been sufficient for maximum growth. Baldcypress tends to be intermediately tolerant to shade and grows best in full sunlight conditions (Wenger 1984, Wilhite and Toliver 1990). The Marsh Road stand has the most open canopy and 58% of available light reached the forest floor. Conner and Flynn (1989) found similar results in a Louisiana wetland forest where baldcypress seedlings planted in more open areas grew better than those planted in shaded areas (9 inches versus 3 inches).

CONCLUSIONS

Natural regeneration in hurricane impacted forested wetland stands is very erratic. To ensure adequate stocking of the stand after disturbance, planting may be necessary. However, there is much to learn before we can recommend large-scale reforestation of baldcypress stands. More detailed, long-term studies need to be conducted to ensure that sound silvicultural practices be formulated.

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THIRD-YEAR RESULTS FROM A TEST OF LONGLEAF PINE (*Pinus palustris* Mill.) SEED SOURCES ON THE FRANCIS MARION NATIONAL FOREST

Earl R. Sluder[1]

Abstract--Containerized longleaf pine seedlings from eight geographic sources from eastern North Carolina to southern Mississippi were planted at three locations on the Francis Marion National Forest in South Carolina and one location in central Georgia. Seedlings were started in the greenhouse in January and field-planted in May 1991. At age 3 years from seed, survival was high and most seedlings had begun height growth. Variation among seed sources was nonsignificant for survival, significant for height (P<0.05) in two locations, and significant for within-plot coefficient of variation in height (P<0.05) in the Georgia planting. Neither height nor survival varied significantly among seed sources when averaged over the four plantings. Differences among plantation averages were significant (P<0.01 or 0.001) for all three traits. Height growth was best in the Georgia plantation.

INTRODUCTION

Hurricane Hugo in 1989 destroyed much of the timber on Francis Marion National Forest (FMNF) near Charleston, South Carolina. Forest managers plan to plant longleaf pine on as many suitable sites as possible in the storm-damaged area. Unfortunately, the longleaf pine seed orchard also was destroyed. Until the seed orchard is re-established and producing, it will be necessary to use seeds from other sources, but some of those sources may not be genetically well-adapted to conditions on the FMNF. Conversely, some sources may do better than the local source. In 1991, a study was installed on the FMNF to evaluate relative performance of eight prospective seed sources. Data from the study will provide a basis for deciding whether to use natural methods such as shelterwood for reproducing stands established from nonlocal sources, and whether some sources perform well enough on the FMNF to be used even after local seeds are available.

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LITERATURE REVIEW

Early European settlers found most of the land in what is now the Southeastern United States to be covered by park-like stands of old-growth longleaf pine. The range of the species extended from southeastern Virginia to eastern Texas and from south-central Florida to north-central Alabama and Georgia (Figure 1). Over this range, it originally occupied approximately 60 million acres. Longleaf stands have been reduced to approximately 4 million acres by land clearing for agriculture or harvesting without provision for reproduction (Coker 1987).

Longleaf pine has always been much prized for its fire, insect, and disease resistance, its deep root system, and its rapid growth through middle age. The very demanding planting requirements for longleaf pine, however, have led to planting failures that discouraged management of the species. Stands with adequate numbers of seed-producing trees can be regenerated with shelterwood techniques that include prescribed burning, and

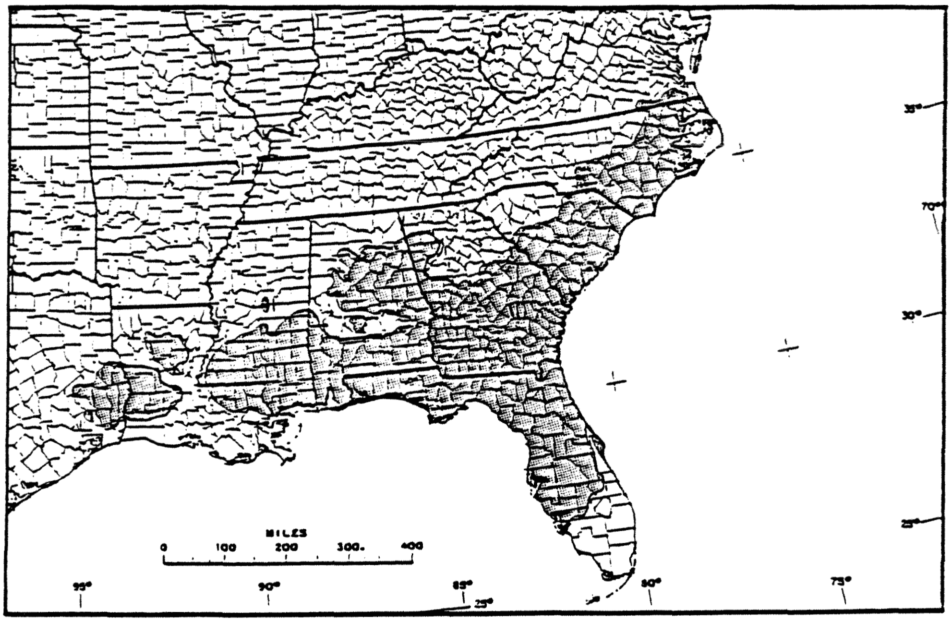


Figure 1--Natural range of longleaf pine.

direct-seeding has had some success (Derr and Mann 1971, Croker 1987).

In part because satisfactory techniques have been developed for planting it, interest in planting and growing longleaf pine has increased a great deal (Croker 1987). These techniques include production of large seedlings, careful handling and storage (including refrigeration), correct planting depth, and control of competition and brownspot needle blight (caused by *Mycosphaerella dearnsii* Barr) (Brissette and others 1990, Croker 1987, Hatchell and Muse 1990, Sirmon 1990, Snow and others 1990, Wakeley 1954).

Successful artificial regeneration techniques bring the ability to use nonlocal seed and the need to know the geographic limits within which seed can safely be moved. The Southwide Pine Seed Source Study has provided information on the broad pattern of genetic variation in longleaf pine associated with seed source. Significant variation in survival, growth, and resistance to brownspot needle blight occurred among the widely spaced sources in the study (Henry and Wells 1967, Schmidtling and White 1990, Wells and Wakeley 1970). Variation patterns permit wide movement of seeds within certain specified climatic limits with low risk of failure. Other studies have indicated that local variation is greater than that associated with broad geographic patterns (Kraus and Sluder 1990, Snyder and Derr 1972).

Successful artificial regeneration techniques also permit breeding prorams for improving the genetic quality of planting stock. Longleaf pine areas on the Region 8 National Forests have been divided into breeding populations, selections have been made, and progeny tests and clonal seed orchards established (Schmidtling and White 1990, Wells and McConnell 1984).

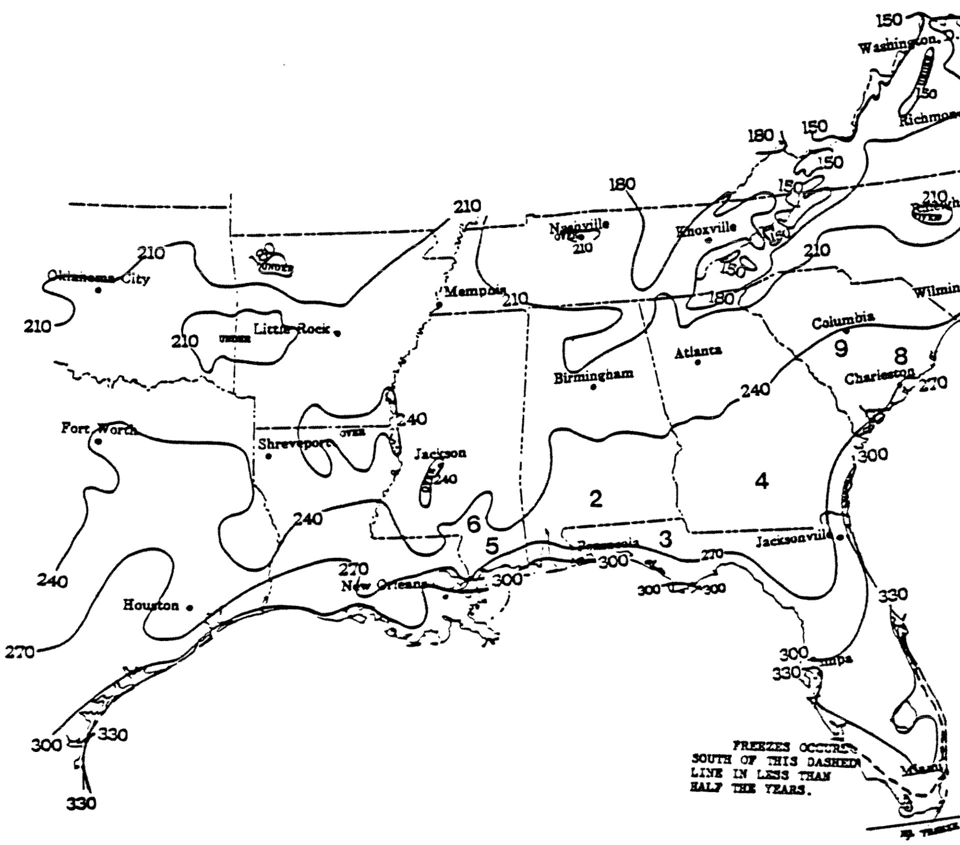
METHODS

Longleaf pine seeds from eight georaphic sources were included in my study. The sources were distributed in six states within or near a zone with 240-270 freeze-free days. This zone includes the Francis Marion National Forest (Table 1; Figure 2). The North Carolina source (Bladen County) is a few days north of the 240-day isobar. Seeds from the various sources were obtained in 1990 from cooperators as indicated in Table 1. Seeds collected

Table 1--Description of seed sources used in the study.

Lot	Source	Description	Cooperator
2	S. Alabama	Seed orchard, 1988[a]	Region 8, Ashe Nursery
3	N. Florida	Forest, 1987	Region 8, Ashe Nursery
4	S. Georgia	Seedling S. O., 1990	Georgia Forestry Comm.
5	S. Mississippi	Seed orchard, 1987	Region 8, Ashe Nursery
6	S. Mississippi	Forest, 1987	Region 8, Ashe Nursery
7	E. North Car.	Seed orchard, 1988	Federal Paper Company
8	South Carolina	Seed orchard, 1987	Region 8, Ashe Nursery
9	South Carolina	Forest (sandhills), 1990	South Car. Forestry Comm.

[a] Year of seed collection. Lot 1 differed from lot 2 only in year of seed collection; it was dropped to facilitate field layout.



MEAN LENGTH OF FREEZE-FREE PERIOD

Days between last 32° (F.) temperature in spring and first 32° temperature in autumn. Spring freezes are assumed to occur between January 1 and June 30; autumn freezes between July 1 and December 31. *Table and map excerpted from pages 31 and 32, "Climatic Atlas of the United States," Environmental Science Services Administration, U.S. Department of Commerce.*

Figure 2--Mean length of freeze-free period, SE U.S., with approximate location of seed sources.

before 1990 had been stored at subfreezing temperatures.

Seeds were planted in the greenhouse in January 1991, in 10-cubic-inch plastic tubes filled with a medium of peat, perlite, and vermiculite to which a slow-release fertilizer had been added. When crowding of the seedlings became evident, tubes were rearranged within the racks to occupy alternate spaces. In April, seedlings were moved from the greenhouse to a shadehouse, then a week later to full sun. A Benlate drench was used periodically to prevent fungal infection.

Three complete installations of the study were planted May 14-16, 1991, and designated as plantations 154-156, on the Francis Marion National Forest. Each installation included a 16-tree square plot of each source in each of four randomized-block replications. Spacing was 10 X 10 feet in plantation 154 and 8 X 8 feet in the other two. Another installation was planted in Peach County in central Georgia in cooperation with Fort Valley State College (plantation 157). This plantation has six replications, 16-tree plots, and 10 X 10-foot spacing; planting dates were May 24 (reps 1-4) and June 14 (reps 5-6). Two border rows of the local source were planted around each plantation. Planting sites were cleared forest on the Francis Marion and old field in Georgia. Each site was disc-harrowed before planting.

Competition control since planting has included burning at the end of the second season in plantation 154; herbicides in plantation 155; and herbicides, mowing, and hand-hoeing in plantation 157. Herbicides caused some mortality in plantation 157 and excess water caused some in plantation 155 during the first growing season. The dead trees were replanted with tubelings from the same sources which earlier had been transferred to larger containers and kept for that purpose.

The study was assessed at the end of the 1993 growing season, when the seedlings were in their third year from seed. Survival was recorded and heights measured to the nearest cm. Data analyzed were survival, plot mean height and within-plot coefficient of variation (CV) in height. Percentage data (survival and CV) were transformed to the arcsines of their square roots for analysis.

RESULTS

Survival was high and did not vary significantly among seed sources within any of the plantations (Tables 3 and 4). Plantation mean survival ranged from 83 percent in plantation 154 to 96 percent in plantation 157. This difference in survival across plantations was significant ($P<0.01$), whether or not the Georgia plantation (157) was included in the combined analysis (Table 5). No plantation-by-seed-source interaction in survival was evident.

Mean heights at age 3 years varied significantly among sources ($P<0.05$) only in plantations 156 and 157 (Table 4). In 156, the Alabama source (lot 2) was tallest and the Florida source (lot 3) was shortest. In 157, the South Carolina sandhills source (lot 9) was tallest and the Mississippi forest source (lot 6) was shortest (Table 3). Combined analyses, however, showed that heights averaged over plantations did not differ significantly among sources (Table 5). Neither was there any significant interaction of seed source with plantation location. Plantation mean heights varied from 10.3 to 14.2 cm for the three in South Carolina (nonsignificant), but the mean for the Georgia plantation of 62.5 cm in height was significantly greater than the others ($P<0.001$) (Table 5).

Within-plot CV in height generally was quite high, as might be expected when longleaf pine seedlings are emerging from the grass stage. Variation among seed sources in this trait, however, was significant only in plantation 157 ($P<0.05$) (Table 4). In combined analyses, variation was significant only among plantations ($P<0.001$) (Table 5). Within-plot height CV was greatest in plantations 155 and 156 at 84 and 74 percent, respectively (Table 3).

DISCUSSION

The influence of vegetative competition and microsite variability on height growth initiation and growth rate is quite evident in these early results. The high water table on the Francis Marion likely is the factor most responsible for the large difference between mean height there and on the Georgia site, where drainage is good but not excessive. The strong effect of drainage could be seen in the South Carolina plantations, where discing left some planting spots noticeably lower than others. After rains, seedlings planted in low spots stayed

Table 2--Analysis of variance design.

Source	D. f.	Expectation mean square
		Individual plantations
Rep (R)	r-1	$V_{rs} + sV_r$
Source (S)	s-1	$V_{rs} + rV_s$
R X S	(r-1)(s-1)	V_{rs}
		Plantations combined
Plantation (P)	p-1	$V_{r(p)s} + rV_{sp} + sV_{r(p)} + rsV_p$
Rep (R) in P	(r-1)p	$V_{r(p)s} + sV_{r(p)}$
Source (S)	s-1	$V_{r(p)s} + rV_{sp} + prV_s$
P X S	(p-1)(s-1)	$V_{r(p)s} + rV_{sp}$
R in P X S	((r-1)p)(s-1)	$V_{r(p)s}$

Table 3--Means data at age 3 years from seed.

Seed lot	Plantation 154	155	156	157[a]	Mean
			Survival, percent		
2 ALSO	84.37	93.75	95.31	95.31	92.18
3 FLF	84.37	93.75	85.94	98.44	90.62
4 GASO	78.12	92.19	92.19	98.44	90.23
5 MSSO	84.37	89.06	96.87	95.31	91.40
6 MSF	85.94	92.19	100.00	96.87	93.75
7 NCSO	84.37	87.50	93.75	92.19	89.45
8 SCSO	81.25	85.94	93.75	100.00	90.23
9 SCF	84.37	89.06	90.62	90.62	88.67
Mean	83.40	90.43	93.55	95.90	90.82
			Height, cm		
2 ALSO	11.42	13.72	12.75	68.82	26.68
3 FLF	8.27	11.02	6.82	57.87	21.00
4 GASO	12.55	13.15	9.37	60.10	23.79
5 MSSO	12.32	19.85	9.50	61.30	25.74
6 MSF	8.57	11.60	11.95	53.25	21.34
7 NCSO	11.15	15.70	8.82	64.30	24.99
8 SCSO	11.50	13.17	12.32	62.32	24.83
9 SCF	10.97	15.55	11.00	72.00	27.38
Mean	10.85	14.22	10.32	62.50	24.47
			Within-plot CV, percent		
2 ALSO	56.99	84.93	91.00	51.62	71.13
3 FLF	55.47	71.11	55.69	56.70	59.74
4 GASO	51.69	94.46	92.13	44.36	70.66
5 MSSO	59.23	82.91	60.29	49.41	62.96
6 MSF	54.72	97.31	83.13	54.03	72.30
7 NCSO	50.03	73.18	78.25	42.25	60.93
8 SCSO	50.52	93.47	66.15	57.10	66.81
9 SCF	57.60	76.36	66.84	44.67	61.37
Mean	54.53	84.22	74.18	50.02	65.74

[a] Plantation 157 means include only reps 1-4.

Table 4--Mean squares from analyses of variance of third-year data, by trait and plantation.[a]

Trait	Variance source	D.f.	Plantation 154	155	156	157(4)	157(6)
Survival			----------Arcsine square root percent----------				
	Rep	3	159.55	170.85	112.90	39.46	31.37
	Seed source	7	19.05	41.79	144.81	119.00	61.78
	Error	21	88.43	102.21	104.55	78.68	85.31
Height			------------------Centimeters------------------				
	Rep	3	33.84***	189.63***	4.92	107.06	317.86**
	Seed source	7	10.13	31.55	16.60*	141.53	262.50*
	Error	21	4.18	21.53	6.64	80.87	85.45
Within-plot	coef. var.		----------Arcsine square root percent----------				
	Rep	3	30.68	300.69	2.26	13.99	68.93
	Seed source	7	15.69	303.66	377.10	44.36	72.90*
	Error	21	52.31	600.80	435.97	33.78	31.55

[a] Two analyses are shown for plantation 157, for 4 and 6 reps.
* P<0.05; ** P<0.01; *** P<0.001

Table 5--Mean squares from combined analyses, age 3 years, 3 or 4 plantations.

Variance source	D.f.	Trait: Survival	Height	Coef. var.
		Arc sq rt pct	cm	Arc sq rt pct
		Plantations 154, 155, and 156		
Plantation (P)	2	1203.15**	143.49	3325.36***
Rep in P	9	147.77	76.13***	111.21
Seed source (S)	7	77.51	28.50	320.04
P X S	14	64.07	14.89	188.20
Rep in P X S	63	98.40	10.78	363.02
		Plantations 154, 155, 156, and 157[a]		
Plantation (P)	3	1398.82**	20,660.42***	3687.90***
Rep in P	12	120.69	83.86***	86.90
Seed source (S)	7	84.03	86.09	245.31
P X S	21	80.21	37.91	165.17
Rep in P X S	84	93.47	28.31	280.71

[a] Only reps 1-4 from plantation 147 were used in these analyses.
** P<0.01; *** P<0.001

under water longer, had higher mortality, and grew less than those in better drained spots.

Competition from weeds and grasses would have been severe on the Georgia old-field site had not intensive vegetation control measures been used. Because of the vegetation control and good site, a majority of the seedlings there initiated height growth during the second season, and several of them were more than 1.5 m tall by the end of the third season.

The brownspot needle blight disease has been no problem in this study. A few seedlings were noticeably infected during the second year in the Georgia plantation, but little or no infection was evident at the end of the third season.

The study plantings are well established now and should provide the seed source information needed for management of longleaf pine on the Francis Marion National Forest. The next assessments will be at ages 5 and 10 years. By age 10, any effects of the grass stage and early competition in masking seed source differences should have become relatively small. Variation patterns evident by then should be reliable bases for management decisions.

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NOTE: RESPONSE OF BALDCYPRESS AND LOBLOLLY PINE SEEDLINGS TO SHORT-TERM SALTWATER FLOODING

William H. Conner and George R. Askew[1]

Abstract--Six-month-old and eighteen-month-old baldcypress and loblolly pine seedlings were subjected to a simulated saltwater surge (salinity = 30 parts per thousand) for 0 to 5 days followed by flushing and daily watering with fresh water. Growth, biomass, and survival were monitored for 9 weeks following inundation. Six-month-old seedlings of both species were extremely susceptible to saltwater flooding, and survival percentages declined rapidly beyond 1 day of saltwater flooding. Eighteen-month-old seedlings were better able to survive saltwater flooding, with some pine seedlings surviving up to 3 days of flooding and some baldcypress up to 4 days of flooding. The general response of surviving baldcypress seedlings to saltwater flooding was to die back and then resprout. For loblolly pine, growth was slowed until a threshold level was reached, at which point the seedlings died. There was a direct correlation between duration of saltwater flooding and diameter growth with six-month-old seedlings but not with the eighteen-month-old seedlings. There was a steady decline in diameter with increasing days of saltwater flooding in surviving eighteen-month-old baldcypress, whereas eighteen-month-old loblolly seedlings showed some diameter growth even after 3 days of saltwater flooding. Root:shoot biomass partitioning in surviving seedlings was not appreciably affected by treatments.

INTRODUCTION

The lower coastal plain region of the southern United States tends to be flat and poorly drained. Permanent swamps have developed in the most poorly drained sites, with baldcypress (*Taxodium distichum* (L.) Rich.) as a dominant tree species. Flatwood areas contain loblolly pine (*Pinus taeda* L.), which is a broadly adapted pine species capable of growing equally well under flooded or drained conditions (Hook and Scholtens 1978). Both baldcypress and loblolly pine can be found growing side-by-side along the edges of the swamps. The general response of these two species to waterlogging has been fairly well documented (Mattoon 1916, Hunt 1951, Dickson and Broyer 1972, Hook and others 1983, DeBell and others 1984, Topa and McLeod 1986, Donovan and others 1988). Among tree species, baldcypress is highly tolerant to waterlogging while loblolly pine is moderately tolerant (Hook 1984).

In contrast to the amount of work that has been conducted on waterlogging response, salt tolerance has received little attention. Most of the available literature comes from studies on the effects of salt spray on trees (Hall 1933, Wells and Shunk 1938, Wallace and Moss 1939, Moss 1940, Little and others 1958). With the increased interest in global warming and sea-level rise in recent years, more emphasis has been placed on determining the response of coastal plant species to increased flooding and salinity. Some research has been

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conducted on the physiological response of baldcypress to salinity (Pezeshki and others 1986, 1988), but only one study was found describing the chloride content of pine needles in response to short-term saltwater flooding (Land 1974).

In addition to the long-term slow rise of sea level, coastal forests are also subjected to saltwater periodically as a result of hurricanes or other severe storms. Hurricane Hazel's storm surge in 1954 killed thousands of hectares of forests in North Carolina and Virginia (Little and others 1958). A 3 m storm surge resulting from Hurricane Hugo in 1989 caused major damage to the Hobcaw Forest in South Carolina (Hook and others 1991). In both cases, mortality was greatest in areas where water drainage was impeded.

Because of the scarcity of information on the salt response of these two dominant coastal plain tree species, we designed a project to determine the impact of short-term saltwater flooding on their survival, stem diameter and height growth, and biomass accumulation. To simulate a hurricane surge, seedlings were flooded with seawater and then flushed with freshwater after varying days of inundation with the seawater. This regime was chosen as being typical of what happened to many well-drained sites on the Hobcaw Forest as a result of Hurricane Hugo and subsequent rains.

METHODS

Seeds of baldcypress and loblolly pine from local sources were stratified according to Schopmeyer (1974) and sown in seed beds in the Baruch Forest Science Nursery, Georgetown, SC. After the production of several fully expanded leaves or needles, seedlings (designated CYPRESS 1 and PINE 1) were transferred to Deepots™ (6 cm diameter by 25 cm deep) filled with a commercial potting mix composed of peat moss, perlite, vermiculite, composted bark (Sunshine All Purpose Plus potting mix, Fisons Western Corporation, Canada), and a slow release fertilizer (Osmocote 14-14-14). One-year-old seedlings of both species (designated CYPRESS 2 and PINE 2) were obtained from the South Carolina Forestry Commission and planted in the same manner. Potted seedlings were placed in an outdoor facility where they were allowed to grow for 4 months. The seedlings were irrigated daily and fertilized with a water-soluble fertilizer (Miracle Gro, 15-30-15) once a week.

In July, ten seedlings of each group were randomly selected and assigned to 0, 1, 2, 3, 4, or 5 days of saltwater flooding. Because of mortality, only 4 seedlings per treatment were available for PINE 2. All seedlings were placed in a plastic pool (1.5 m diameter, 0.3 m deep) filled with seawater [salinity = 30 parts per thousand (ppt)] collected from North Inlet on July 5, 1991, and one treatment was removed each day. Flooding was maintained throughout the study at approximately 5 cm above the soil surface of the pots by the addition of tap water as needed. Salinity was monitored daily using a meter. Salinity in the pool dropped from 30 ppt to 23 ppt by day 5. The pool was placed under a shade cloth (50% reduction in sunlight) to prevent the water from becoming too hot. Water temperature remained fairly constant throughout the five day flooding period, varying from 26-27.5°C, and tracked air temperature within 1°. These temperatures are consistent with those occurring during the summer in shallow, nonflowing swamps on Hobcaw Barony. After removal from the pool, the seedlings were flushed with fresh water and placed in the outdoor facility where they were watered daily with freshwater and fertilized weekly with water-soluble fertilizer (Miracle Gro, 15-30-15). All seedlings were allowed to grow for 9 weeks after flooding ceased, and their status was recorded weekly.

Basal diameter and height of each seedling were recorded at the initiation of flooding and at the end of the experiment. As seedlings died (did not resprout within three weeks after loss of foliage), they were harvested and separated into root and stem parts, dried to a constant weight at 65°C, and weighed. After 9 weeks, all surviving seedlings were harvested and processed in a like manner, except that foliage was also included as a component.

RESULTS

Survival

Both PINE 1 and CYPRESS 1 seedlings were extremely susceptible to saltwater flooding. One week after flooding at all levels, survival of CYPRESS 1 seedlings was 100%, but survival percentages declined rapidly beginning in week 2 for seedlings flooded more than 1 day. Thirty percent of the CYPRESS 1 seedlings subjected to one day of flooding were able to survive to the end of the study, and none survived flooding for ≥ 2 days. PINE 1 seedlings were more tolerant than CYPRESS 1 seedlings of 1-2 days of saltwater flooding. Ninety percent of the 1-day-flooded and 10% of the 2-day-flooded PINE 1 seedlings survived to the end of the study. Beyond 2 days, however, there were no PINE 1 survivors.

Eighteen-month-old seedlings of both species were more tolerant of saltwater flooding than the six-month-old seedlings. Ninety percent of CYPRESS 2 seedlings survived up to 2 days of flooding, and 30% survived up to 4 days of flooding. Eighteen-month-old loblolly pine were able to survive 3 days of flooding (50%), but none survived 4 or 5 days of flooding.

Height and Diameter Growth

Height growth of CYPRESS 1 and 2 and PINE 1 was negative because of die-back of the main stem and resprouting of the seedlings. CYPRESS 2 seedlings had increasing die-back with increasing days of saltwater flooding. PINE 2 seedlings that survived saltwater flooding had positive height growth with 1 day of flooding and no growth after 2 or 3 days of flooding. The overall response of the baldcypress seedlings to saltwater flooding was to die back and resprout, whereas the loblolly pine seedlings showed slow growth or death in response to flooding.

Diameter growth patterns were the same for CYPRESS 1 and PINE 1 seedlings. Both species had reduced growth with increasing days of flooding. After 3 days of flooding, PINE 1 seedling diameters shrank. Diameter growth of CYPRESS 2 and PINE 2 seedlings differed in their responses to flooding. A steady decrease in diameter growth occurred with increasing days of flooding in CYPRESS 2, with shrinkage after 3 days of flooding. PINE 2 seedlings had positive growth for 1 and 2 days of flooding and small, but positive, growth for 3 days of flooding.

Biomass

One day of saltwater flooding reduced the biomass of shoot, leaf, and root components in CYPRESS 1 seedlings but not in CYPRESS 2 seedlings. The dry weight of the three components after 2 or more days of flooding declined but seemed to stabilize with 4 days of flooding. Very little growth occurred in PINE 1 seedlings, even in the unflooded treatment. Even so, there was a slight reduction in biomass of the three components after 1 day of flooding. PINE 2 seedlings showed a slight increase in biomass of all components with 1 day of flooding. Two and 3 days of flooding resulted in only slightly reduced biomass of all 3 components. Loblolly pine is apparently not a die-back species; it halts growth when a threshold level of salt is reached and then dies beyond that point. Root:shoot+leaf ratios are fairly consistent for each species regardless of age or treatment. Baldcypress ratios are in the 0.6-0.7 range, and loblolly pine ratios are in the 0.4-0.5 range. Biomass partitioning in surviving trees was not appreciably affected by the treatments.

DISCUSSION

In the present study, six-month-old seedling growth of baldcypress and loblolly pine was very susceptible to short-term flooding with saltwater. Neither species could withstand more than one day of flooding, which is consistent with our field observations following Hurricane Hugo. Although eighteen-month-old seedlings were better able to tolerate saltwater flooding, surviving up to four days of saltwater, there was no appreciable difference in root:shoot+leaf ratios. Ratios of 0.4-0.5 for saltwater-flooded loblolly pine are consistent with the results obtained by McKee and others (1984), Hook and Denslow (1987), and Shear and others (unpublished data) for loblolly pine seedlings grown in soil tanks for 1.0-2.5 years with continuous freshwater flooding during the growing season. More study is needed to determine if salinity tolerance increases with age and size, as waterlogging tolerance does (Gill 1970), or if tolerance is related to environmental or genetic factors.

In other studies with baldcypress and loblolly pine, it has been noted that stomatal conductance and net photosynthesis were reduced when salinity levels exceeded 3 ppt (Pezeshki and others 1987, Pezeshki 1990, Pezeshki 1992). Over the long-term, Pezeshki and others (1988) speculated that ion accumulation, such as Na, in baldcypress leaves would continue until leaf death occurred. Leaf injury in the present study was evident within three days of flooding, but new buds appeared along the stem or at the base of the seedling by the end of the first week after removal from saltwater.

Baldcypress and loblolly pine are limited in their distribution in coastal regions by salinity. Tolerance levels of these species, however, is unknown. Salinity tolerance of baldcypress has been reported variously to be 0.002 ppt (Beal 1977), 2 ppt (Chabreck 1972, Wicker and others 1981), or 8.9 ppt (Penfound and Hathaway 1938). Loblolly pine is susceptible to saltwater flooding, especially in areas where drainage is impeded (Little and others 1958, Land 1974, Gardner and others 1991, Hook and others 1991). Little and others (1958) hypothesize that hardwoods are more susceptible to saltwater flooding, and this might account for the fact that few hardwoods are found in pine stands near the Chesapeake Bay. As sea level continues to rise in coastal areas and storm surges occur with future storms, it will be interesting to observe and document the response of coastal forests to these stresses.

ACKNOWLEDGMENTS

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LONG-TERM RECOVERY OF PLANTATION-GROWN LOBLOLLY PINE FROM HURRICANE DAMAGE[1]

P. H. Dunham and D. M. Bourgeois[2]

Abstract--A study established in nine plantations to quantify the long-term recovery of plantation-grown loblolly pine from damage by Hurricane Hugo was installed in early 1990. After three years, mortality of storm damaged trees was 8.1%, with 2% of the trees being non-leaners, 8% had an initial lean between 0 an 25°, 15% were leaning between 25° and 50°, 40% were leaning between 50° and 75° and 35% of the dead trees were leaning at least 75° initially. The initial average angle of mortality trees was 61°. Three-year diameter growth gradually decreased as initial average angle increased. On average, height growth increased as initial angle increased, up to a given angle, then decreased below the growth of the non-leaners. Initial angle significantly influenced diameter growth for the three-year period for all initial ages, but was a significant contributor to three-year height growth for initial ages 2 and 5 only. For all leaning trees, the average positive change in stem angle generally decreased as the age of the stand increased, particularly for those stands initially older than age 5. Recovery, however, did occur along all measured points on the stem, with the greatest improvement occurring during the first year.

INTRODUCTION

Tropical storms and hurricanes strike the Gulf and Atlantic Coasts almost annually (Touliatos and Roth 1971). On September 21, 1989, Hurricane Hugo struck the Coastal Plain of South Carolina with sustained winds of approximately 135 mph (estimated) and gusts up to 160 mph (Powell 1990). Based on aerial and ground surveys, 23 counties were judged to have substantial forest damage (Sheffield and Thompson 1992). Monetary loss, if the timber could have been salvaged for its highest product use, was estimated at $10 billion (Spell 1990).

Westvaco Corporation, a major pulp, paper and packaging manufacturer, suffered timber damage on 150,000 acres. While the salvage of marketable timber received the most immediate attention, relatively young loblolly plantations also had extensive damage, generally in the form of stem lean. A review of the literature showed most of the published storm-related material dealt with either damage assessment (for example, Van Hooser and Hedlund 1969 or Trousdell and others 1965) or changes in ecological succession (see Foster 1988). There was little in the literature on the recovery of existing trees and stands from any storm damage, much less hurricanes.

McKellar (1942) reported on the short-term recovery of six- and seven-year-old plantation-grown loblolly, slash and longleaf pines from ice damage in the Piedmont of Georgia. More recently, an unpublished Westvaco

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[1] A paper presented at the IUFRO Conference on Inventory and Management in the Context of Catastrophic Events, University Park, PA, on June 21-24, 1993.
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Forest Research Report[3] covered the eight-year response of ice damaged ten-year-old plantation-grown loblolly in the Piedmont of Virginia. In both cases, individual pines showed partial to complete recovery, depending on the amount of damage and the response variable measured.

Brewer and Linnartz (1973) conducted a one-year recovery study of twenty-six, eleven-year-old, plantation-grown loblolly pine trees damaged by Hurricane Camille. Trees leaning less than 45° from vertical recovered to some extent while trees leaning 15° to 25° straightened to the point where the lower portion of the bole had returned to vertical. The authors recommended salvaging any trees leaning more than 45° as these trees are not likely to recover substantially.

Their results indicate that at least for one age class, plantation-grown loblolly pine will recover to some extent, depending on the initial lean after the storm. Long-term responses to hurricane damage over a range of ages are unknown. Guidelines are needed to determine which plantations will recover and which to salvage or replant. Growth and yield of damaged plantations need to be quantified to determine if and how our models should be modified to reflect these conditions.

The study has three specific objectives: (i) to quantify individual loblolly tree and stand responses to hurricane damage; (ii) to develop operational guidelines for determining the future status of damaged loblolly plantations; and (iii) to publish the results in the forestry literature. This paper reports the recovery and growth responses three years after Hurricane Hugo.

PROCEDURES

Field Location

Nine existing Westvaco Forest Research study sites, all on the coastal plain, were selected on the range and degree of storm damage present. The majority of the studies were age 5 or younger based on the assumption that stands much older than five could be salvaged. Three older stands (ages 8, 10 and 20) are being followed, primarily for survival information.

The original objectives of the studies ran the gamut of applied forestry research. Three locations were genetics studies, three locations tested various site-preparation treatments, and three locations were fertilizer trials with one trial also having a thinning treatment. In addition to the degree of damage, the plots for the recovery study were those treatments which would most likely be used in the future by operations. Due to the vagaries of the storm, no attempt was made to link the original treatments with the frequency or severity of storm damage.

The study was installed in late February and early March of 1990, approximately five months after Hugo. At seven of the locations, all or portions of the original measurement plots were used. The size of the measurement plots varied but generally centered around 0.05 acre. At two locations the recovery plots were established in the buffer areas surrounding the original plots due to study salvage efforts.

Response Variables

Several objective and subjective attributes were measured. These included traditional variables such as dbh and crown class. They also included angle measurements for quantifying initial stem lean and subsequent recovery by stem position. Three sets of horizontal and vertical distances were measured on all study trees. The vertical distances are the height to eight feet of stem length, crown base, and the tip of the tree. The horizontal distances were measured from the stem base to the point perpendicular to each of the vertical distances. A carpenter's level was used periodically to insure both measures were true. The horizontal distance defaults to zero for non-leaning trees. A subjective adjustment factor to account for badly bending stems of leaning trees was ocularly estimated to "correct" the calculated total stem length and length to crown base.

Because crown base and terminal distances on surviving trees will change irrespective of recovery, on a subset of the trees ages 2 through 5,

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[3] Bell, R. D. and P. H. Dunham. 1987. Response of ten-year-old plantation-grown loblolly pine subjected to ice damage. Westvaco Forest Science Laboratory - Biometrics Group, Res. Report No. 65. 17 pp. (Unpublished)

horizontal and vertical distances to 4.5 feet, one half of original stem length and the original tip were also measured and marked on the stem (Figure 1). The number of trees selected varied by plot but was the greater of 10% or six trees.

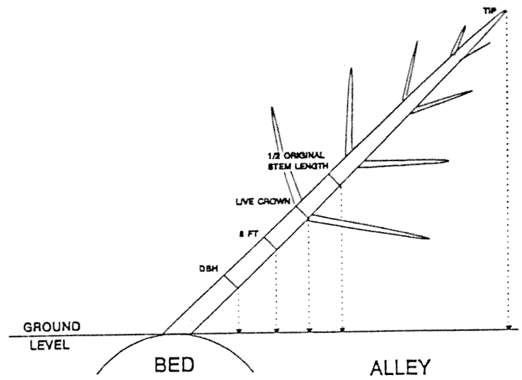

Figure 1--Stem measurement locations.

Several subjective codes were used to describe stem form, stem damage, crown damage and root damage. The seven stem damage codes reflect the most severe stem damage inflicted by the hurricane and may be used later in the study to help select trees for wood quality analyses. The eight stem form codes include lean, forking, bole sweep, butt sweep and short crook. These codes are expected to change over time as trees recover. Crown damage reflects the amount of foliage and or branches lost in 25% increments. Root damage differentiates between visible, broken roots and "wallowing" (the formation of a hole in the soil at the root collar).

At every location, selected trees and vistas are being photographed during each measurement to visually document change.

Analyses

The data were analyzed using graphic, correlation, and regression analysis to determine the relationship between post-storm and pre-storm tree size and the influence of initial lean on three-year growth and angle recovery. For presentation purposes the data are grouped into five lean categories, no lean (0°), $0°<x25°$, $25°\leq x<50°$, $50°\leq x <75°$, and $\geq 75°$, loosely based on Brewer and Linnartz (1973). Statistical significance is based on an a priori alpha level of 0.05. In most cases, however, the actual probability values are presented.

RESULTS

Some variables could not be measured over time or were dropped for these analyses due to confounding. The original tip could not be located after even one year and was dropped. The angle at the base of live crown was also dropped from the analyses due to ambiguous changes in angle.

Initial Damage

At establishment there were 1534 living trees across the nine locations. Initial hurricane mortality found during establishment was 2.7%. On a percentage basis, 61.5% of the live trees were classified as leaning. The average stem angle (leaning trees only) was almost 36°. Table 1 presents these data according to age class, along with the occurrence of other damage.

Across the study, initial average angle (average of all angles collected for a given tree) was significantly negatively correlated with initial dbh, plantation age and stem length (analogous to total height prior to the storm - measured or calculated from horizontal and vertical measurements). Through initial age 5, dbh and stem length were significantly correlated with initial angle although the sign of the coefficients varied by age. For the three older stands the correlations were generally not statistically significant (Table 2).

Post-Storm Mortality

First-year mortality overall was 4.4%. Mortality of trees judged to be damaged by the hurricane was 5.7% or 61 trees. By year three, total mortality had increased to 6.5% with storm-damaged mortality rising to 8.1% (Table 3). By lean category, the damage mortality was 2% (2 trees) for non-leaners, 8% (7 trees) for trees initially leaning between 0° and 25°, 15% (13 trees) leaning between 25° and 50°, 40% (35 trees) leaning between 50° and 75° initially and 35% (30 trees) leaned at least 75°. Initial average angle of the mortality trees was 61°. Approximately 70% of the mortality of storm damaged trees to date occurred in the first year.

Root damage and blowdown were also factors in the mortality. By the end of the third year, almost 45% of the root damaged trees had died. This

Table 1--Initial stand conditions by age for the nine study locations

Age	Number of Sites (plots)	Avg[1] DBH (in)	Stem[2] Length (ft)	Hurricane Mortality (percent)	Total Trees Damaged[3] Living	Alive	Leaning	Average[4] Angle (degrees)	Total Trees With Root[5] Damage	Blow-[6] down
2	2 (12)	0.6	4.4	1.7	407	307	305	39.7	165	14
4	2 (22)	2.6	12.6	1.7	510	281	258	37.4	69	6
5	2 (5)	4.0	14.8	1.4	285	231	211	39.9	27	1
8	1 (4)	6.6	31.4	7.3	102	94	81	21.8	7	5
10	1 (2)	6.0	37.6	2.9	68	37	25	18.6	5	0
20	1 (8)	9.3	59.3	6.9	162	119	60	22.4	14	7
	Mean (M) or Total (T)			2.7 M	1534 T	1069 T	943 T	35.8 M	287 T	33 T

[1] For trees > 4.5' in height.
[2] Vertical height from groundline to terminal - all trees.
[3] No. of living trees visually damaged by the hurricane.
[4] Average based on all angle measurements per stem, degrees from vertical - leaning trees only.
[5] Visible root damage - all trees.
[6] No. of living trees with one entire side touching the ground. Average angle of 90°.

Table 2--Linear correlations with average stem angle at study establishment across ages and by age.

Variable	No. Trees	Correlation	Probability
--------------Across Locations--------------			
Age	1534	-0.2425	0.0001
DBH	1423	-0.2988	0.0001
Stem Length	1534	-0.2583	0.0001
---------------Initial Age 2---------------			
DBH	297	0.1918	0.0009
Stem Length	407	0.3662	0.0001
---------------Initial Age 4---------------			
DBH	509	-0.3280	0.0001
Stem Length	510	-0.2871	0.0001
---------------Initial Age 5---------------			
DBH	285	-0.2231	0.0001
Stem Length	285	-0.1308	0.0272
---------------Initial Age 8---------------			
DBH	102	0.0211	0.4824
Stem Length	102	0.2123	0.0322
---------------Initial Age 10---------------			
DBH	68	-0.1321	0.2830
Stem Length	68	-0.1882	0.1244
---------------Initial Age 20---------------			
DBH	162	-0.1035	0.1900
Stem Length	162	-0.0921	0.2439

compares with the study population of approximately 19% of the living trees in 1990 with root damage. Twenty-one percent of the third-year damage mortality occurred in trees marked as "blowdown" (where the one entire side of the crown touched the ground). This is over one-half of the trees coded initially as blowdown. Not surprisingly, 67% of the "blowdown" trees also had visible root damage.

Proportionally, mortality of damaged trees was least in the youngest stands, increased with age through age 5, then decreased slightly through age 10 with a slight increase at age 20. Three years after the storm, mortality ranged from 0.3% for the initial age-2 stands to 14.7% for the initial age-4 stands. The decrease in mortality for the age-10 stand is probably due to the low number and severity of leaners (Table 1). Except for the initial age-2 locations, weighted average mortality over the three-year period for hurricane damaged trees was 11.3% (combined information from Tables 1 and 3).

Growth

After three years, the tips of most of the surviving leaners had essentially returned to vertical. No horizontal measure was required, thus stem length was not estimated. To keep height values compatible across measurement periods, height growth refers to changes in vertical height rather than stem length.

Because initial average angle was significantly correlated with initial diameter and stem length, linear regression was used to examine the relationship of three-year growth to initial average angle after accounting

Table 3--Three-year growth and mortality by five categories of stem lean and initial age.

Lean[1] Category	Age	DBH (inches)	Height (feet)	Percent: Hurricane[2] Related Mortality	Percent: Blowdown[3] Mortality	Percent: Root[3] Damage Mortality
0°	2	2.7*	10.8*	0		
0°<-<25°		2.8	11.7	0		
25°≤-<50°		2.5	11.5	0		
50°≤-<75°		2.1	12.3	0.1	0	0.3
≥75°		1.5	11.6	0		
0°	4	2.4*	13.6	0		
0°<-<25°		2.3	13.8	0.1	0	0
25°≤-<50°		1.9	13.9	0.1	0	0
50°≤-<75°		1.5	12.5	0.5	3.0	1.0
≥75°		0.7	7.4	1.5	6.1	3.5
0°	5	2.3*	13.1*	0		
0°<-<25°		2.4	15.0	0		
25°≤-<50°		1.7	15.6	0.6	0	0.3
50°≤-<75°		1.3	13.5	2.3	6.1	2.4
≥75°		0.9	7.2	0.3	3.0	0.7
0°	8	0.9*	6.1	0.1	0	0
0°<-<25°		1.3	9.5	0		
25°≤-<50°		0.9	7.2	0.2	0	0.3
50°≤-<75°		0.4	7.0	0.2	3.0	0
≥75°		All died in 1991		0.4	12.1	1.4
0°	10	0.7*	5.6	0		
0°<-<25°		0.7	6.2	0		
25°≤-<50°		0.1	3.0	0.3	0	0.3
50°≤-<75°		None recorded at establishment				
≥75°		None recorded at establishment				
0°	20	0.5*	1.8	0.1	0	0
0°<-<25°		0.5	1.7	0.6	0	0.3
25°≤-<50°		0	8.0	0.1	0	0.3
50°≤-<75°		All died in 1991		0.2	0	0
≥75°		All died in 1991		0.7	21.2	2.4

[1] Based on initial average angle at establishment.
* Initial average angle was statistically significant at the $\alpha=0.05$ level in the model growth = $\alpha + \beta_1$ initial size + β_2 initial angle.
[2] Based on 1069 hurricane-damaged trees recorded at establishment.
[3] Based on total number of trees in 1990 classified as blowdown or having visual root damage (Table 1).

for initial size. Residuals from the simple linear regression of growth on "initial" size were plotted over initial angle. The residuals showed a distinct decreasing trend as average angle increased, at least for the younger ages (Figure 2a). Including average angle in the regression removed the trend in the residuals (Figure 2b). For three-year growth, initial average angle was a significant addition to the diameter-growth regressions for all initial ages but only contributed significantly for ages 2 and 5 in the three-year height-growth regressing. Average angle did not significantly improve the regressions on height growth for ages 4, 8, 10, and 20.

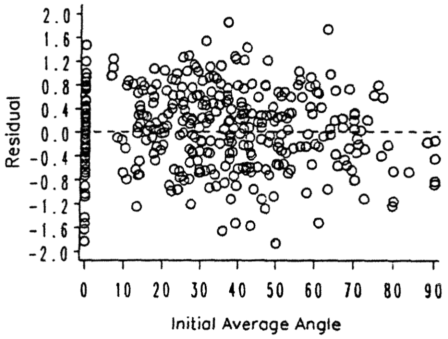

Figure 2a--Residuals from regression of three-year diameter growth on initial dbh at establishment over initial average angle at establishment for age-2 stands.

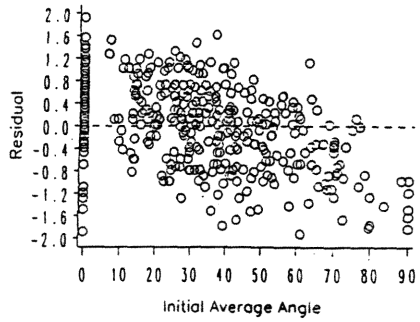

Figure 2b--Residuals from regression of three-year growth on initial dbh and initial average angle at establishment over initial angle for age-2 stands.

Based on the sign of the regression coefficient for initial average angle, three-year diameter growth by initial age shows a gradual, though significant, decrease as average angle increases. While not total agreement, this trend in decreased growth as angle increases is evident in Table 3. The sign of initial angle for three-year height growth, however, is not consistent across ages. Where initial average angle was significant (ages 2 and 5), the sign is positive, indicating increasing vertical growth as initial angle increases. Otherwise, the sign of the coefficient is generally negative, and the coefficient is not statistically significant. The mean height-growth values by age in Table 3 (and scatter plots of the data) indicate a parabolic relationship with growth increasing as initial average angle increases, then decreasing after the angle reaches some "critical level." Including a quadratic term in the model did not change the results dramatically.

Recovery of Lean

The greatest improvement in average angle $[(Angle_{90} - Angle_{93}) / (Angle_{90}) \times 100]$ always occurred in the 0°≤-<25° category while the least improvement occurred on those trees leaning at least 75° initially, irrespective of age. This is true for both the one- and three-year changes. The largest percent recovery toward vertical occurred after the first year for the two initial lean categories less than 50° but this varied somewhat by age (Table 4).

Three years after the storm, the leaning trees on the initial age-2 locations had at least a 90% recovery, regardless of initial angle. For initial ages 4 and 5, the recovery was 80% or better for the trees leaning less than 75° at establishment. Trees leaning at least 75° at establishment improved less than 50%. As the initial age increases, the percent recovery decreases, particularly for trees leaning more than 25° initially. Simple linear regressions of percent change to initial average angle were significant for all ages, for both one- and three-year recovery. The sign of the angle coefficient was consistently negative, indicating a decreasing percent recovery with increasing initial lean (Table 4).

By stem position, the greatest change in angle occurred at the tip of the tree. Three years after the storm the average improvement at the tip was 97%. The least recovery occurred at the 8-foot position, which showed a three-year change of 77%. While proportionally a small number, several leaning trees showed a negative change in angle

Table 4--First- and third-year changes in average angle by five categories of stem lean and initial age.

Lean[1] Category	1990[2] Average Angle (degrees)	1991[3] Average Angle (degrees)	1991[3] Change in Angle (%)	1993[4] Average Angle (degrees)	1993[4] Change in Angle (%)
Initial Age 2					
0°	----				
0°<-<25°	16.9	2.7	85.0*	0	100*
25°≤-<50°	36.1	6.9	80.5	0.2	99.6
50°≤-<75°	60.4	17.1	71.5	0.2	99.7
≥75°	83.5	35.9	57.2	8.8	90.3
Initial Age 4					
0°	----				
0°<-<25°	15.3	2.4	85.4*	0.1	99.4*
25°≤-<50°	36.0	10.3	71.2	0.8	98.3
50°≤-<75°	60.2	34.6	43.5	12.5	80.3
≥75°	79.6	69.2	13.0	43.8	45.0
Initial Age 5					
0°	----				
0°<-<25°	14.4	2.1	87.2*	0.5	96.8*
25°≤-<50°	37.7	14.1	63.7	4.7	88.2
50°≤-<75°	60.1	37.7	37.6	11.6	81.1
≥75°	78.5	69.6	13.0	46.2	40.5
Initial Age 8					
0°	----				
0°<-<25°	9.5	2.0	87.3*	0.6	96.2*
25°≤-<50°	36.3	25.5	29.6	17.4	55.6
50°≤-<75°	58.3	42.0	23.0	37.1	31.1
≥75°	88.8	All died in 1991			
Initial Age 10					
0°	----				
0°<-<25°	11.3	6.7	56.3*	3.5	78.8*
25°≤-<50°	33.8	31.1	2.6	28.7	14.0
50°≤-<75°	None recorded at establishment				
≥75°	None recorded at establishment				
Initial Age 20					
0°	----				
0°<25°	10.7	9.3	26.6*	3.2	74.7*
25°≤-<50°	39.1	28.4	9.3	29.6	9.3
50°≤-<75°	55.4	All died 1991			
≥75°	89.6	All died 1991			

[1] Based on initial average angle at establishment.
[2] All live trees in 1990 by initial lean category.
[3] Based on all live trees by category in 1991.
[4] Based on all live trees by category in 1993.
* Initial average angle was statistically significant at the α=0.05 level in the model % change = $\alpha + \beta_1$ initial angle. The "zero-lean" category was dropped for this analysis.

at the 8-foot position one and three years after the storm (19 and 11 trees, respectively). Overall, the initial average lean improved by 92% after three years although this varied considerably by age (Table 5). Leaning trees will return towards vertical over time, especially the younger trees.

While the results do show a dramatic improvement in initial angle by stem position, that does not necessarily mean the trees have returned to pre-storm straightness. Three years after Hugo, 808 of the 855 surviving leaning trees had shifted from "leaners" to some other stem form condition. Of the 808, 31% were classified as straight, 21% had bole sweep, 27% had butt sweep and 14% were recorded as having some other stem form condition. Five percent of the surviving leaning trees were still considered leaning (Table 6).

DISCUSSION

These results apply only to the initial conditions of this study. The study areas were selected to represent a range in damage conditions and may or may not apply to the storm path as a whole. Similarly, while several existing research studies were utilized to take possible advantage of past stand history, no attempt was made to link the severity or types of damage with study treatments. The vagaries of the storm preclude such an exercise.

The correlations between initial tree size and initial average angle are interesting. Preliminary observations immediately following the storm indicated the tallest, largest trees took the brunt of the damage. Across all study locations this appears to be true with negative correlations between tree size, age and initial angle. By age, however, initial angle was significantly positively correlated with tree size for the age-2 stands, negatively correlated with tree size for ages 4 and 5 and generally not significantly correlated for trees age 8 and older.

Reasons for the change for the younger stands from a positive to a negative correlation between tree size and initial angle are not obvious and probably involve factors such as soil rooting depth which were not part of the sample-selection criteria. As conjecture, however, the positive correlation for the age-2 locations may be related to a possible sheltering effect of the smaller trees by the taller trees and slight competition on the sites. By age 4 the sheltering effect becomes negligible while the larger trees, because they are better established, are better able to withstand the wind.

The lack of correlation for trees in the older stands is in part due to the relatively low initial average angle. This, in turn is partially due to stem length and stocking. Many of the leaning trees were caught in their neighbors, artificially limiting the initial angle. Almost 11% of the trees in the ages 8-, 10- and 20-year stands contained trees leaning into them. This compares with 2.3% for ages 4 and 5 and 0% for age 2.

The growing season following the storm was relatively dry[4]. Yet first-year mortality of those trees noted as visibly damaged at establishment was fairly light. Only 5.7% of the damaged trees died during the first year. Of the 5.7%, 77% were leaning at least 50° immediately following the storm. Forty-four percent of the trees that died the first year had visible root damage. For ages 8 and 20, all trees initially leaning at least 75° died during the first year (no trees in that category at the age-10 location). These results would suggest that salvage efforts should concentrate first in stands where a majority of the trees are leaning at least 50° and have a strong occurrence of root damage. This roughly agrees with recommendations by Brewer and Linnartz (1973).

Three years after the storm, cumulative mortality to visibly damaged trees increased to 8.1% with 75% of the mortality again occurring in the two most severe-lean categories. By age, the greatest mortality for the two-year period 1991-1993 occurred for ages 4 and 5 (22 trees). This represents almost 85% of the increase from the first-year mortality and is due to the vast majority of the most severely leaning trees in the older ages having died during the first year.

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[4] Based on the average total precipitation and departure from normal (period 1951-1980) for all recording stations in the five counties where the study is located (Anonymous 1991).

After three years, recovery in angle towards vertical was noted at all points on the stem. The greatest recovery occurred at the tip. The least recovery occurred at the lower stem positions, dbh and 8 feet. Almost 66% of the recovery noted after three years occurred after the first year. Still, average stem angle returned to within 92% of vertical for all initially leaning study trees surviving after three years. As expected, angle recovery varied by age.

Approximately 94% of the initially leaning trees surviving after three years had changed their subjective stem form code from leaning to some other condition such as bole sweep or butt sweep. These codes will continue to be applied for the duration of the study and are expected to change further as the trees mature and possible additional recovery occurs. They will also be used later as part of the selection process for determining which trees to destructively sample for wood quality analysis.

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ECONOMICS OF LOW DENSITY STAND MANAGEMENT[1]

Stephen K. Nodine[2]

I want to congratulate each of you for being here today. Your presence distinguishes you from other foresters by your willingness to accept a challenge. The recovery of forest land damaged by Hurricane Hugo offers each of you the challenge to apply the *art* of forestry in addition to the *science* of forest management. If I may generalize a bit, *any* forester with half his senses can prescribe the old tried-and-true treatments for a site. The forester who goes beyond the cookbook solutions to match the site, the landowner and the possibilities is the true artist of our profession—an individual who has both the courage, insight and foresight to respond to the challenge.

In the aftermath of Hurricane Hugo and in the context of today's workshop, what is the challenge facing you? It is to efficiently restore forest land to a productive state. This new level and type of productivity may or may not resemble that which was present before the hurricane. It will vary, depending on the conditions of the land, the landowner's objectives and resources, and the resourcefulness which you can bring to bear on the situation. Since some of you work for government agencies, some for forest industry, and others as private consultants for nonindustrial private forest (NIPF) landowners, each of you will face a unique set of circumstances in each tract of land that you consider. Your options may range from "let it ride"—in other words let Nature take its course with whatever remains on the site, to pushing everything over, regardless of cost or complexity, and starting over from scratch.

In my discussion, I want to set the backdrop for the technical discussions and demonstrations that are to come later in this workshop. We will consider how to look at the various alternatives that may be available, and how to evaluate their relative merits.

WHAT ARE THE FACTS?

A question which seems obvious but which must be addressed at the outset is "Why should we worry about new and different methods or approaches for doing things that we've been doing for years?" The first reason is that a lot of land is now understocked—now that's an understatement if there ever was one! This creates specific situations of land producing at less than its biological and economical potential. If the landowner's objectives include achieving that potential, then there is a problem (or opportunity) that needs to be addressed.

Second, landowners possess limited capital resources to support forest regeneration and management activities. This is always the case with NIPF landowners, but was never more true than after Hugo. In addition to having many other expenses facing them in their personal recovery from the storm, those who have been successful in having some timber salvaged have seen the prices they received for post-Hugo timber drop to as low as 10-25 percent of its pre-Hugo value. Cost-sharing assistance is available through various programs, but it is insufficient to cover the breadth of the need. Corporate landowners also face limited capital available for massive restoration. Even though they may have greater resources from which they can draw, they still must justify their actions as economically efficient.

Third, all landowners in general, and NIPF landowners in particular, have

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[1] Presented at the workshop "Vegetation management on storm-damaged lands" in Summerville, S.C. on October 22, 1991. This workshop was sponsored by Clemson University Extension Forest Resources.
[2] Stephen K. Nodine is Instructor and Extension Forester, Clemson University, Department of Forest Resources.

limited knowledge of the options available to them. Residual debris is present in quantities never before seen or imagined. The profile of the forest site, the accessibility, and special environmental concerns pose problems that have never been addressed at such a scale.

Fourth, NIPF landowners have expressed in surveys a profound and deep-seated conviction and expectation of the natural regenerative powers of the forest. Although they may not express it directly, their past experiences tell them that the forest can do remarkably well at rebuilding itself. Although they recognize that Nature may not work as fast on its own without human intervention, they find themselves less willing to invest large amounts of money and energy in reforestation and stand rehabilitation.

Fifth, several factors are more limited than usual. Since everyone needs help at the same time, foresters and service vendors are in short supply. Also, seedlings to replant all the acres that need replanting simply aren't available at present.

The sixth reason is based in the context framed by the previous five reasons. Because landowners of all types are more dependent now than ever on foresters for advice and encouragement, it is important for us to look for all the best ways available to help stretch the vastly insufficient resources across a field of need that vastly exceeds anything we have ever faced up until now.

WHAT ARE OUR OPTIONS?

Without trying to justify any of the alternative stand treatments that have been suggested, and without getting into their technical requirements, I'd like to make note of four options and a few pros and cons of each.

If a stand is still adequately stocked, meaning that there is still at least 60 percent stocking on the site, you may choose to do nothing other than routine maintenance and protection activities. Because of a stand's ability to draw upon the resources of a site with whatever number of trees are available, you may expect to receive near-normal returns. There would be little additional cost above that which would have normally occurred. It will not be a perfect stand of trees--there will likely be some unevenness in the stem distribution, and undesirable species may begin to encroach more readily into the stand. Internal damage to the residual stems may result in some degradation of product quality that can't be predicted, but the high level of stocking should reflect lower degrees of damage and minimize value loss.

Several methods of rehabilitating stands have been discussed recently which move some of the debris, rather than removing it, followed by planting a few additional trees to achieve a mixed-age stand. This avoids the high cost of more drastic treatments, and allows some revenue to be received sooner by harvesting the residual stems before the new seedlings would ordinarily reach a first thinning size. Again, the landowner is left with a less-than-ideal stand, but that is the trade-off. Because this is an unfamiliar treatment to most foresters and landowners, with more uncertainty about the results, adopting this type of approach represents a step of faith for both the landowner and forester.

Natural regeneration is a more familiar option to many of us, but practicing it here adds a few new twists. As with any natural regeneration option, you trade off less guaranteed success for lower up-front costs. A fully-stocked stand is assumed, but you can't take advantage of genetically-improved seedling stock. The available seed trees may be more dispersed than usual and if they have suffered significant damage, they may not be alive for several years in case the first seed crop doesn't take. One other factor that can influence natural regeneration practices--the use of prescribed fire is more risky under the heavy fuel loads that remain in this area. This practice would likely be more expensive, if it is even an option on some sites.

Finally, artificial reforestation is an available option. This approach traditionally achieves a greater degree of success and allows more control over the resulting stand. However, few of us have tried debris removal in site preparation that comes close to what some damaged stands will require. If the damaged trees were salvaged, this may not be a problem, but in most cases there will be greater hurdles to clear, and higher costs associated with them.

WHAT ARE THE PAYOFFS?

This brings us to the bottom-line questions we always face—"Can this be done?" and "Is this profitable for me?" Research by Baker (1989) indicates that these approaches can result in successful restocking of a damaged stand. The key to success is evaluating the residual stocking levels. Those stands with greater than 60 percent stocking have found to approach near-normal growth and returns. Stands with lower stocking levels have been successfully managed using rehabilitation techniques. In one example, stands with less than 60 percent stocking were cut back to levels of 10 to 50 percent stocking, primarily by removing trees greater than 12 inches dbh. They anticipate that such stands will reach acceptable stocking levels within 15 years at low investment costs ($45-$50 per acre).

In analyzing the results of this study after ten years, Straka and Baker (1990) evaluated three alternatives: selection management of an under-stocked stand, natural even-aged regeneration, and artificial regeneration to a plantation. In calculating the profitability of each alternative, they considered situations that would include and exclude the cost of land. For a landowner whose options include selling the land, land costs should be considered. For the landowner who will continue to own the land regardless of its condition, land costs can be excluded.

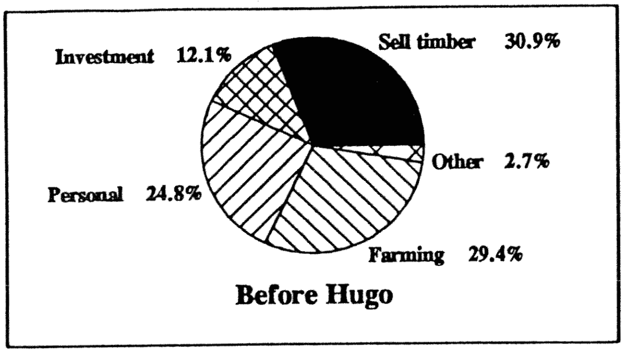
Highlights of the four options considered are summarized in Table 1. When land costs were excluded from the analysis, lower-cost alternatives provided higher rates of return on the investments, and had higher net present values at all but the lowest discount rates. Including land costs changed the perspective, requiring higher levels of timber production to cover the additional costs. Here, however, all options were profitable only at a low four percent discount rate.

WHAT ARE THE LANDOWNERS THINKING?

Those of you who work with NIPF landowners have already heard from them, and could share many "war stories" from their experiences. In designing programs and other forms of assistance for landowners, we conducted a survey to gather and analyze their attitudes and concerns (Nodine, 1992). We found that most landowners still have many of the same priorities for their land, but fewer cited timber production as their highest priority after Hugo (Figure 1). Their dependence on timber production as a source of income declined sharply, with many no longer expecting timber income and others shifting their expectations farther into the future (Figure 2). Given these lowered income expectations, we can assume that they will be more reluctant to invest significantly in timber stand recovery.

Table 1--Net present values (by discount rate) and internal rates of return of timberland investment alternatives, including and excluding land cost, on a per acre basis (Straka and Baker 1990).

Alternative	Net Present Value			Internal Rate of Return (percent)
	4%	7%	10%	
Excluding Land Cost				
Selection management	$397.86	$ 96.71	-$ 2.16	9.9
Chemical release	442.00	71.96	- 33.04	8.6
Plantation (est. cost $150)	488.89	26.26	- 111.14	7.4
Plantation (est. cost $250)	388.89	- 73.74	- 211.14	6.2
Including Land Cost				
Selection management	$ 54.15	-$289.71	-$398.75	4.1
Chemical release	98.29	- 314.46	- 429.63	4.4
Plantation (est. cost $150)	145.18	- 360.16	- 507.73	4.5
Plantation (est. cost $250)	45.18	- 460.16	- 607.73	4.2



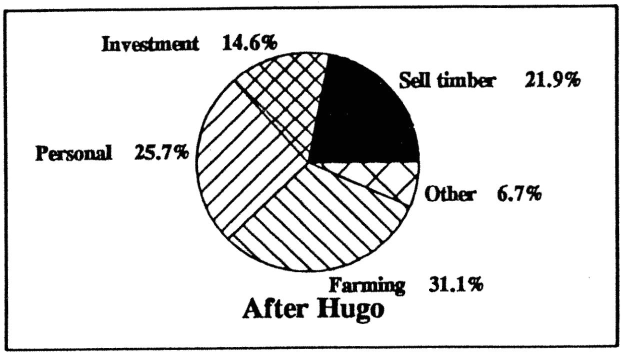
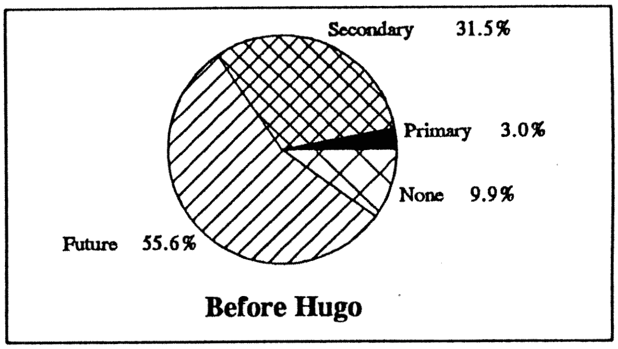


Figure 1--Top forest land use priorities of landowners before and after Hurricane Hugo.



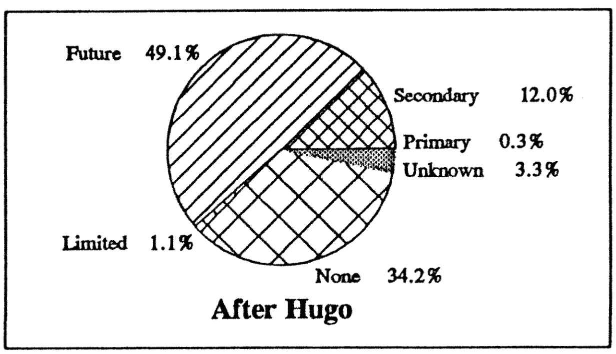
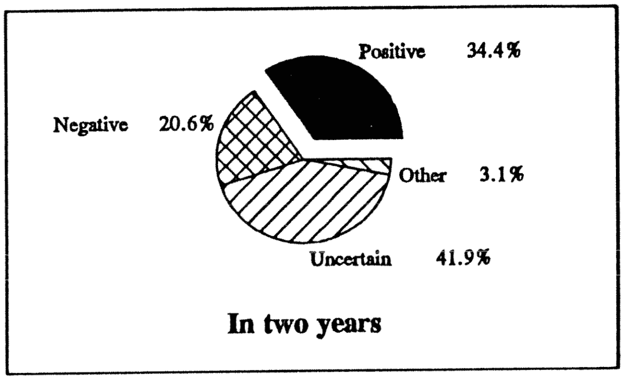


Figure 2--Forest landowners' dependence on their forest land for income, before and after Hurricane Hugo.

We did find, however, that as they look forward in time, their general expectations for their land become more positive (Figure 3). One-third of the landowners expressed positive expectations for their land two years from now, while more than half expect their land to be improved five years from now. This result poses the possibility of the proverbial two-edged sword. Cutting in a positive way, these generally positive feelings about their land, coupled with a land ethic which is generally strong among NIPFs, may help overcome some of their reluctance to act. Cutting against the grain, however, is the likelihood that some landowners will not be swayed to actually spend much money on the process, leaving it instead to Nature to achieve the restoration.



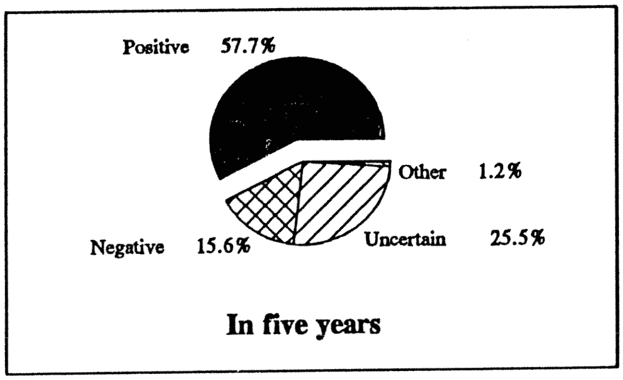


Figure 3--Forest landowners' expectations for their forest land following Hurricane Hugo.

When asked about the effect of cost-sharing on their plans, many did indicate that this would influence their decisions. Many others, however, indicated that cost was not their only significant concern. Their own lack of familiarity with traditional forest practices is compounded by the extreme damage they experienced and the lack of technical information and advice that they have received so far. If there ever was a time for forester contacts with landowners, this is it!

WHERE DOES THIS LEAVE US?

We can conclude that there **are** cost-effective ways to approach these damaged stands, but I think you already know that there are no simple blanket prescriptions that can be applied profitably in a blanket approach. You will see during the remainder of this workshop some of the technical aspects of forest restoration and recovery. I think that you should view those within the context of the landowners that you will be facing after the workshop. Obviously, it is in the best interest of the landowner to make his investment best for his situation. If he can earn a reasonable profit under natural stand management with a low initial investment, why should you recommend a system that may earn a little more but which is much more expensive up front and which may not provide as many other benefits which serve his other ownership objectives?

Landowners are hungry for technical information and advice, especially in the area affected by Hugo and in the subject of natural regeneration and management. In fact, the **landowner** is the first resource to be managed by the forester. The forest resource must come second. You as foresters need to be facilitators for landowners, providing them with options and general recommendations, and then either helping to implement the needed actions or passing the landowner on to someone else (particularly consulting foresters) to further develop and implement the plan.

You may be saying to yourself or to each other, "I'll sure be glad when this Hugo mess is over. Then we can go back to the way things were." If you think that's what you heard me say, then you fell asleep at a bad time. The aftermath of Hugo and responses of foresters and landowners to it are not an anomaly in the progression of forest management skill and understanding. Most of these changes were already underway before September 21, 1989—Hugo just exaggerated the scale of activity a little, speeded up the timetable somewhat, and forced us to look at some new ideas before our inertia might otherwise have led us. As proof of this, look at the number of hardwood management and mixed stand management workshops and meetings that are springing up everywhere, not just in the area affected by Hugo.

Hurricane Hugo was in very real terms an extreme harbinger of what is to come. "Kinder, gentler" forestry which is less "by the book" and more the practice of the art of forestry as well as the science is here to stay. This isn't bad—we're just learning more about forest systems and how to work with them rather than against them. The move toward natural/mixed stand management is being driven by forces that are broader and stronger and longer lasting than even the wind and fury of Hurricane Hugo. Those of us who try to resist the change/ maturation that is inevitable will be like many of those boats, houses and trees that were swept away by the storm and left lying about, broken and useless. Those who see the early signs of permanent growth and change in the way we work with people and help them manage their forests will find safety in the high ground of new understanding, new ideas, and broader sets of options.

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EVALUATION OF RECOVERY PROGRAMS

FINAL REPORT: AN EVALUATION OF THE POST-HUGO FOREST RECOVERY PROGRAMS: SALVAGE, WILDFIRE HAZARD MITIGATION, AND REFORESTATION

Marie Lynn Miranda[1]

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EXECUTIVE SUMMARY

Hurricane Hugo damaged 4.4 million of South Carolina's 12 million acres of forested land, totalling almost $1.2 billion in lost timber value alone. The state's response to this forest disaster required two simultaneous planning strategies. One strategy alleviated immediate emergencies and consequences of so much forest destruction, including recovering some value of the downed and damaged timber and preventing and suppressing wildfires. The other strategy addressed the long-term goal of restoring South Carolina forests to their previous stature and economic value by encouraging reforestation. The policy response was coordinated by the state government and utilized programs, personnel, and funding at the state and federal level. A review of this effort provides lessons to improve aspects of each program component--timber salvage, wildfire hazard reduction and mitigation, and reforestation.

*** State forestry personnel, especially the South Carolina Forestry Commission (SCFC), and the Governor's office were prepared for extensive forest damage and responded immediately.**

The day before Hugo struck, the SCFC tried to alert landowners to the potential for heavy damage to their forest land. SCFC personnel and equipment were in place to assist with clearing roads and restoring communication. They also watched for and suppressed fires, and surveyed the forest damage. The Governor's office worked with the SCFC, the Forester's Council, and State Forester to form the Governor's Forest Disaster Salvage Council. Council members represented all divisions of the forestry sector --industry, nonindustrial private, state and federal. They took charge of implementing a forest emergency plan. This organized and quick response facilitated the initial steps of recovery efforts in the forestry sector, as well as material and personnel support for post-Hugo recovery in many other sectors.

*** Clear goals and delegation of responsibilities contributed to many successes of the forest recovery response.**

The magnitude of the forest disaster in South Carolina was unprecedented. Some aspects of the recovery plan were borrowed from Mississippi's response to Hurricane Camille in 1969. However, most of the response relied on separate committees and planning groups to devise program goals and assign responsibilities. This was particularly crucial with salvage and wildfire hazard mitigation efforts; clear goals and responsibilities allowed both programs to begin very soon after Hugo. The Governor's Forest Disaster Salvage Council began salvage efforts just weeks after the hurricane. The responsibilities for the salvage effort were divided among several separate committees: government affairs; public information; utilization (with transportation, storage, out-of-state movement, and utilization subcommittees); and, statistics and monitoring. The wildfire hazard mitigation program emphasized three goals--fuels management, fire prevention, and fire suppression--which allowed the program to go beyond emergency response. Outlining goals and responsibilities allowed accountability and communication among all agencies and personnel involved. In addition, in the months after the hurricane, it kept the governor informed and provided him with guidance on how to assist in the forest recovery efforts.

*** Each area of the response required sustained coordination of federal, state, and private efforts.**

In the timber salvage effort, the SCFC worked closely with the U.S. Forest Service and numerous private industries, small businesses, and individuals. The wildfire hazard mitigation effort required coordination among the SCFC, the U.S. Forest Service, and the Federal Emergency Management Agency (FEMA). The duration of FEMA's involvement in the wildfire hazard mitigation effort has been particularly unique; FEMA provided funding for this effort for four program years after the hurricane. For the reforestation effort, the SCFC worked with the U.S. Forest Service and numerous private forestry consultants. This coordination across levels of governance was sometimes achieved by pulling together and utilizing a number of pre-existing state, federal or local programs. At other times it required state policymakers and forestry agency personnel to work creatively to initiate and sustain state-federal and state-private sector working partnerships.

*** The timber salvage, wildfire hazard mitigation, and reforestation efforts each had components of technical, educational, legislative, and monitoring strategies.**

Timber salvage, fire hazard mitigation, and reforestation all required innovative technical solutions, acquisition of equipment and machinery, and coordination of plans and activities. The hurricane destruction and subsequent weather conditions presented challenges to salvage, construction of fuel breaks, and reforestation. To address these challenges, in many instances, forestry personnel had to gain new technical skills, while at the same time, extend some technical information to landowners.

Dissemination of post-hurricane recovery information through mailings, print media, broadcast media, word-of-mouth were crucial to inform a broad population of landowners of their options, available assistance programs and advise on how to avoid future disasters. This was particularly important in the fire prevention effort, one component of which attempted to enlist residents in the Hugo-affected areas to sustain a 12-month period of no backyard fires, prescribed burning of land, campfires, or other human-started fires.

Lobbying campaigns, public hearings, visits to and by politicians kept the needs and concerns of landowners on political agendas and helped to pass some funding and other relief legislation. Reforestation received the greatest federal legislative assistance--a total of $11 million was secured for cost sharing. Other federal legislative efforts for help with the salvage operation, tax assistance or crop loss compensation were unsuccessful.

Information on the number of landowners assisted and the number of acres salvaged, reforested, or protected by fire breaks help to gauge whether the level of assistance was adequate, and whether assistance was distributed among a broad range of landowners. Additionally, the salvage committee monitored sawtimber, pulpwood, and chip prices, and levels of demand and supply. This information helped determine whether strategy changes were needed and when the duties of each of the committees, teams, and commissions could be turned over to pre-existing forestry agencies.

Integrating all these components best utilized the capacities of the state and federal agencies involved in the forestry disaster response to achieve a coordinated effort.

*** Timing was crucial to all parts of the forest recovery response.**

Weather factors and deteriorating timber quality made timber salvage operations feasible only during a limited window of opportunity. The optimal period for salvage was set by unusually heavy rains in the fall and an early start to warm weather in the spring--most operations slowed considerably after June of 1990. However, this short period coincided with the time landowners were most preoccupied with other damage. State policy makers and forestry personnel need to design policies that take maximum advantage of the limited window of salvage opportunity.

In the hazard mitigation program, fuels management required initial emphasis on constructing fuel breaks on lands prioritized according to level of risk. Fire suppression required that localities throughout the blowdown areas received sufficient equipment and personnel. Finally, fire prevention initially required a large-scale campaign to inform residents about the fire hazard and urge them to avoid burning.

The advertising efforts for the needs-check and the reforestation cost-share program may have been mistimed. In the year subsequent to the hurricane, landowners were most concerned with repairing damage to their homes and personal property. During this time, the SCFC also was pushing salvage and wildfire hazard mitigation goals. Greater response to Gimme Green and the Hugo Incentive Program may have been possible with more strategic timing in advertising and program implementation.

*** Funding was only available for some of the forest recovery efforts.**

Securing federal funding was most successful for the wildfire hazard mitigation and reforestation programs. For wildfire hazard mitigation, federal funds came from three sources: FEMA, the Dire Emergency Supplemental Appropriations Act, and the U.S. Forest

Service. South Carolina state government worked creatively to ensure FEMA's extensive involvement in hazard mitigation efforts. State forestry officials lobbied for FEMA involvement. The Governor's Office issued guidelines for localities to follow when applying for FEMA funds through the new Hazard Mitigation Grant Program, Section 404 of the Stafford Act. As a result, FEMA's involvement in hazard mitigation was achieved by expanding the eligibility, funding, and revising the justifications[2] in the 1988 Robert T. Stafford Act. FEMA funding was mandated through four separate sections of the Stafford Act: sections 403, 404, 420, and 421. Dire Emergency Funds also were allocated for a technical assistance program, Gimme Green, that provided free consultations on reforestation needs. Cost-share assistance, through the Hugo Incentive Program, was appropriated through the U.S. Forest Service in 1990 and 1991.

The priority given to funding salvage efforts was very low. State and federal funds were high demand from many other sectors, and compared to other aspects of the hurricane recovery, salvage lacked any dramatic appeal to prevent human suffering. State forestry agencies attempting to secure federal assistance in the early aftermath of recovery might have been more successful by describing forest damage in terms of its effects on the thousands of small landowners who rely on their land as their "nest-egg" and by drawing the clear link between unsalvaged downed timber and wildfire hazards.

PART 1: TIMBER SALVAGE

By the time Hurricane Hugo made landfall in South Carolina on Thursday, September 21, 1989, agencies in the forestry sector had already begun to prepare for extensive and severe forest damage. The Foresters' Council, originally established in 1942 to respond to forest crises, met and decided a course of action within a week. This swift response led to the creation of the Governor's Forest Disaster Salvage Council, which spearheaded the aggressive salvage program in South Carolina.

Salvage was the first, and shortest-term, part of South Carolina's three-part forest recovery plan; the other two parts, wildfire hazard reduction and mitigation, and reforestation, are covered in Parts 2 and 3 of this report. Hurricane Hugo blew down 6.7 billion board feet of timber on over 4.4 million acres of land in South Carolina alone. The Governor's Forest Disaster Council's strategy for salvaging the downed timber used an approach that addressed technical challenges to salvaging, pursued legislative measures, informed and educated the public, and monitored salvage progress and forest product markets. As a result, South Carolina landowners were able to salvage over 350 million cubic feet of downed timber--roughly 13% of the timber blowdown. This multilevel approach was then used in subsequent, more long-term policy responses directed at wildfire hazard reduction and reforestation efforts.

The following review of the salvage effort reveals how the response worked, how it utilized the efforts of local, state, and federal forestry personnel, the challenges that were encountered, and the lessons learned.

PART 1A: IMMEDIATE ACTION

Before the hurricane struck, the South Carolina Forestry Commission (SCFC) compiled action pamphlets "Your Trees AFTER HUGO" and distributed them via FAX to coastal areas and the media for general public information. SCFC headquarters and district offices remained on full alert in cooperation with South Carolina's Emergency Preparedness Division (EPD). Offices were staffed 24 hours a day with a liaison representative at the State Emergency Operations Center (SEOC).

Early Friday morning (September 22), SCFC dispatched 155 workers and 89 truck/tractor units to the damaged areas and arranged for standby staff and equipment to be brought in from areas with lesser damage. These work crews cleared transport routes and assisted local Emergency Operation Centers in removing timber from communication lines. The Commission conducted an initial aerial survey of part of the storm-damaged area and later that night started flights for a

[2] John M. Ols, Jr. 1990. "Preliminary Information on the Federal Government's Response to Recent Natural Disasters." Testimony given to the Subcommittee on Investigations and Oversight on the Federal Emergency Management Agency's Response to Natural Disaster's. May 1, 1990.

systematic damage assessment of Charleston County. The surveys helped to assess the number and location of roads needing clearing and the extent and degree of damage to forest land. Aerial and ground surveys continued throughout the next two weeks to assess damage to forest industry facilities, as well as more careful inspection of forest damage. At least 13 Forestry Commission facilities--nurseries, district shops, residences, fire towers--suffered damage from wind or downed trees. Timber damage extended over 4.4 million acres in 24 counties, totaling 6.7 billion board feet valued at $1.181 billion. These figures are summarized in Table 1.

By Saturday morning (September 23), 242 SCFC employees and 124 tractors were assisting with the relief effort. Fire detection aircraft and fire suppression helicopters were kept on standby for the EOC. State Forestry statute 48-23-86 gave the State Forester responsibility to establish a disaster plan in the event of a forest emergency; Acting State Forester Jack Gould decided there was sufficient damage to warrant declaration of a Forest Disaster. Gould first contacted John McMillan (Director, Division of Energy, Agriculture, and Natural Resources) of the Governor's Office to notify the Governor of his decision, and then declared the Forest Disaster through Media Advisory. Gould immediately contacted other members of the forestry sector, including the chair of the Forestry Commission (Boris Hurlbutt), the U.S. Forest Service (Don Eng), the South Carolina Forestry Association (Bob Scott), and the Clemson Extension Forester (Don Ham), as well as representatives of forest industry and major resource agencies. Gould wanted to schedule an emergency meeting of the Foresters' Council of South Carolina to seek its advice, but was unable to contact the chair, Ken Bailey, at this point.

On Sunday (September 24), SCFC met with the Highway Department, the National Guard, and representatives of South Carolina Electric and Gas Company to plan the restoration of electric service to Charleston. SCFC prepared the Governor's Briefing and presented it to John McMillan at the State House.

By Monday (September 25), Jack Gould had reached Ken Bailey, chair of the Foresters' Council, and had scheduled an emergency meeting of the Council for Thursday, September 28. The Governor issued a statewide burning ban; SCFC advised all districts of the ban.

On Tuesday (September 26), SCFC compiled damage estimates. This information was relayed to the Governor through his press secretary and released to the public through a news conference held at Forestry Commission headquarters. Media advisories were sent via FAX to all major television stations and newspapers.

On Wednesday (September 27), the Federal Emergency Management Agency (FEMA) conducted a meeting for agency heads to discuss and coordinate response activities throughout the disaster area. At this point, FEMA did not have any explicit role in responding to the effects of the hurricane on the forest sector. FEMA's responsibilities post-disaster include: coordinating the roles of emergency response agencies; providing assistance for individuals and families affected by the disaster; and providing funds for the repair of damaged public

Table 1--Timber Damage from Hurricane Hugo in South Carolina.

	Sawtimber Damage Volume (MMBF)*	Pulpwood Damage Volume (MMBF)*	Sawtimber Saleable Value (millions)	Pulpwood Saleable Value (millions)
Pine	6,319	6,130	$891	$92
Hardwood	3,984	7,038	$163	$35

Total value of damage to all timber = $1.181 billion
* MMBF = million board feet, a board foot is a unit of volume with the dimensions 12" by 12" by 1".

facilities.[3] Although FEMA did not have any obvious role or jurisdiction in the salvage and recovery of South Carolina forests, the Forestry Commission and the Governor's Forest Disaster Salvage Council would begin meeting with FEMA to discuss emergency funding. South Carolina Officials understood that creative policy making and strong leadership were required if the forest sector was to benefit from FEMA support. The members of the Commission and the Governor's Council were aware that FEMA funds for the forest sector had to be justified on the basis of public safety and/or public health.[4] In the coming weeks, several meetings between FEMA representatives and the Governor's Council would take place to discuss funding of salvage, reforestation, and wildfire prevention and suppression efforts.

On Thursday, September 28, the Foresters' Council held its emergency meeting. Thirty five members and guests attended, including representatives of the Governor's Office, SCFC, Clemson University Extension Service, U.S. Forest Service, U.S. Soil Conservation Service (SCS), consulting foresters, industry, and media. The Forestry Commission presented a Basic Salvage Council Plan to create the Governor's Forest Disaster Salvage Council; the plan was accepted by the Foresters' Council. The plan borrowed from Mississippi's plan following Hurricane Camille, and set a goal of salvaging 25% of the damaged timber.[5] Officials in Mississippi communicated their willingness to offer advice on any aspect of the timber salvage effort, if called upon.[6] An eleven-person ad-hoc committee was designated by the Foresters' Council to present the plan to the Governor's Office, solicit input, and select Salvage Council members.

On Friday, September 29, Jack Gould (SCFC), Bob Scott (SCFA), Bill Sullivan (SCFA), and Corky Lee (SC Forest Industries) met with Warran Tompkins, Chief of Staff to Governor Campbell, to request an Executive Order creating the Governor's Forest Disaster Salvage Council. For the next week (September 30 - October 6), the Commission continued intensive assessment of needs concerning aerial photography, FEMA eligible expenses, a forest survey of damaged areas by the USFS Inventory Analysis Group (Asheville), truck weight concessions, railroad rate changes, specialized forest fire control needs, and basic reforestation planning.

On Wednesday, October 4, Dean Carson (SCFC) contacted the offices of U.S. Senator Ernest Hollings and U.S. Senator Strom Thurmond regarding Agricultural Conservation Program (ACP) and Forestry Incentives Program (FIP) special allocations. USFS in Atlanta advised SCFC of an invitation to provide a Congressional Briefing to legislative delegates in Washington, DC. Acting State Forester, Jack Gould, and Salvage Council Chair, Scott Wallinger, appeared before the U.S. House of Representatives and the U.S. Senate for a briefing on the Forest Disaster and SCFC needs on Tuesday, October 10. They addressed Hugo's damage, salvage efforts, and wildfire implications, as well as the assistance needs of South Carolina's forest landowners.

On Thursday, October 5, one week after the request, the Governor issued an Executive Order (89-45) creating the Governor's Forest Disaster Salvage Council.

PART 1B: GOVERNOR'S FOREST DISASTER SALVAGE COUNCIL

Members

Governor Campbell's Executive Order established a governor-appointed 17-member Salvage Council consisting of representatives from the USFS (Don Eng), SCFA (Bob Scott), SCFC (Jack Gould), S.C. Society of Consulting

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[3] Details of FEMA's responsibilities and policy response to Hurricane Hugo can be found in : Marie Lynn Miranda. Coordinating Federal, State, and Private Sector Response to Natural Disasters: A Case Study of Hurricane Hugo. Sanford Institute of Public Policy, February 1994.

[4] Testimony of Mac Lupold. Effects of Hurricane Hugo on Forest Resources. Hearing before the Subcommittee on Forests, Family Farms, and Energy of the Committee on Agriculture. November 6, 1989, Moncks Corner, SC.

[5] Allan P.C. Marsinko, Thomas J. Straka, and Jeffrey L. Baumann. 1993. "Hurricane Hugo's Effect on South Carolina: The Impact After Three Years" in Journal of Forestry, September 1993, pp. 9-17.

[6] Minutes of the initial meeting of the Governor's Forest Disaster Salvage Council from Scott Wallinger. October 6, 1989.

Foresters (Dwight Stewart), Agricultural Stabilization and Conservation Service (Bryan Patrick), Governor's Office (Ralph Strong), S.C. Department of Agriculture (Leslie Tindal), S.C. State Senate (Hon. John Drummond and Hon. John Courson), S.C. House of Representatives (Hon. Thomas Limehouse and Hon. Woodrow McKay), Clemson University Extension Service (Don Ham), and forest industry (Mitchell Scott, Collum's Lumber Mill, Jim Haygreen, Georgia-Pacific Corp., Bill Sullivan, International Paper Company, Corky Lee, Stone Container Corp., and Scott Wallinger, Westvaco, Timberlands Division.)

Duties

The Council's mandate included the following duties:

* to make immediate determinations of all needs of the forest products industry;
* to explore in detail all avenues of assistance; and
* to make specific recommendations of the most efficient and effective procedures for realizing the greatest return on the damaged resources.

By the Council's second meeting on October 13, committees were organized and its mandate had been translated into more concrete responsibilities, including:

1) Initiate an aggressive salvage effort.
2) Broaden the base of markets for wood products.
3) Expand logging and transportation.
4) Promote wood products storage.
5) Communicate salvage techniques and strategies.
6) Remove regulatory hurdles impeding the salvage.
7) Record and monitor salvage activities and results.
8) Work within the antitrust laws.

Funding

SCFA provided $25,000 up front to facilitate the salvage operations. The Association was then reimbursed by a variety of sources. From that $25,000, an Executive Secretary was salaried; most others involved were volunteers. All office costs (printing, telephone, etc.) were absorbed by SCFC. Other than the $25,000 for the Executive Secretary's salary, no funding was made available for the salvage effort. Eventually, the South Carolina Senate allocated approximately $10,000 to partially reimburse the SCFA. Later, another $12,000 was allocated by the S.C. House and Senate from discretionary funds.[7]

Structure

On advice from the Forestry Commission, the Governor appointed Scott Wallinger (of Westvaco Corporation) Chair of the Salvage Council. Mac Lupold was appointed the full-time Executive Secretary for a provisional term of 90 days (through December 1989) with continuation after that on a month-to-month basis contingent upon need, availability, and funding; he remained in his paid position until June 1, 1990. Lupold's salary was $375/day (gross), including all benefits and costs except travel, meals, lodging, and telephone. He operated from his home office in Holly Hill, with office space and support staff in Columbia provided by SCFC and SCFA.

The Council was initially broken into five committees: Information, Utilization, Transportation, Environment, and Inspection. However, at the Executive Committee meeting on October 17, the proposed duties were reorganized under four committees: Public Information, Utilization, Government Affairs, and Statistics and Monitoring. Because the tasks for the Environment Committee were primarily technical and could be handled by other standing committees, the responsibilities of that committee were parceled out to other committees, primarily the Government Affairs Committee. The Transportation Committee became a subcommittee under Utilization, and the Inspection Committee changed its name to Statistics and Monitoring. The Chair of the Council, Executive Secretary, and the four Committee Chairs formed the Executive Committee, which was charged with keeping the Council updated on committee activities and facilitating action.

At the Salvage Council's initial meeting, the members discussed committee responsibilities. By October 17, the committee responsibilities and chair persons were finalized as listed below.

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[7] Governor's Forest Disaster Salvage Council. Briefing Book for the Economic Recovery Commission. 8 January 1990.

Government Affairs, Bob Scott (SCFA), Chair

* Initiate, draft, and promote the adoption of state and federal legislation and/or regulations to enhance salvage operations and forest regeneration.

Public Information, Don Ham (Clemson University Extension), Chair

* Develop an information network to target timber landowners, foresters, buyers, processors, and the general public using press, print, and Educational Television (ETV).

Utilization, Bill Sullivan (International Paper), Chair

* Initiate an aggressive salvage program to reclaim as much downed timber as possible.
* Promote an aggressive program of storage of salvaged logs and pulpwood under standing water or water spray, by individual companies and through collective storage facilities, to absorb one-third of the salvageable material.

This committee was further divided into four subcommittees:

Out-of-State Movement, Storage, Utilization, and Transportation.

Statistics and Monitoring, Jack Gould (SCFC), Chair

* Survey mill capacity for salvaged materials.
* Determine weekly salvage removal.
* Facilitate a USFS 24 county survey of the damaged area.
* Establish county monitoring teams to report weekly salvage status.
* Provide constant review of conditions in the field to ensure maximum salvage.

This committee was further divided into two subcommittees:

Statistics and Monitoring

PART 1C: ACTIONS OF SALVAGE COUNCIL COMMITTEES[8]

Government Affairs Committee

The Government Affairs Committee worked to initiate and encourage the development of state and federal legislation that would help fund the salvage operation and other aspects of the forest disaster relief efforts. The Executive Committee assisted the Government Affairs Committee in developing a long-term priority list of legislative proposals and in lobbying state and federal officials.

Shortly after Hugo, with minimal lobbying effort by the Salvage Council, two non-legislative initiatives were enacted (one by Governor Campbell and one by the Department of Health and Environmental Control) aiding salvage operations almost immediately. By October 4, the governor issued an executive order allowing the Highway Department to increase the gross weight limits for log trucks from 80,000 to 90,000 lbs. This increase was first granted for 60 days, until December 5, 1989. At the request of the Council, Governor Campbell issued an extension on December 5 for 60 additional days. And, again in January, he extended the executive order 60 more days until April 4. However, by early February, there was some sentiment that the truck weight limit was being abused and that small rural farm to market roads were being overused by logging trucks. On February 15, Captain Corbin of the Highway Patrol expressed concern to the Council about extending the 90,000 pound weight limit. He cited a higher than normal violation pattern for trucks carrying excess weight, trucks violating the tree length requirement at night, roads being overused in some locations, and uninsured, underinsured, or unregistered salvage vehicles. Corbin emphasized that the conditions must be improved immediately or the

[8] This section of the report is based on information available from: "Hugo Timber Salvage Information," a weekly newsletter created and distributed by the South Carolina Governor's Forest Disaster Salvage Council from 13 October 1989 to 1 June 1990.

truck weight would not be extended past March 15. The Council warned loggers of the possible cancellation of the weight extension. However, the Governor chose to cancel the extension of the weight limit on March 15.

A second state initiative, issued through the Department of Health and Environmental Control, established a special wastewater permitting procedure. Short-term log storage and sprinkler operations were exempted from the usual permitting process, typically a six-month procedure. A workshop on notification and/or permitting for wet storage sites was held on January 16. Mills needed to: locate sites; describe sprinkler systems and the type of recirculation pond (if used); set a time frame; and communicate with DHEC in order to meet the April 6 deadline to operate prior to notification or permit. DHEC stated that logs could be stored before the mills notified DHEC, but plans had to be submitted within 30 days; no logs could be stored on an unreported site after July 1. DHEC declared that a closed-loop recirculation system had to meet a 10-year, 24-hour rain capacity and only required notification (not permitting). Wet sites where sprinkled water was not collected required permits to operate and required a monthly water runoff sampling. The Council advised DHEC that pine sawlogs would probably be placed in wet storage as late as May and June for use in the wet months of December to March 1991. Hardwoods, they claimed, would be logged in the dry months of 1990 to 1993 and stored with use the following winter months.

The Executive Committee recommended that the Government Affairs Committee concentrate on the following legislative proposals, defined as the "1990 Hugo Forest Disaster Relief Needs":

STATE

1) Income tax casualty loss (to recover 5 to 6 percent of actual and lost timber value);
2) Investment tax credits for reforestation costs; and
3) Funding for Council expenses for 1989-1990 ($88,000).

FEDERAL

1) $750,000 for Forest Resurvey;
2) $100 million for a reforestation cost sharing program; and
3) Forest Crop Loss Bill (similar to farm crop loss bills for freezes, droughts, hurricanes, etc.)

At the state level, the Salvage Council lobbied for these proposals at a meeting of the House Agriculture Subcommittee on December 12, during which Bob Scott, Mac Lupold, and Jack Gould presented information on Congressional Hugo legislation status, salvage progress, and the SCFC fire prevention, pre-suppression program. In addition, the S.C. Tax Commission proposed three more specific legislative tax incentives for private forest landowners:

1) Property tax relief;
2) Casualty tax provisions to allow a loss on SC tax returns in excess of basis; and
3) Investment tax credit for reforestation applied to SC tax returns.

The Council, SCFC, and USFS conducted a tour for House Committee members on January 3 in the Moncks Corner area. They hoped an on-the-ground observation of the damage, salvage operations, and comments from landowners would assist in preparing relief legislation.

In late January, Executive Committee Chair Scott Wallinger sought the Governor's support for a South Carolina casualty tax write-off provision. By early February, the Council detailed the casualty tax legislation's effects on the average forested landowner. Losses from Hugo totalled $1 billion on 4 million acres of <u>private</u> timberlands, with an average loss of $250 per acre. The average casualty tax write-off as determined by the terms of the proposed legislation would be $9.28 per acre. Using the average S.C. timber tract of 90 (±) acres, the average tax credit would be $835.00, split into $167.00 over five years. This proposed legislation did not include any provision for a timber basis. It was based on a 75% casualty tax cap, and it used a 5 1/2% tax rate (average for South Carolina). The Council encouraged landowners to maintain records of the salvage and to develop a photograph trail of forest damages for tax purposes in case pending legislation passed and a professional appraisal was necessary.

Despite all the lobbying efforts, little progress was made in advancing any of these proposals through the South Carolina legislature. The casualty tax write-off provision and funding of the Salvage Council's operations were endorsed in the March report issued by the Governor's Economic Recovery Commission. The Economic Recovery Commission was charged with recommending how the governor should address the short-term and long-term needs of the state five months after Hurricane Hugo. The writers of the report argued that the casualty tax program's estimated revenue losses of $6 million per year would be offset by federal reforestation program dollars estimated to total $5.5 million over five years. However, this endorsement failed to sway the South Carolina legislature.

At the federal level, the Government Affairs Committee lobbied for $750,000 to fund the USFS Forest Resurvey, $100 million for reforestation cost sharing, and $280 million for a "Crop Loss" proposal. In addition, they provided information to a Congressional delegation on tax and financial assistance to landowners.

The Government Affairs Committee's agenda for Hugo relief legislation was brought to the forefront after a public hearing of the House Subcommittee on Forests, Family Farms, and Energy in Moncks Corner, an area particularly hard hit by Hugo. The hearing, titled "Effects of Hurricane Hugo on Forest Resources" was requested by S.C. Congressperson Tallon, member of the House Agriculture Committee, in order for Congressional Representatives to "hear firsthand from the people most affected by the hurricane."[9] The meeting was attended by four subcommittee members (Volkmer, MS; Olin, VA; Harris, AL; and Herger, CA) as well as South Carolina representatives Tallon and Spratt and Senator Hollings. Jack Gould, Mac Lupold, Bill Sullivan, and Scott Wallinger all made statements. Lupold and Wallinger, on behalf of the Salvage Council, sought $30 million from FEMA or through special legislation for storage of logs, chips, and lumber and for logger assistance. Other testimony was presented by industry representatives, consultants and landowners. During the hearing, the U.S. Forest Service presented its proposed funding needs, totaling $243 million.

Rep. Volkmer, Chair of the Subcommittee commented, "It's obvious that the national news media never got to the woods to illustrate the tremendous loss to South Carolina's forest landowners. Your timber losses, salvage efforts, fire danger, and reforestation needs will be actively presented to the Congress."[10] Subsequent to the hearing, Tallon, Spratt, and Hollings cosponsored three of the several bills proposed in both the U.S. House and Senate to provide relief to forest landowners.

The Government Affairs Committee worked with Senator Strom Thurmond to prepare the Hugo Forestry Restoration Act. In the House, Representative Tallon introduced a companion bill, the Hurricane Hugo Forestry Restoration Act. Thurmond's bill (S1728) would authorize $100 million in cost share assistance to landowners who wished to reestablish timber stands damaged by Hugo. Although the Salvage Council recommended a 90% cost share for landowners with 100 acres or less and 65% for those with more than 1000 acres, the bill provided 75% and 50% cost share ratios. This bill was immediately referred to the Senate Committee on Agriculture, Nutrition, and Forestry after being introduced on October 5 and never received any other action. The components of Thurmond's bill were eventually subsumed by the Hugo Relief Omnibus Bill. This bill, introduced by Senators Mitchell (Democratic Majority Leader) and Dole (Republican Minority Leader), would have amended the Robert T. Stafford Disaster Relief and Emergency Assistance Act to deal specifically with recovery of losses by forest landowners. Besides providing $100

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[9] Harold Volkmer, Representative. Opening statement at hearing of the House Subcommittee on Forests, Family Farms, and Energy Effects of Hurricane Hugo on Forest Resources. Moncks Corner, SC. November 6, 1989.
[10] Ibid.

million in reforestation cost share assistance (Thurmond's bill), the omnibus bill proposed three other measures:

(1) A $200 million Forest Land Bank Program for Emergency Relief for Forest and Environmentally Sensitive Areas. This set up a program for timberland owners similar to the Conservation Reserve Program offered to agricultural landowners. Timber landowners could receive compensation beyond the cost of salvage in order to insure reforestation.

(2) $30 million for salvage operations. This proposal included $10 million for the Salvage council administrative costs, logger assistance, and storage costs. The other $20 million would provide loans to businesses involved with logging and storage.

(3) $5.8 million to the S.C. Forestry Commission for Additional Fire Suppression Equipment and Programs.

This bill incorporated all three of the Salvage Council's legislative priorities. However, the Senate never took action on this Omnibus bill. Attempts to pass a separate scaled down bill for $50 million for site preparation and clean up also failed. SCFA's Bob Scott, chair of the Government Affairs Committee, said, "We missed a golden opportunity to get these bills passed. There was strong sentiment on our side. I don't think we'll have that same degree of concern when Congress reconvenes next year as there will be new concerns and different priorities. ... It's going to require a better organized nationwide lobby effort to get the legislation approved next year."[11]

Tax assistance legislation was also proposed in the House and Senate. Senator Hollings' and Representative Spratt's proposed legislation provided for deduction of business and investment losses. Their bills, both titled the Hurricane Hugo Tax Assistance Act (S.1748 and HR.3655), were referred to the Senate Finance Committee and the House Ways and Means Committee, respectively. Like the previous Hurricane Hugo relief measures, after these bills were referred to committees, all action on them stopped. Neither the Senate or the House approved the acts before Congress adjourned on November 22.

In March, Executive Committee Chair Scott met with members and staff of the S.C. Congressional delegation to create a national lobbying effort for Hugo legislation. The campaign involved allied forestry and farm organizations, industry coalitions, and leaders of natural resource agencies. Over the next several months, legislation was enacted providing funds for reforestation and wildfire prevention efforts (detailed in Parts 2 and 3 of this report), although salvage efforts were overlooked.

Public Information Committee

The Public Information Committee prepared articles explaining the responsibilities of the Salvage Council and updating committee activities. The Committee's goal was to keep the public informed about the Hugo forest disaster and recovery efforts. They urged landowners to contact professional foresters for advice on salvaging downed timber, safety concerns, and the elevated wildfire hazard risk.

The committee issued press releases, prepared flyers on logging, trucking, and hunter safety, and compiled information for landowners on conversion relationships (tons, cords, and MBF). Once or twice weekly, the Council published listings of "wants and needs" of loggers, landowners, consultants, buyers, and trade companies. By mid-October, the Clemson Extension Service agreed to provide a full-time writer for the Council's effort; in November, the Extension Service hired Julie Walters-Steele.

The committee used television, videos, and educational television (ETV) in their efforts to keep the public and the forest community informed about the state of the relief efforts. At the request of the Council, ETV prepared a ten-minute salvage background feature, a "Crosstalk" special entitled "Hurricane Hugo's Effect on South Carolina's Forests," four public service announcements, several focus features, and a documentary of the salvage effort.

[11] Governor's Forest Disaster Salvage Council, "Hugo Timber Salvage Information," 1 December 1989.

The committee made several attempts to schedule Governor Campbell for a salvage tour in Sumter County. The media was invited to attend. The three woodland stops and bus commentary focused on the salvage status, the hardwood resource and hardwood salvage problems, forest rehabilitation, legislative issues, fuels management, and the economic outlook for forestry. A March 2nd and 16th tour were postponed; eventually, the tour was held on April 25.

Utilization Committee

The committee formulated a reasonable salvage goal. In late November, seven weeks after the storm, the committee determined that the "at best" salvage goal was 25% by volume and 10% by value. That estimate considered low volume, inaccessible and unloggable areas, product change from pine sawtimber to pulpwood in the snapped trees, logging and mill/user capacities, logging and transportation conditions, and time frames for each product use.

The **Transportation Subcommittee** negotiated discounts with railroads for pulpwood and wood rack cars, distributed bumper stickers to identify trucks involved with Hugo salvage, and investigated the possibility of shipping wood out-of-state. The railroads responded to the committee's requests: both CSX and Norfolk-Southern offered rate reductions and various equipment alternatives. Santee-Cooper volunteered 45 to 50 of its aluminum coal cars (25 ton capacity) for free use for 15 to 20 weeks; those cars could be cleaned and used for chips until late spring. Stone released 250 woodrack cars for use at Panama City and Norfolk-Southern made 300 woodrack cars available. By November 8, the subcommittee had located 3500 surplus woodrack cars from CSX Railroad. However, both CSX and Norfolk-Southern Railroads reported very few requests for equipment in the salvage effort in late November. The companies had surplus shortwood pulpwood racks, gondolas, and bulkhead flat cars, but few used them. In January, Norfolk-Southern extended its rate reduction until April 8 because bad weather in South Carolina had slowed down the salvage.

The committee convinced the state to allow out-of-state loggers to work in South Carolina without fuel stickers or registrations. After the governor's original executive order increasing truck weight limits to 90,000 pounds from 80,000 pounds, the transportation subcommittee was instrumental in convincing the Governor to extend his executive order until January to increase salvage harvests. The transportation subcommittee encouraged the Governor to extend the weight allowance until at least June, but concerns of abuse of the limits resulted in the governor canceling the order on March 15.

Transportation Subcommittee members contacted 64 State Forestry and Logging Associations to locate additional loggers. The subcommittee convinced the North Carolina Governor to accept South Carolina fuel stickers and registrations, and located available ocean-going barges for transportation of salvaged logs.

The **Storage Subcommittee** needed to: project wet (underwater and sprinkler) and dry storage capacity; disseminate information on the technical data, design, and cost of wet storage options; and inventory locations for storing particular types of wood for a particular length of time. Wet storage delayed blue stain and insect attack, thus preserving the volume and value of timber that could not be utilized immediately. The committee projected that storage could protect timber from blue stain and insects for up to two years.

The storage subcommittee had the difficult job of anticipating the need for wet storage facilities in the face of unpredictable logging conditions (slowed by rain) and, later, an unpredictable market. The committee was successful in identifying sites for wet storage. By November 13, the SCFC had offered to provide water-sprinkler storage areas for Hugo-damaged timber to those interested in establishing log-buying/storage areas. The available sites included a pond in Manchester State Forest and a seed orchard in Wedgefield, SC. The Forestry Commission also offered to assist with technical data on wet storage. By mid-December, over 30 wet storage sites had been established or would soon be available, with a capacity of 160 million board feet or 20% of the salvage goal. In addition, the Land Resources Conservation Commission (LRCC) stated that the use of an owner's pond was acceptable as a water source. Lakes within the Francis Marion National Forest were proposed as potential storage sites, but were not used because of concerns about the difficulty in retrieving wood from the lakes and impacts on water quality.[12]

Many of these storage sites went unused early on in the salvage efforts. Milling operations utilized the salvaged timber as fast as it was logged and were reluctant to store timber until it was absolutely necessary. Manufacturers to whom the milling operations were selling lumber do not like stored wood because it can be splotchy and stained. Not until February or March did some mills begin to consider using storage. By April, however, 139 million board feet of pine and 6 million board feet of hardwood sawtimber, worth $38 million, were in wet storage. Most logs were stored for only a few months, but in some instances, storage was used for over a year.[13] Towards the end of the salvage effort, wood prices began to rise again; some companies, in hindsight, would have placed more logs in wet storage.

During this time, Lupold, the Council's Executive Secretary, met with DHEC officials to discuss the technical aspects of wet storage. Industry officials also met to discuss the issue of wet storage and to obtain a time extension for temporary storage. The USFS conducted a research program on sampling log storage piles (from wet storage) every two months to monitor lumber quality. The Forest Service found that the quality of stored lumber was maintained for longer than they had anticipated. Clemson extension agents found that serious problems did not occur when "processing the sprinkled logs into lumber, veneer, and plywood, and no product degrade could be attributed to sprinkler storage."[14]

The committee considered storing chips left in the woods from salvage and fuel reduction operations to be recovered at a later date. The committee also found that mills were sawing wider lumber than usual (2x8, 2x10, and 2x12) because some salvaged trees had large diameters. The committee encouraged storage of this low volume product to protect its high market value.

The Out-of-State Movement Subcommittee determined that the pulp and sawmill manufacturing capacity in the southeast that could use South Carolina's damaged wood was favorable. However, the volume of salvage material that actually left the state was limited because there was a constant demand for sawlogs and pulpwood within the state. Ultimately, 90% of the salvaged timber was used in-state.[15]

The Subcommittee found that the chipping capacity in South Carolina could be greatly increased by using 2nd and 3rd shifts and by operating seven days a week, but there was no economical way to move chips from chipping sites to the pulp mills more quickly. Chip cars were in short supply. Members planned to contact pulp mills in the southeast for commitments. By October 20, two sawmills had diverted over 200 log cars and 65 new chip cars to the salvage effort. Gondolas were brought into the area for log movement. The subcommittee determined the needs of the pulp and paper mills for chips, shortwood, pulpwood, and hardwood, and found several mills in Virginia, North Carolina, Georgia, Florida, and Alabama that were low on inventory. They found that there were opportunities available for exported logs; the problem was finding an economical means of delivery.

The Council worked with state ports to determine reasonable port unloading, storage, and ship loading charges. State ports were not commonly used for the export of wood and lumber products. This resulted in tariffs plus stevedoring charges at approximately

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[12] Steve Nodine, Clemson University Extension Forester, personal communication.
[13] Allan P. Marsinko, Thomas J. Straka, and Jeffrey L. Baumann. 1993. "Hurricane Hugo: A South Carolina Update" in Journal of Forestry, September 1993:9-17.
[14] Syme, John and J. R. Saucier. 1992. "Impact of Hugo Timber Damage on Primary Wood Manufacturers in South Carolina." U.S.D.A. Gen. Tech. Rep. SE-80. 28 p.
[15] Allan P. Marsinko, Thomas J. Straka, and Jeffrey L. Baumann. 1993. "Hurricane Hugo: A South Carolina Update" in Journal of Forestry, September 1993:9-17.

$135/MBF, making log exports prohibitively expensive.

The subcommittee presented its salvage program to the Southeastern Technical Committee of pulp and paper procurement personnel of the American Pulpwood Association on November 15. By mid-December, there was little out-of-state movement due to wet logging conditions. In-state consumption, however, matched the logging effort.

The heavy rains after the hurricane prevented loggers from starting the salvage for several weeks. During this time, the **Utilization Subcommittee** distributed publications on logging safety, coordinated the Wildlife Department for hunter safety and use of rifles, refined a list of wood users for mailings, and began to address fire concerns for when the tops of downed trees dried out. After the weather cleared up and logging began, it urged landowners with standing timber to keep it off the market so that damaged material could be used first. The subcommittee contacted 38 pulp and paper mills and 75 sawmills out-of-state by phone or letter to ask them to use Hugo-damaged wood. The committee convinced the Governor's Office to contact railroad CEOs and 49 pulp and paper CEOs to ask for their help and cooperation. By October 27, the subcommittee found that hardwood stands were often in low-lying, wet areas preventing logging operations, but pine sawtimber stands were dryer, and as long as the rains held off, were logged.

The Committee served as an information clearinghouse providing forest landowners with information on available loggers and equipment. By November 13, the subcommittee had contacted 37 of 65 logger and forestry associations throughout the U.S. and Canada about South Carolina's need for loggers and had begun an inventory of South Carolina logging capacity, number of crews involved, and out-of-state input in the logging effort. A meeting in mid-December revealed mixed opinions about the need for loggers; since some still had a need, the Council continued to locate out-of-state loggers.

The Committee initiated many small projects to facilitate salvage. They provided 500 road signs advising "Hugo Logging Ahead". They issued a statement urging caution at sawmills because of the danger associated with compression breaks. More heavy rains in December caused all logging operations on the Francis Marion to close. By that point, most higher-elevation sites (where flooding was not a problem) had been logged.

The committee found that professional foresters handling logging sales were selling logs at 50 to 75% of pre-Hugo prices depending on the damage to the stand. The committee compiled over 200 notices of needs and capabilities to list in the "Classified Ads," an attachment sent out to over 500 businesses with the "Timber Salvage Information" newsletter.

Statistics and Monitoring Committee

The Statistics and Monitoring Committee developed salvage response forms, had them reviewed by industry representatives, and mailed them to over 250 wood processing companies in South Carolina, North Carolina, and Georgia by October 20. These surveys were designed to determine production capacity, wet storage plans, and weekly consumption of salvaged wood. The **Statistics Subcommittee** received weekly reports from mills accepting primary forest products from the salvage. It then gave those numbers to the SCFC, which compiled the information for weekly progress reports; the progress reports were attached to the "Timber Salvage Information" weekly newsletter and distributed to over 500 people. The subcommittee also helped organize and report results form the U.S. Forest Service Resurvey of the 24 disaster counties.

By November 20, the **Monitoring Subcommittee** had received these comments from the field about the salvage:

		Number
1)	can't sell wood	71
2)	unsatisfactory price	49
3)	poor logging conditions	28
4)	tight quotas	22
5)	not enough loggers	20
6)	USFS flooding market	4
7)	free wood	3

The Monitoring Subcommittee also learned that there was some need for more shortwood products and markets, loggers tended to prefer clearcutting salvage areas, and owners of small tracts were having difficulty finding buyers for their downed timber.

Executive Committee

The Council's Executive Committee met weekly. They published a weekly "Timber Salvage Information" newsletter, which was distributed to over 500 members of the forestry community. The newsletter contained information on committee progress, reported salvage status, and listed "classified ads" to match needs with availability of loggers and equipment. The committee reviewed timber sale procedures for the Francis Marion National Forest and other timber salvage alternatives. They listened to concerns from the Governor's Office, members of Congress, private landowners, and consulting foresters on the economic effect that Forest Service sales would have on stumpage prices, availability of loggers, and local wood processing capacity. The committee also discussed the proposed forest survey and specific committee tasks.

By October 20, at the suggestion of the Executive Committee, Council Chair Scott Wallinger contacted George Leonard, Associate Chief of USFS to discuss the economic impact that a large volume of pine sawtimber might have on the existing Hugo area manufacturing capacity over the next several months. Wallinger urged the USFS to release factual data on their current sales procedures to counteract various rumors that they would flood the market with National Forest timber. He suggested three alternatives: 1) minimize the short-term volume available to wood-using facilities; 2) install major wet storage sites throughout the forest for mill consumption in one to two years; and 3) secure loggers from outside the Hugo area. Wallinger assured the USFS that the Council would be willing to assist in any way possible in securing storage funds, environmental compliance, loggers, and wet storage technology.

Don Eng, USFS Supervisor, provided an update on the timber sales procedures and status. He stated that the Francis Marion had 70% of its mature pine trees on the ground and that no live trees over a 45 degree angle would be cut. Since the Council's involvement in the USFS salvage effort, Eng said, positive steps were taken by the Forest Service at the national, regional, and local levels to lessen the impact on the local forest economy. For example, the Forest Service was considering the following actions: storing 40 to 50 million board feet of wet log storage in the forest, additional wet storage by buyers at their mills, using whole tree chipper operations with chip piles left in storage for later removal, and using loggers from other national forest areas. The Forest Service pursued all of these options except wet storage within the National Forest.

At an October 26 meeting of the Salvage Council, the Council endorsed the immediate need for a USFS resurvey of the 24 county area to determine the mortality due to Hugo by ownership class, species, and age class. The estimated cost of the survey was $750,000; efforts to secure federal funding were pursued by the Executive Committee and Government Affairs Committee. After many unsuccessful attempts at securing funds from FEMA and through President Bush's discretionary funds, the Council eventually obtained $750,000 for survey work by the Forest Inventory Analysis (FIA) research unit at the Southeastern Forest Experiment Station.

FIA began the survey on February 20th and eventually surveyed 2,530 forest plots in 23 counties. Noel Cost, Project Leader of FIA, prepared status reports published bi-weekly with the "Timber Salvage Information" newsletter. The Council requested that two interim reports be prepared first on the heavily damaged and moderately damaged counties. The first report appeared in the March 2 edition of the newsletter documenting progress as of February 23. The crews had visited 77 plots in a severely damaged five county area (Charleston, Sumter, Lee, Clarendon, and Berkeley counties) and found 59% of the total pine volume and 65% of the total hardwood volume was damaged. By this date, only 5 of the 77 plots visited had any salvage cutting activity. The March 2 newsletter reported that a total of 292 plots had been examined, and less than one percent had experienced any salvage harvest activity.

The Executive Committee was a coinitiator of many of the Council's funding and legislative proposals. The Executive Committee arranged meetings during November among the Council, SC Forestry Commission, and the Federal Emergency Management Agency (FEMA) officials to request money from FEMA for additional fire suppression equipment and programs. The Executive committee also initiated the effort to secure loan money (by FEMA or special legislation) for storage loans (for logs, chips, and lumber), logger assistance, and administrative costs of the Council. Although the loan program never passed (as a component of the Mitchell/Dole Omnibus bill), FEMA eventually provided fire prevention funds totalling $8.4 million.

By November 23, the Executive Committee was considering options for longer-term alternatives for the salvaged wood. The weather was good, and if it continued, the alternatives included:

1) Establish wet log storage in the woods and at mills.
2) Contact companies about export potential.
3) Set up shortwood operations at rail sidings to utilize surplus woodrack cars.
4) Contact out-of-state pulp and paper companies to release some chip cars for the Hugo effort.
5) Adapt woodracks, lumber flats, and gondolas (all in surplus) for moving logs by rail.
6) Investigate barge movement of logs and chips.
7) Try chipping in woods for later recovery.

Executive Secretary Mac Lupold presented the Council's program to various groups throughout the salvage effort to solicit their help. He asked the S.C. State Development Board to assist with rail loading and wet storage sites and the American Pulpwood Association to encourage procurement personnel to receive wood out-of-state, to free up some chip cars to South Carolina for 6 to 10 months, and to accept shortwood. He asked Timber Products Inspection to convey the importance of pine sawlog utilization in the salvage effort, and the Agricultural Communications Center at Clemson' Extension Service to encourage Clemson's role through targeted communications.

In late January, the Council presented 12 recommendations to the Governor's Economic Recovery Commission (see Appendix). The recommendations included all the state and federal legislative proposals on the Council's (Government Affairs Committee and Executive Committee) agenda as well as additional reforestation programs, fire prevention, property tax and capital gains tax provision. Eight of the twelve proposals were endorsed by the Governor's Economic Recovery Commission in their March 26 report.

On May 2, the Executive Committee met to review the Council's activities and needs related to salvage, fire control, and reforestation. The committee agreed that the salvage effort had made sufficient progress so that daily responsibilities should shift back to the normal state agencies. Thus, the Council recommended that the duties be distributed as follows:

Responsibility	Organization
Salvage Volume Reporting	SCFC
Legislative Matters	SCFA
Reforestation	SCFC
FEMA Fire Prevention	SCFC
Log Storage	DHEC
Utilization, Loggers, User Listings, Wet Storage	SCFC
Forest Survey	USFS
Council Reports	SCFC
Casualty Tax Questions	Clemson

With the support of Governor Campbell, the Council remained intact to support longer range programs for fire suppression and reforestation. On June 1, Mac Lupold completed his paid position as Council Executive Secretary; he continued to serve as a member of the Executive Committee. SCFC continued to collect and analyze salvage data.

A **Reforestation Committee** was established in mid-December to address reforestation concerns. It worked with the Salvage Council although it was not part of the Council; its mission was much more longterm in nature compared to the Salvage Council's. The work of the Reforestation Committee and the entire reforestation effort will be covered in Part 3 of this report.

PART 1D: OTHER POLICIES

In early November, FEMA joined a multiagency planning group to develop a Hugo area fire plan and to discuss salvage alternatives that might qualify for federal funds. The **Interagency Hugo Hazard Reduction Planning Team** consisted of the SCFC, USDA Forest Service, FEMA, and the Governor's Forest Disaster Salvage Council and met in Columbia for a week in mid-November to create a mitigation plan that considered fire prevention, fuels management, fire suppression, and timber salvage. Section 421 (d) of the FEMA enabling legislation, the Stafford Act, granted funds to states for timber salvage when salvaging costs exceed the value received for the timber. Although this was used mainly to assist in wildfire hazard reduction, it also aided reforestation by reducing site preparation costs.

The Farmers Home Administration (FmHA) made loans to forest landowners after Hugo. The Business and Industrial (B&I) Loan Program through DARBE (Disaster Assistance for Rural Business Enterprises) used existing private sources to provide guarantees of up to 90% of unpaid principal or up to $2.5 million. These loans were made specifically to businesses that were directly or indirectly affected by adverse weather conditions in 1988 or 1989. Interest rates were negotiated between lender and borrower. Tree farmers, either individually or collectively, could obtain a 4% disaster loan if they obtained the loan for storage of their own logs, paid the logger, and either stored the logs themselves or contracted with a mill to store the logs until the product was used. Ten B&I loans were made to private businesses providing over $13 million.[16]

By February 2, the Soil Conservation Service (SCS) determined that $34 million was needed for debris removal on woodland watercourses. The Council recommended to the Economic Recovery Commission that the debris removal begin as soon as possible to improve logging and site preparation conditions. Phase I, October to December 1989, cleared 210 miles and was funded by $3.9 million from SCS's 1990 appropriations. Phase II, February to mid-March 1990, cleared an additional 461 miles, funded by $12.5 million from the President's discretionary fund. On March 14, SCS issued a Congressional Update listing remaining needs as $36,702,872 to clear 1,502 more miles of clogged woodland watercourses.

PART 1E: SALVAGE RESULTS

The destruction in the wake of Hugo challenged traditional mechanized logging techniques. During the salvage operation, crews supplemented conventional logging methods by using wide-tired skidders, helicopters, chain saws, cable systems, and animal logging. The quantity of downed timber combined with wet conditions resulted in twice the normal timber harvest time.[17]

After ten weeks of logging, only 8.3% of the salvage goal had been achieved. If salvage progressed at this rate, only 50% of the "25% by volume" goal was attainable after one year. To reach the goal of 750 MBF of pine sawtimber by June, the weekly salvage rate needed to be 20 to 25 MBF per week. In fact, only four of the previous 10 weeks reached pine sawtimber salvage volumes greater than 20 MBF, with an overall average of about 17 MBF.[18] Pine sawtimber (and pulpwood) salvage did eventually increase. Rain kept loggers from working in the wetter hardwood forest stands, while pine stands were on dryer land. Economics also served as an incentive to focus on pine salvage; pine sawtimber comprised 80% of the estimated salvage value to landowners. By the end of June, the pine sawtimber goal was 99.6% complete, while hardwood sawtimber salvage had only reached 10% of its goal.

The upland counties, Calhoun, Fairfield, Kershaw, Lancaster, and York, had 20% or more damaged volume salvaged as of mid-March. The two worst-hit and wettest counties, Berkeley and Charleston, had a salvage rate of only 4 to 5%. Counties with scattered damage in the Pee Dee area (Darlington, Dillon, Florence, Horry, Marion, and Marlboro) also reported less than 5% salvage.

Weather was a significant factor influencing salvage operations. Heavy rain during the months of November and December slowed salvage logging, especially for hardwoods. By as late as May and June, saturated, wet soils still prevented loggers from getting to areas with 10-20 MBF per acre.[19] At the same time, the wet weather and cool

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[16] Connally Bradley, Community and Business Programs Specialist, personal communication, October 1992.
[17] Mac Lupold, Salvage Council Executive Secretary. Personal interview, July 1992.
[18] Governor's Forest Disaster Salvage Council. "Hugo Timber Salvage Information Newsletter", December 1989.
[19] Lupold, Mac. "Salvage of Storm Damaged Timber" in Hurricane Hugo: Recovering from Disasters. Proceedings of the 72nd Annual Meeting and Regional Technical Conference, January 20-22, 1993, Appalachian Society of American Foresters.

temperatures minimized insect damage and kept bark tight on the wood, delaying bluestain. However, by March 1990, bluestain was advanced by the onset of 85 degree weather. High heat in the spring also shortened the pine salvage period because pines died more quickly than hardwoods.

As of March 16, 217 million board feet were sold from the Francis Marion National Forest. Less than 100 million board feet had been cut by mid-March. Stumpage price varied from approximately $12 per MBF for helicopter sales to more than $100 per MBF for easily accessible areas.

Sixty-two percent of the original salvage goal (25% of damaged timber) was met by November 1990. This figure is a bit misleading because the salvage emphasis was so unevenly split between softwood and hardwood. The softwood goal was met (sawtimber - 99.64% of goal met; pulpwood - 106.65% of goal met). But for hardwood, only 10-15 percent of the goal was met (10.38% of sawtimber goal and 15.16% of pulpwood goal). For comparison purposes, South Carolina salvaged two times the entire loss of timber following Hurricane Camille in 1969.

The decision of the USFS not to allow wet storage in Lake Marion and Lake Moultrie within the Francis Marion National Forest has been criticized as contributing to a premature end to the salvage effort.[20] Without storage sites in the National Forest, mills filled up quickly, and, with slower movement of logs and timber, loggers were discouraged from coming to the area.

Table 2 lists the percent of forest land area affected and the percent of volume salvaged by ownership class. Although 66.4% of the damaged forest acres were non-industrial private forest (NIPF) lands, only 47% of the timber volume salvaged occurred on NIPF lands. Though the USFS and industry made an effort not to absorb all the loggers, some landowners had a hard time getting their land logged. In addition, salvage rates among NIPF lands varied. Some landowners who had a previous association with a consulting forester or were participants in a cooperative forest management program with forest industry were "hooked into the system" and had a better chance of finding a logger. With loggers in short supply (one person estimated 60 to 70% more loggers were needed[21]), many landowners--especially those with small tracts, were unable to salvage their downed timber.

The uneven participation of private nonindustrial landowners in salvage efforts may be due in part to inadequate communication. Communication efforts failed to convey a sense of urgency (damaged timber was a perishable product); this part of the policy response also lacked a clearly laid out media campaign. Shortly after Hugo, the Salvage Council, SCFC, and SCFA handed over the duties of educating forest landowners and encouraging salvage (and reforestation) to Clemson

Table 2: Percent of damaged forest land and percent salvaged by ownership class.[22]

	Acres Damaged	% of Damaged Acres	% of Salvaged Acres[1]
Nonindustrial Private Landowner	2,995,604	64	47
Forest Industry	1,092,775	26	13
Publicly Owned Land	420,358	10	18

[1] Does not equal 100% because 22% of salvaged timber was reported as coming from an unknown source.

[20] John Syme, Clemson University Cooperative Extension. Personal interview, May 1992.
[21] Mac Lupold. Personal interview, July 1992.
[22] Governor's Forest Disaster Salvage Council Statistics and Monitoring Committee Progress Report, 1 November 1990.

University's Cooperative Extension Department. Clemson had traditional expertise in extension education and was thought to possess a mechanism for rapid communication. Also, SCFC was devoting its efforts to fire prevention and mitigation[23] and SCFA did not have the means to network.[24] Clemson approached the communication effort by utilizing existing mailing lists and seminars encouraging landowners to use professional consulting foresters. The mailing lists, however, were not current, and the seminars were few in number. The location of Clemson in the western part of the state made some question if extension agents could comprehend the consequences of the disaster on landowners without having shared their experience. For future disasters, Mac Lupold recommends more seminars; more in-field, show-me training; more direct meetings with landowners; and a greater emphasis on long-term education.

Though there was a glut in the market for pinewood, small hardwood operations still needed logs. Owners and procurement personnel with small independent 1 to 2 species hardwood operations for 8 to 12 loads per week complained about a lack of available logs. All of the plants had a strong order file, but they were receiving no logs. Hardwood salvage picked up toward the end of May/June.

After the salvage operation was complete, the hurricane's potentially devastating effect on the people dependent on the longterm health of the forest sector began to be as apparent as the damage to the forest itself. Many small loggers who relied on buying timber from private landowners went out of business. These loggers had a limited range of operation, and little sophisticated equipment. Small loggers who worked on contract for forestry companies (Georgia-Pacific, International Paper, or Westvaco) fared better and were able to stay in business.[25]

During the salvage, most mills used all the raw material they could get, and, in many cases, increased their operating hours. Once the salvage was over, a supply squeeze closed down many mills. The impact on mills depended on their size, location, and the extent to which they required sawtimber for operations. Forty-three mills are located in the Hugo-affected area.[26] Some sawtimber mills found their buying radius of 50-75 miles to include only Hugo-damaged area. By March of 1992, many of these small or medium sized mills had already closed, others were expected to follow.[27] Those on the border of the damaged area (such as plants in Walterboro and Umplett) were forced to look for timber sources in Georgia or other areas of the state.[28] Pulpwood operations that survived the supply crunch either: prior to Hugo, routinely received pulpwood from upland areas in the northwest portion of the state; or were large milling operations with diversified operations and/or the capital to modify operations to use more pulpwood.

A few processors whose land was not damaged and who were close enough to purchase salvaged timber actually received some short-term benefit from Hugo. Purchasing salvaged timber at depressed prices assured higher future prices for their own timber once the salvage timber supply ran out.[29]

PART 1F: CONCLUSIONS

South Carolina forestry agency personnel, state officials, and landowners lacked any means to prevent hurricane destruction to the forest resource. Their response instead needed to focus on preventing further forest catastrophes, protecting lives and surrounding property, and reducing financial losses of forest landowners. South Carolina's response to these challenges provides some useful lessons for future recovery programs aimed at forest disasters. Some important lessons are outlined below.

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[23] Mac Lupold, Salvage Council Executive Secretary. Personal interview, July 1992.
[24] Robert Scott, SC Forestry Association. Personal interview, May 1992.
[25] John Howard, Forester, South Carolina Forestry Commission, interview, 27 May 1992.
[26] Allan P.C. Marsinko, Thomas J. Straka, and Jeffrey L. Baumann. 1993. "Hurricane Hugo's Effect on South Carolina: The Impact After Three Years" in Journal of Forestry, September 1993, pp. 9-17.
[27] Ibid.
[28] John Syme, Clemson University. Personal communication, 28 May 1992.
[29] Ibid.

All organizations involved in the forest recovery efforts, the SCFC, the Forester's Council, SCFA, and the state forester, were prepared for immediate action. The SCFC quickly organized to send personnel and equipment to damaged areas. They assisted the state's Emergency Preparedness Division in clearing roads and restoring communication lines. The state forester, Jack Gould, quickly brought together the SCFC, the Forester's Council, and the SCFA to design a forestry emergency plan that proposed creating the Governor's Forest Disaster Salvage Council. By exercising such a well coordinated response, the forestry organizations facilitated: (1) the initial steps of forest recovery; (2) material and personnel support for other aspects of post-Hugo recovery; and (3) the governor's ability to stay informed and rely on advice concerning actions to aid in salvage efforts.

The technical solutions required to harvest hurricane-damaged timber provide many useful lessons. By using diverse and innovative harvesting techniques, loggers working in South Carolina overcame some problems with inaccessible damaged timber. Developing wet storage techniques was crucial to preserve timber for future markets. The biggest technical constraint on harvesting was weather. Initially, unusually rainy weather in the fall of 1989 left lowland sites waterlogged and unharvestable. Later, hot spring days encouraged fungus growth and death in many damaged pine trees.

Landowners had a limited window of opportunity to salvage their damaged timber. Salvage became unfeasible once timber was further damaged by fungus, blue stain, and insect infestation. The onset of insect and fungal damage after Hugo was slowed by the cooler, unusually rainy weather in the fall and winter. The rain also, however, left some soils too wet throughout the winter to handle logging equipment. Salvage operations were then cut short with an early start to warm weather in the spring. This short optimal period for salvaging coincided with the time when landowners were most preoccupied with other damage to their houses and personal property. As a consequence, of the 1.33 billion cubic feet of damaged timber on NIPF land, the percentage salvaged totalled only 9%. Unlike damage losses to homes, cars, or other personal property, timber loss is uninsurable. State policy makers and forestry personnel need to design policies that take maximum advantage of the limited window of salvage opportunity.

The Salvage Council successfully balanced a couple of competing objectives. Primarily, they were interested in maximizing the amount of timber salvaged and recovering as much value of the damaged resource as possible. However, they also needed to consider the source of the salvaged timber. South Carolina's forest industry and Francis Marion National Forest were more able than non-industrial private forest landowners to secure loggers, provide equipment, and find buyers for their timber. In response, Salvage Council and Francis Marion National Forest personnel cooperated to help private landowners salvage their timber. They attempted to recruit as many out-of-state loggers as possible and find out-of-state markets for salvaged timber.

Dispersing information and developing educational materials was immediately important to let landowners know how to avoid further forest disasters and their range of options. Landowners were contacted through mailings. While NIPF landowners had 66% of the damaged land, their land accounted for 47% of total salvaged acreage. At the same time, salvage operations on Francis Marion National Forest were not hindered from reaching the goal of salvaging up to one third of the area's damaged timber.

The priority given to funding salvage efforts was very low. Funding for salvage on private land was never made available at either the state or federal level. State funds were in demand by many other sectors and federal funds were stretched between South Carolina and California after the Loma Prieta earthquake in October. Compared to other aspects of hurricane recovery--rebuilding homes, providing food, clothing, and water, and ensuring health and sanitation--salvage lacked any dramatic appeal to prevent human suffering. State forestry agencies attempting to secure federal assistance in the early aftermath of recovery might have been more successful by describing forest damage in terms of its effects on the thousands of small landowners who rely on their land as their "nest-egg" and by drawing the clear link between unsalvaged downed timber and wildfire hazards. To ensure FEMA involvement, state governments will have to lobby for revision of the Stafford Act.

No state or federal legislative precedents were set providing disaster relief for forest landowners. The Salvage Council made proposals for legislation at the state and federal level modeled after tax relief and crop loss provisions for agricultural crop farmers, but none were passed. Essentially, forests remained an uninsurable asset. The Council was more successful in putting its energy into pursuing cost-share assistance for reforestation--a more traditional federal role in forest legislation.

Monitoring gave crucial information to forestry personnel throughout the state on the status of the salvage operation. Monitoring created the capacity for the Salvage Council and other forestry personnel to make changes in the salvage operation as needs arose. For instance, salvage operations on the Francis Marion National Forest were regulated so as not to flood the market with damaged timber. However, monitoring did not always facilitate needed changes in the salvage operation. Some reasons for this are not easily solvable, such as the difficulty of predicting future prices, demand, and supply of timber. For instance, it became apparent late in the salvage operations that more wood could have been stored in earlier stages to take advantage of price increases later on.

Forest recovery efforts continued well beyond the time salvaging ended in June 1990. Although salvaging was a short-term effort, this does not diminish its importance; salvaging facilitated subsequent efforts to reduce the risk of wildfire and to promote reforestation. Salvaged forest land reduced the amount of fuel created by downed and damaged timber. Salvaging also was an important first step to prepare sites for artificial regeneration.

PART 2: WILDFIRE HAZARD REDUCTION AND MITIGATION

The 2.3 million acres of timber damaged by Hurricane Hugo in South Carolina caused a tremendous short-term salvage problem, and sparked major concerns about long-term fire hazards in the state. South Carolina boasts over 12 million acres of forestland. Hugo moderately or severely damaged more than 2.3 million of those acres, the largest timber blowdown area caused by a natural disaster in the United States. Massive amounts of fuel litter still remain on the ground (50% southern pine and 50% hardwoods), creating the potential for uncontrollable wildfire. Since less than 25% of the downed timber was salvaged, the remaining acres of twisted trees created a dramatic increase in the probability of catastrophic wildfires. The elevated fire risk will likely last for five to ten years after the disaster, until the crowns of regenerated stands shade the debris. At that point, the temperatures will decrease and the humidity will increase, allowing the downed timber to decompose more rapidly.

The Hurricane Hugo Wildfire Hazard Reduction and Mitigation Plan (Phase I and II), developed by a State and Federal Interagency Planning Team, outlined policies designed to address the fire danger. This part of the evaluation of the post-hugo forest recovery programs looks at the Wildfire Hazard Mitigation Program in two sections. The sections cover Phase I and Phase II of the program. For each we discuss: the coordination among the federal, state, and local efforts; organizational structure; sources of funding; program goals and the plan to fulfill these goals; and, the results of each Phase.

PART 2A: WILDFIRE HAZARD REDUCTION AND MITIGATION PLAN: PHASE I[30]

In response to the elevated threat of serious wildfire, a State and Federal Interagency Hazard Mitigation Team was formed to create a plan to reduce the

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[30] Information in this section based on:
1) Interagency Planning Team. Hurricane Hugo Wildfire Hazard Reduction and Mitigation Plan. November 1989.
2) Interagency Planning Team. Hurricane Hugo Wildfire Hazard Reduction and Mitigation Plan: Phase II. June 1990.
3) Progress reports for the Hurricane Hugo Wildfire Hazard Reduction and Mitigation Project. 3/20/90-6/15/92.

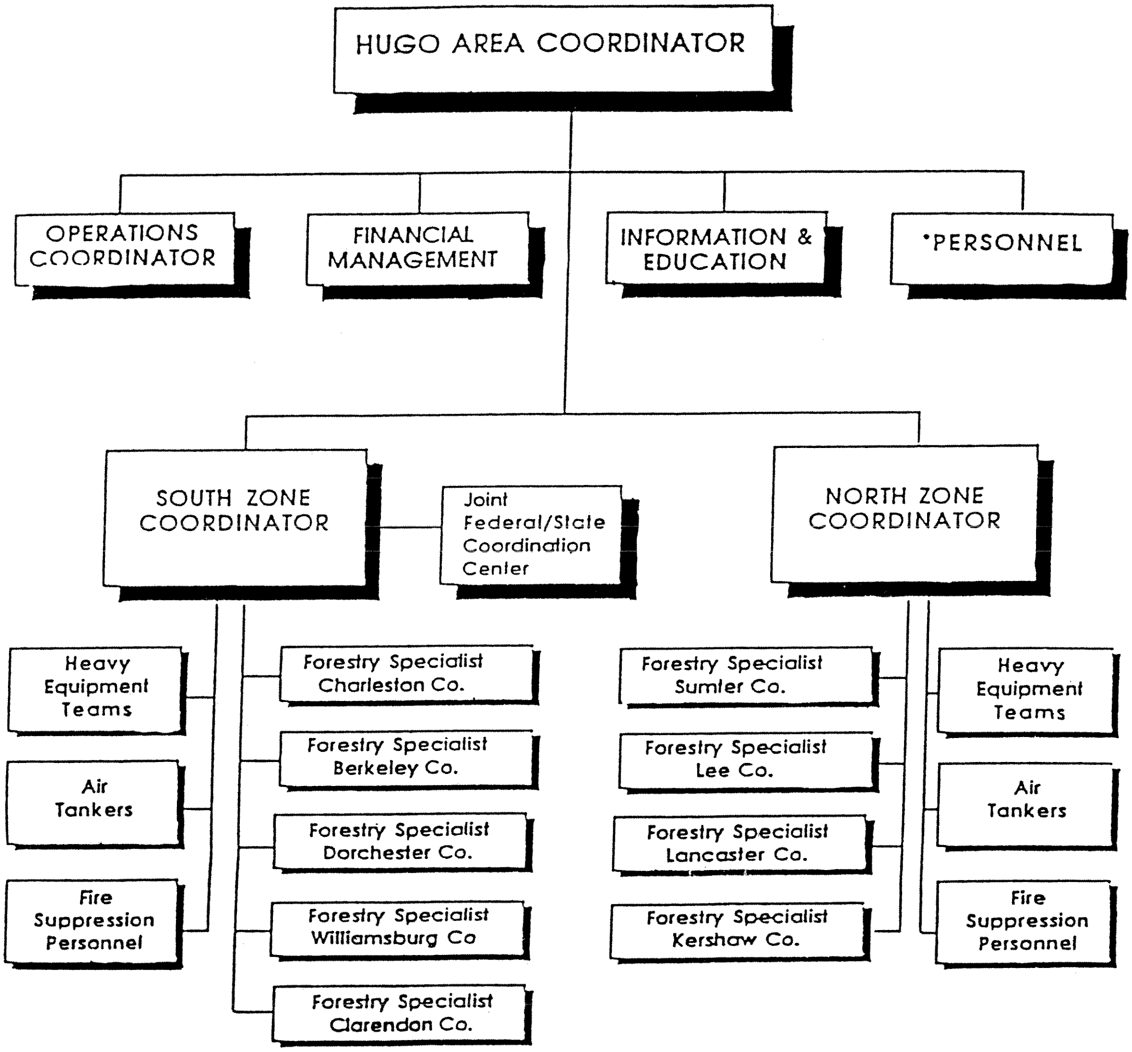

Figure 1--Organizational structure of personnel implementing the Wildfire Hazard Reduction and Mitigation Plan, Phase I. NOTE: * positions funded by South Carolina Forestry Commission.

danger. The Team consisted of representatives from the South Carolina Forestry Commission (SCFC), the Governor's Forest Disaster Salvage Council, the U.S. Forest Service (USFS), and the Federal Emergency Management Agency (FEMA). The group developed the Wildfire Hazard Reduction and Mitigation Plan, including goals for fuels management, fire suppression, fire prevention, and timber salvage. No current or former program existed in South Carolina or elsewhere to serve as a model. South Carolina's plan was the first state level, post-disaster fire mitigation program of its kind.

Federal and State Programs

The Plan integrated federal, state, and local resources and programs into a single comprehensive wildfire prevention and suppression program. **FEMA**, under the Stafford Act, is authorized to assist state and local governments by performing work and services to save lives and protect property. These services include debris removal from public and private property, clearance of roads, and warning the public of further risks and hazards. In addition, FEMA may provide grants to state and local governments to reduce the risk of future damage, to suppress wildfires that threaten severe destruction (that, by themselves, would constitute a major disaster), and to salvage timber, where the cost of salvage exceeds the payment received for the salvaged timber.

The **USDA Forest Service** administers two federal programs that were incorporated into the Hazard Mitigation Plan: the Rural Community Fire Protection Program (RCFPP) and the Rural Fire Prevention and Control Program (RFPCP). The Rural Community Fire Protection Program authorizes the Secretary of Agriculture to provide financial and technical assistance to State Foresters to organize, train, and equip fire departments in rural areas and in communities of less than 10,000 people. This program disburses approximately $3.5 million annually across the nation. South Carolina receives approximately $45,000 a year to assist 85 fire departments. The departments must match the federal grants with their own money and must use the funds to buy needed equipment including hoses, pumps, tools, tanks, safety clothing, breathing apparatus, etc. Because the Farmer's Home Administration provides loans for costly fire trucks and stations, the FEMA money may not be used toward those purchases.

The Rural Fire Prevention and Control Program provides money for state governments to secure and process fire, law enforcement, weather, smoke management, and prescribed fire information and data. In fiscal year 1989, RFPCP allocated $278,050 to the South Carolina Forestry Commission for those purposes. The information obtained was used to analyze and plan fire control activities. Fire weather, smoke management, and prescribed burn information was disseminated to the SCFC, Cooperators, and the general public to enhance prescribed burn programs throughout the state. In addition, RFPCP: reviews telecommunications system to provide better contact between the SCFC and the public; updates radio communications to enhance information flow during emergencies; revises and updates County Fire Organization and Fire Prevention Plans to improve coordinated efforts of all agencies involved in emergencies; and identifies high risk wildfire/urban interface areas to help develop protection plans.

At the state level, the South Carolina Forestry Commission oversees fire prevention, pre-suppression, and suppression of wildfires. In 1989, the agency operated with a budget of $19.4 million.

Structure

The organizational structure created to implement Phase 1 is diagramed in Figure 1. The Planning Team created an entire substructure, the Coordination Team, within the already-established structure of the SCFC. That is, the Hugo Coordinator (newly-created position) reported directly to the Assistant State Forester, Field Operations (established position) at the SCFC. The Hugo Coordinator was responsible for managing the entire FEMA-funded portion of the Plan. He and his staff operated out of a leased double-wide office trailer located at the SCFC Columbia office. The Coordinator headed a staff including an Operations Coordinator, a Financial Management Accountant, a Public Information Officer and Assistant, a Personnel Officer, two Zone Coordinators, and nine Forestry Specialists.

The Operations Coordinator reported directly to the Hugo Coordinator and was responsible for equipment leased from FEMA, monitoring salvage operations, contracting work authorized by FEMA, compiling costs, overseeing final inspections, receiving reports from the North Zone and South Zone Coordinators, and compiling those reports into monthly progress reports for FEMA.

The Financial Management Accountant was responsible for compiling all FEMA-approved costs, tracking costs, submitting requests and preparing vouchers for payments, and keeping files on all financial documents.

The State Public Information and Education Officer and assistant were funded by FEMA with any remaining balance covered by the state. They were responsible for the entire Information and Education program, including all press releases, public service announcements, press conferences, mailings, video tapes, and television and radio spots. In addition, the Officer was responsible for developing and implementing a massive outreach program for young children.

The State Personnel Office was funded by the State through SCFC; this office processed all necessary personnel activity. The remaining staff positions (zone coordinators and forestry specialists) were funded by FEMA. In addition, a joint State/Federal Coordinating Center was created to coordinate fire suppression activities by state and federal personnel in or near the Francis Marion National Forest; the center was staffed by members of the USFS and the SCFC.

Zone Coordinators and Forestry Specialists were responsible for identifying high wildfire risk areas for fuel hazard reduction projects, acquiring right of entry permission from landowners for Team projects, scheduling and supervising heavy dozer teams, identifying property lines, and administering contracts. In addition, they were supposed to speak to groups to promote fire prevention, work with schools, keep in contact with local media, inspect sites for fire threats, assist residents in reducing their fire hazards, schedule and coordinate prevention patrols, ensure personal contacts with residents in rural areas, and work with the Fire Prevention Council, the State Fire Marshall's Office, local fire departments, and state and county agencies.

Each Zone Coordinator and Forestry Specialist was given a FEMA-funded pickup truck with a 250 gallon slip-on tank and a radio. The South Zone Coordinator was in charge of activities in Charleston, Berkeley, Dorchester, Williamsburg, and Clarendon counties, and the North Zone Coordinator was responsible for Sumter, Lee, Lancaster, and Kershaw counties. The SCFC, under their own authority, provided part-time criminal investigators to investigate arson.

The USFS served as technical advisor to both SCFC and FEMA. The USFS conducted training programs for the forest specialists hired by SCFC to work in each of the nine blowdown counties. In addition, FMNF staff helped with public information. Staff went door to door to residents within the FMNF distributing fire prevention information. They helped with TV advertisements, posting road signs, and distributing t-shirts and hats. Finally, they constructed 250 miles of fire breaks in FMNF with FEMA funds.

Funding

Federal funding for Phase 1 came through two programs. In November, 1989, the Plan was submitted to the Federal Emergency Management Agency (FEMA) and subsequently approved with initial funding of $9.3 million over a nine month period ending September 30, 1990. FEMA funding was mandated through four separate sections of the Stafford Act: sections 403, 404, 420, and 421. These programs covered debris removal, road clearing, damage mitigation, wildfire suppression, and timber salvage for hazard mitigation. The Governor's Office assisted localities with the process to obtain FEMA funding, particularly through Section 404 of the Stafford Act. Section 404 was a new harzard mitigation grant program and the Governor's Office issued a report giving localities clear guidelines on how to complete an application for a hazard mitigation grant.[31] In an unrelated program, the Dire Emergency Supplemental Appropriations Act provided $500,000 for fire prevention;

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[31] Office of the Governor. "State Hazard Mitigation Grant Program: Applicant's Guide." undated publication.

this money was distributed to 117 fire departments in the Hugo area.

The Forest Service allocated $1.266 million in 1989-90 to fund fire prevention and mitigation activities. These funds were used primarily for buying equipment and carrying out operations.

Goal 1: Fuels Management

The fuels management section of the Plan attempted to reduce the risk of wildfires to life and property, with the following priority:

1) Towns, municipalities, and communities;
2) Individual homes;
3) Other structures [unspecified]; and
4) Control lines to reduce risk of catastrophic fire.

The goal was to be achieved by constructing fuel breaks in "risk areas," defined as "an area of heavy blowdown fuel accumulation which constitutes a threat or risk of wildland fire capable of destroying towns, municipalities and communities, residences, or other structures."[32] Fuels management risk areas were prioritized as follows:

1) Communities or areas with histories of high fire occurrence and heavy fuel accumulation near towns or communities;
2) Areas with heavy fuel accumulation that threaten homes or other structures; and
3) Areas with heavy accumulation to provide access and control lines, as in existing wood roads and old fuel breaks.

Other methods of fuels management were considered, including chipping, hand piling, and clearing 100- to 200-foot wide fuel breaks, but 10- to 20-foot wide fuel breaks were chosen as the most cost-effective way to prevent large-scale fires. Fire suppression guides advised that a fire line with 1 1/2 times the depth of the downed fuel would provide a sufficient control line. After Hugo, the fuel accumulation was five to ten feet deep, so 10- to 20-foot fuel breaks were considered an effective width. In addition, this method would not cause fuel cleared from the lines to accumulate into piles and windrows (providing more hazardous material for fires).

Fuel break construction proceeded under a 30/70 Management Plan. Thirty percent of fuel break miles were to be constructed with FEMA-leased heavy equipment. The remainder were to be built by private sector contractors. The 30% fuels management plan included a total of 3420 miles of fuel break construction (2300 miles in the South Zone and 1120 miles in the North Zone). The Team estimated that each unit (one heavy dozer and two men with chainsaws) could construct approximately two miles of fuel break per day, so 19 units could complete 38 miles a day, and 3420 miles in 90 days. The estimated cost for the initial 30% was over $2.9 million. Another 7,980 miles were to be contracted to private crews at an estimated cost to FEMA of $3.3 million.

Goal 2: Fire Suppression

The fire suppression section of the Plan attempted to:

1) Provide early detection and reporting of all fires;
2) Provide rapid initial attack with specialized equipment and increased manpower;
3) Provide intensified mop-up operations to prevent breakovers and reduce residual smoke; and
4) Provide management and logistical support for multiple fires of long durations.

The fire suppression general strategy set the following priorities:

1) Eliminate life hazards;
2) Protect structures and property;
3) Confine fire within existing fire breaks; and
4) Construct fire lines to minimize the size of the fire.

To manage the large area of backlogged fuel effectively, the Hugo area was divided into two smaller areas, the North Zone and the South Zone. Three operating bases within these zones were proposed: Camden (North Zone), Manning (South Zone), and Moncks Corner (South Zone.) Each zone was supplied with its own equipment and personnel. Equipment assignments included air tankers, detection aircraft, heavy equipment, water handling equipment, and staging areas for crews. The Plan called for

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[32] Interagency Planning Team. Hurricane Hugo Wildfire Hazard Reduction and Mitigation Plan. November 1989, p. 9.

adding two detection aircraft to the existing forces and increasing the number of flight hours of the aircraft in operation.

Fire prevention and suppression personnel in each zone were augmented by a task force, consisting of a Zone Coordinator and Forest Specialists. The Zone Coordinator managed resources to support existing county and district fire suppression operations. The Forest Specialists worked with the Zone Coordinator on public information (promoting the program, speaking to school groups, and working with the media) and fire prevention and suppression (inspect fire threats, assist local fire department in suppression, and assist residents in reducing fire threats).

The presence of the Forest Service in the South Zone made possible a special cooperative wildland fire suppression effort between the SCFC and the Francis Marion Dispatch Center. According to the Cooperative Fire Control Agreement, state resources would respond to fires on federal lands and federal resources would respond to fires on state land. District, state, county, and Forest offices were to maintain open communications channels; radios (and personnel, if necessary) were to be exchanged between the Kingstree and Marion offices.

Goal 3: Fire Prevention

The fire prevention campaign had two main purposes: 1) to advise the public of the danger to life and property from wildfire; and 2) to educate the public about the dangers of indiscriminant outdoor burning in Hugo-affected areas. Its short-term objective was to saturate every person five years and older with fire prevention messages by the end of January 1990. In the next year, the campaign wanted to sustain an awareness of the fire danger through reinforcement techniques. In the three to five years after the storm, the Public Information office wanted to encourage the responsible use of fire.

The Public Information Coordinators attempted to saturate people with the message of fire prevention using all media avenues. The cornerstone of this program was the GIMME 12 campaign. The objective and slogan of this campaign was "Gimme 12 months of fire safety". GIMME 12 was advertised in newspapers, on posters, through public service announcements, and on parade banners. Mayors were encouraged to make public proclamations endorsing the program; schools were given information packets on prevention and fire safety and were rewarded for fire prevention education efforts. GIMME 12 stickers and bumper stickers as well as stationary were distributed, and the campaign was advertised on roadside signs.

Additional information efforts included an initial 45-day campaign emphasizing the potential for wildfires, protection of homes and lives, and an "avoid burning" message. This shorter campaign coincided with the time of greatest chance for severe and dangerous forest fires predicted by local fire experts. Continual public information efforts also included weekly news releases to newspapers and public service announcements informing people in Hugo-affected areas of precautions, fire situations, alerts, burning bans, etc.

Results

The procurement of additional equipment and hiring and training of extra personnel proceeded as planned. All Forest Specialists were trained and assigned to the nine blowdown counties by mid January 1990. Two 1400-gallon scooper type air tankers were contracted for the fire season. Thirty temporary firefighters were employed, trained, and equipped to suppress fires. By March 1990, much of the fuels management and fire suppression equipment was or soon would be under lease. USFS detailers conducted fuel assessments of all Hugo counties from mid-December 1989 through March 1990. By October of 1990, crews with heavy dozers and chainsaws had constructed over 1800 miles of firebreaks around threatened homes and communities, and in national forests. Over 3000 landowners had been contacted regarding fuel break construction on their property, with a very high acceptance rate.[33] Most of the fire breaks were constructed to eliminate fire hazards and protect structures and property (priorities 1 and 2), while improving

[33] It is estimated that about 95% of all landowners that were contacted by SCFC for fire break construction granted permission (personal communication, SCFC personnel).

existing fire breaks (priority 3) only began in the later months of the program year.

During the first 5 months of the GIMME 12 campaign, over 300,000 households had been reached through direct mailings; radio and TV spots were broadcast; and t-shirts, baseball caps, painters caps and banners appeared throughout the Hugo area.

Spring fires were down by 40% compared to an average year, with only one occupied residence burned and no deaths. In the four-month period from 1 December 1989 to 15 March 1990, 693 fires burned 4,243 acres in the nine county Hugo area compared to the same period in the previous year during which 1,210 fires burned 6,943 acres. However, rainfall for the southern region of the state during these periods also differed. For instance, the city of Charleston in the '89 through '90 period saw a net precipitation surplus of 2.82 inches, while during the same period the previous year there was a precipitation deficit of 6.78 inches. In addition, Charleston's precipitation for September and October of 1989 was above normal by 9.57 inches, while September and October of 1988 was above normal by only 2.59 inches. Wet weather after Hugo helped reduce the risk of fire by causing the water table to rise and moistening soil.

Because of the perceived tremendous success of Phase I and the extended threat of wildfire, the Interagency Team developed a proposal for Phase II, a five-year continuation of fire prevention, detection, and suppression. However, before Phase II was approved, the Interagency Team requested a time extension of Phase I; it was approved through December 1990.

PART 2B: THE PLAN: PHASE II

The purpose of Phase II was to solicit additional funding and support from FEMA and the USFS to continue to implement the Hurricane Hugo Wildfire Hazard Reduction and Mitigation Plan over the next five years. Phase II built on the momentum of Phase I and set the goals of: 1) eliminating the threat of catastrophic wildland fires in the Hugo area; and 2) reducing the occurrence of wildland fire by at least 50% over the next five years.

Structure

Like the Phase I plan, Phase II outlined a personnel structure that worked within and supplemented the current SCFC structure. Phase II of the Plan proposed augmenting the SCFC staff by creating 75 new positions. Although some jobs were changed and/or responsibilities redefined, many of these positions were similar to those under Phase I. The fire management coordinator--analogous to the Hugo Coordinator under Phase I--oversaw the entire project. The fire management assistant, like the operation coordinator of Phase I, reported to the fire management coordinator and provided coordination at the district level. The documents and reports manager covered all the duties of the financial manager under Phase I. The writer/editor and the fire prevention coordinator continued the public education responsibilities of the Phase I plan's information and education specialist. And the Forest Specialists under Phase I were renamed Fire Hazard Mitigation Specialists under Phase II and assisted county rangers in fuels management, fire prevention, pre-suppression, and suppression activities.

In the field, personnel structure remained essentially the same as in the Phase I plan: 18 heavy dozer operators/crewmembers, 35 seasonal firefighters to assist county fire wardens, and two tanker base operators. The North and South zones still existed, although the southern operating bases changed from Manning and Moncks Corner to Kingstree and Walterboro. All of the proposed positions (with the exception of the fire prevention coordinator) were to be funded by FEMA.

Funding

In December 1990, FEMA gave partial approval to Phase II and eventually appropriated $3 million for the 1990-1991 program year. Each year, FEMA based continued funding upon an assessment of whether a fire emergency still exists. This assessment was positive in 1991 and 1992. A summary of FEMA's funding for the fire hazard mitigation program is shown below in Table 1:

In addition, USFS allocated another $1.4 million for Phase II, bringing their total contribution to $2.7

Table 1--Summary of FEMA funds for the Hurricane Hugo Wildfire Hazard Reduction and Mitigation Project 1989 - 1993.

Program Year	Funding Amount (in millions)
1989 - 1990	9.622
1990 - 1991	3.012
1991 - 1992	2.219
1992 - 1993	1.541

million. SCFC has contributed $4.327 million above and beyond the annual $11 million it spends to provide statewide forest fire protection. The State also provided $500,000 to purchase heavy truck tractors to replace ones leased from FEMA.

Goal 1: Fuels Management

To build on the success of the Phase I fuels management plan, Phase II set the goal of safely incorporating the use of prescribed fire in its effort to minimize the threat to life and property from wildfire. To achieve this goal, the Team planned to continue the construction of 20-foot wide fuel breaks, begin on-site inspections of prescribed burn operations to ensure safe and acceptable practices, and initiate a Burning Qualification Program to provide training in post-Hugo burning operations. Additionally, a Prescribed Burning Program was planned to reduce fuel loading, establish fuel breaks, and provide protective strips in high risk areas.

Goal 2: Fire Suppression

The Phase II fire suppression plan remained virtually the same as Phase I, focusing on protecting the lives and homes of the 750,000 people living in the Hugo blowdown area. The Phase II Plan pointed to the success of Phase I as proof that its rapid detection/quick suppression method worked well and needed to be continued.

Goal 3: Fire Prevention

The Phase II Fire Prevention Plan revolved around a public information and education program about the safe use of outdoor fire. An annual campaign, called Take 5, was planned for five years. Its primary emphasis varied from year to year to allow flexibility as fire hazard conditions changed. In addition, each year's campaign would have a primary message and a secondary message; the secondary message would become the next year's primary message to provide reinforcement and continuity. The campaign plan follows:

Year	Primary focus
1989-90	Avoid burning ("Gimme 12")
1990-91	Safe burning ("Take 5")
1991-92	Law Enforcement
1992-93	Hazard Reduction Burning
1993-94	Fireproofing Interface Homes
1994-95	Preserving Lifestyles

Through the 1992-1993 campaign year, the campaign used paid advertising. After that, the campaign relied solely on print media and public service announcements to reach its audience.

Results

Fuel break construction continued through June 1991, resulting in a total of 4500 miles cleared, involving 5500 landowners. A goal of 5000 miles by September 1991 was hampered by wet conditions in the winter 1990 - 1991 and spring 1991. Construction was prematurely stopped because of a greater need for equipment in fire suppression activities.

Like 1989-1990, the fire season of 1990-1991 was another below average year for wildfires. A total of 1,364 fires burned. The following year, however, had the worst wildfire occurrence since 1985. During 1991-1992, 2603 fires burned over 21,300 acres.

PART 2C: CONCLUSIONS

In the aftermath of Hurricane Hugo, the Interagency Hazard Mitigation Team faced a complex combination of circumstances. First, prior to 1989, Hugo had been the most destructive and devastating hurricane to hit the United States; response and recovery was bound to take longer than previous natural disasters merely because of the magnitude of the damages. State policymakers and forestry agency personnel worked creatively to ensure federal involvement in the wildfire hazard mitigation efforts. The organized response by the state's forestry agency and the Governor's office gave immediate attention to severity of the forest disaster and the need for a wildfire hazard mitigation plan to ensure safety and avoid compounding the disaster. State forestry officials lobbied for FEMA involvement, and the Governor's

Office issued guidleines offering a model for localities to follow when applying for FEMA funds through the new Hazard Mitigation Grant Program, Section 404 of the Stafford Act. As a result, FEMA's involvement in hazard mitigation was achieved by expanding the eligibility, funding, and revising the justifications[34] in the 1988 Robert T. Stafford Act. While FEMA anticipated post-Andrew efforts in Florida to last at least a year and was active in Mobile, Alabama for 9 months after Hurricane Frederick, FEMA has participated in South Carolina's fire prevention efforts ongoing for four years after Hugo. FEMA defined its continuing involvement not as recovery, but as emergency response, since the fire hazard threatens life and property. FEMA officials have decided that the fire hazard still persists and, consequently, have continued funding phase II of the fire hazard reduction and mitigation plan.[35]

The goals of the Wildfire Hazard Mitigation Program were well defined. Clear goals were essential to begin the program soon after the hurricane and to organize the numerous agencies taking part in this 24 county effort. In addition, by emphasizing fuels management and fire prevention, as well as fire suppression, the program clearly went beyond emergency response. The plan maximally utilized the expertise of the SCFC by placing the Coordination team within SCFC's organizational structure and explicitly outlining the responsibilities and priorities of all personnel to guide their work. This aided in accountability and communication among all agencies and personnel involved.

A multilevel approach to wildfire hazard reduction was found to be most successful by dividing the Hugo damaged area into zones and coordinating some activities at the zone level and others at the state level. Zone coordinators directed the technical and monitoring components of the strategy, using the priorities and guidelines for fuel break construction developed at the state level. The fire prevention education program was directed at the state level.

Wildfire hazard mitigation was a multi-year program and required sustained coordination of efforts across levels of governance. The plan effectively pulled together and utilized a number of pre-existing programs at the federal, state, and local levels. Each program and level of government provided their own particular expertise or essential resources: funding came from FEMA, primarily, as well as the USFS and the SCFC; equipment was procured through FEMA to supplement local stations; and personnel came from SCFC, the Forest Service, or were hired and trained by these agencies.

Throughout Phase I and Phase II of the plan, the sequence and timing of efforts to achieve each of the goals was crucially important. Fuels management required initial emphasis on constructing fuel breaks on lands prioritized according to level of risk. Fire suppression required that localities throughout the blowdown areas were assigned sufficient equipment and personnel. Finally, fire prevention initially required a large-scale campaign to inform residents about the fire hazard and urge them to avoid burning. Dealing first with these initial high priority issues eventually allowed many aspects of the program to move to a maintenance mode in Phase II.

As with every other aspect of the disaster response, the wildfire hazard mitigation efforts were greatly affected by chance factors. The fire hazard created by the blowdown of so much timber was in part regulated by factors exogenous to and superseding most state and federal responses (i.e. tree growth rates and weather). Weather significantly affected the success with which many of the program goals were met. While heavy rains in 1989 kept fuels and soils moist, it slowed fuel break construction in many areas. Lower than average fire occurrence in two fire seasons (1989-1990 and 1991-1992) was followed by above average number of fires in 1991-1992 once there was a net rain deficit. Wildfire hazard mitigation programs need to consider how exogenous weather factors might affect the success of the policy response.

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[34] John M. Ols, Jr. 1990. "Preliminary Information on the Federal Government's Response to Recent Natural Disasters." Testimony given to the Subcommittee on Investigations and Oversight on the Federal Emergency Management Agency's Response to Natural Disasters. May 1, 1990.

[35] FEMA Region IV official, personal communication. November 1992.

PART 3: REFORESTATION

When Hurricane Hugo struck on September 21, 1989, it leveled over $1 billion worth of forest resources in South Carolina. The South Carolina Forestry Commission (SCFC) estimated that more than one million acres of damaged land needed reforestation; approximately 679,000 of those acres were on private lands. The Hugo Reforestation Committee, a group representing all facets of the forest sector, formed to address the reforestation needs of non-industrial private forest (NIPF) landowners. Since then, $11 million of federal funds have been disbursed through the South Carolina Forestry Commission to help South Carolina landowners reforest. The funds have supported "Gimme Green" (a free needs assessment) and the Hugo Incentive Program (a cost share agreement for reforestation).

The South Carolina case provides an example of how state and federal agencies formulated forestry assistance policy in the face of emergency conditions. The challenges to these agencies were: (1) to effectively provide reforestation information to the thousands of landowners with devastated forest land; and (2) to insure an equitable distribution of reforestation aid. An analysis of each program's results provides lessons to other states on how to target assistance programs to NIPF landowners.

PART 3A: THE REFORESTATION COMMITTEE

On December 14, 1989, less than three months after Hugo hit South Carolina, the Hugo Reforestation Committee formed to consider reforestation plans for 679,000 acres of NIPF land. The committee represented all areas of the forest sector, including consulting foresters, forest industry, landowners, the South Carolina Forestry Association (SCFA), the South Carolina Wildlife Federation, the South Carolina Forestry Commission (SCFC), Clemson University Extension Service, the U.S. Forest Service (USFS), and South Carolina Wildlife and Marine Resources.

The primary concerns of the Reforestation Committee were as follows:[36]

(1) To create a "Forest Rehabilitation Vision" to consider the necessary state, industry, local, and individual effort needed to rehabilitate SC's forest lands;
(2) To consider the impact of various financial scenarios on what the forest in the disaster area would look like in 10 or 20 years;
(3) To inform legislators about reforestation progress and the need for and timing of future funds; and
(4) To prepare a plan to assure that the South Carolina resource would be restored and ultimately surpass the current forest growth capacity while maintaining a good balance of forest types, age classes, and habitats.

Joe Mills (SCFC) chaired the Committee and Steve Scott (SCFC) served as its Executive Director. The Committee split into three subcommittees, and Mills appointed chairpersons for each: Public Education/Information, chaired by George Kessler (Clemson University Extension Service); Technical Assistance, co-chaired by Pete Bischoff (SCFC) and Jeff Baumann (SCFC); and Reforestation Promotion, chaired by Alan Alexander (SCFC).

The Public Education/Information Subcommittee was responsible for: educating and training foresters and landowners about reforestation; producing educational and training materials and technical publications; conducting landowner meetings, opinion surveys, interviews, and demonstrations; and issuing news releases.

The Technical Assistance Subcommittee was charged with: providing technical assistance to landowners; developing and assisting with regeneration techniques and equipment; training site preparation and tree planting vendors; assuring seed availability; conducting mapping, surveying, and photography; and providing herbicide information to landowners. Before assessments of reforestation needs had been completed, the technical assistance subcommittee was divided into an artificial regeneration section and a natural regeneration section. Once work in the field began, however, this division of duties and expertise became impractical; most landowners found they could not rely exclusively on either natural or artificial regeneration and needed technical assistance on both procedures.

[36] **Governor's Forest Disaster Salvage** Council Newsletter. 2 January 1990.

The Reforestation Promotion Subcommittee was supposed to create and implement a promotional campaign for the reforestation effort, and produce and distribute public service announcements, television and radio spots, print advertisements, and promotional literature.

Two weeks after its initial meeting, the Reforestation Committee proposed offering every private landowner in the Hugo area a free reforestation needs-check in the fall. Though there was no money available at that time, the group decided the needs-checks were necessary for the Committee to understand fully the extent of the problem. The Committee planned to use volunteers for all parts of its plan until Dire Emergency Funds were appropriated for technical assistance in July 1990. Once the money was approved and designated to be disbursed through the South Carolina Forestry Commission (SCFC), the Committee was used strictly in an advisory capacity. The SCFC solicited input from the Committee, but SCFC had final responsibility for the use of the money. Because the Chair, Executive Director, and Subcommittee heads were all SCFC employees, the transition from Committee responsibility to Commission responsibility was smooth.

Funding--Dire Emergency Funds

The Dire Emergency Funds were the first funds made available in South Carolina to the forest sector. Because of the efforts of South Carolina Senators Hollings and Thurmond, the USFS, and the President, Congress allocated $5 million over a three-year period to SCFC for NIPF technical assistance. The money, appropriated through the Dire Emergency Supplemental Appropriations Act, was used to fund the Committee's reforestation plan, which included the GIMME GREEN program and a landowner survey. It provided funds to hire additional foresters and consulting foresters for site check inspections, obtain equipment for county foresters, provide travel support for foresters, promote the inspection through the Clemson Extension Service, train area foresters, and provide herbicides for timber stand improvement activities on NIPF land.

Landowner Survey

In September, Clemson Extension Service conducted a landowner survey for the Reforestation Committee. The primary objective of the survey was to ask NIPF landowners "What do you need to enable you to restore your land to a forested condition?"[37] A series of questions addressed:

(1) the damages NIPF landowners suffered to their land, other private property, and quality of life;
(2) forest management actions they had taken so far;
(3) forest management actions they were planning for the future;
(4) what they required to carry out those plans; and
(5) any change in attitude towards their forest land.

The answers to the survey revealed several important points. First, in excess of 60% of landowners had already conducted either reforestation (natural or artificial) or harvesting (thinning or final harvest) activities on their land previous to Hugo. More than half the landowners had made contact with a forester since Hugo, indicating interest in maintaining their land in forest. However, the survey also revealed that many landowners changed their attitude towards their lands. Timber production became less of a priority. Landowners were less willing to make the potentially high forest management investment required now for what was perceived as an even more uncertain future outcome. While assistance programs, such as cost-sharing or reforestation tax incentives, could help alleviate some of these worries, a relatively small number of NIPF landowners used them or even knew of the programs.[38]

Gimme Green

In the first weeks of July 1990, the Committee's proposed reforestation needs-check, "GIMME GREEN," started; direct mail, billboards, and advertisements on radio, television, and in newspapers were used to alert landowners to the free check-up. The SCFC also set up a toll free number that landowners could use to make requests.

In October, the SCFC, the USFS, and Clemson Extension Service jointly

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[37] Stephen K. Nodine. 1992. Forest Landowners' Responses to Hurricane Hugo. Forest Research Series No. 47. Department of Forest Resources, Clemson University.
[38] Ibid.

trained public, private, and industry foresters on reforestation methods. By November, the Commission had started requesting proposals from private consulting firms to provide technical assistance to landowners through GIMME GREEN. Thirty firms submitted proposals. By February 1991, SCFC had contracts with 29 consulting firms.

The GIMME GREEN program emphasized natural regeneration. The SCFC and Clemson Extension Service advocated natural regeneration for several reasons. First, it was biologically viable. 1989 had been a good seed year, and seedlings had just gotten started when Hugo struck.[39] Post-Hugo conditions, especially the more open conditions on salvaged land, were ideal for pine regeneration. Second, though cost-share funds were available, they could not meet the demand for subsidized reforestation. Natural regeneration represented a low-cost method that saved funds for those stands absolutely requiring artificial regeneration. Finally, the SCFC wanted to give landowners positive news (e.g. "your land is well-stocked" or "you need to use minimal inputs to restore your forest") rather than add to the landowners' sense of loss.[40] In brochures advertising the program, the SCFC and Clemson Extension Service advised landowners to "wait for natural regeneration" and only consider artificial regeneration if the chances for natural regeneration looked unlikely.[41] They also advised that any salvaging of damaged land should avoid taking live trees.

During the request period from 15 October 1990 through 1 January 1991, 1072 landowners signed up for the free reforestation needs-check, representing approximately 309,000 acres. State foresters and consulting foresters hired by SCFC conducted the site check-ups. While these landowners constituted only a small proportion of the estimated 37,000 private landowners whose timberland was damaged by Hugo,[42] their combined acreage represented just under half the total number of private acres estimated by the SCFC to need reforestation. Predominantly landowners with large landholdings participated; the average tract size was 288 acres. By April 1992, foresters had serviced over 960 requests covering 223,000 acres. Most of the acres were in pine (84%). Foresters conducting the site checks determined that: artificial regeneration was needed on 23% of the sites; natural regeneration could be used on 21% of the sites; and 54% were adequately stocked.[43]

Hugo Incentive Program (HIP)

In January 1991, less than one month after the check-ups began, Congress appropriated another $3 million of emergency reforestation money. With support from Senator Hollings, Senator Thurmond, the President, and lobbying by the USFS, the proposed funds were included in a provision in the Interior Appropriation Bill for the U.S. Forest Service. The allocation provided cost-share funds for reforestation to be administered through the SCFC. The Hugo Incentive Program (HIP) is the only federally-funded landowner assistance program in the country being completely administered by a state agency.

Landowners in the 24-county disaster area with forest stands damaged 35% or more and in need of artificial reforestation could apply for HIP cost-share funds. GIMME GREEN field foresters determined landowner reforestation needs. HIP did not place landowner acreage ownership limitations, but corporations with over $5 million annual gross income did not qualify. 75% cost-share would be provided, based on the average cost for the prescribed methods of reforestation. Compared to the Forestry Incentives Program (FIP), HIP reduced the amount contributed by the landowner from 50% to 25%. Originally, a cap was set at $25,000 per landowner. Due to the unexpected number of applications, the cap was lowered to $10,000 per landowner.

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39 SCFC personnel, personal communication, November 1992.
40 SCFC personnel, personal communication, November 1992.
41 Brochure entitled "Step Two--Restoring the Forest After Hurricane Hugo," July 1990.
42 South Carolina Forestry Association pamphlet: "The Facts About Hurricane Hugo and Forestry in South Carolina." undated.
43 Allan P. Marsinko, Thomas J. Straka, and Jeffrey L. Baumann. 1993. "Hurricane Hugo's Effect on South Carolina: The Impact After Three Years," Journal of Forestry, September 1993, p. 9-17.

The initial signup period was March 11-22, 1991. 1,017 people submitted 1096 applications. Servicing those applications with the $25,000 cap would have required approximately $16 million--much more than the $3 million originally allocated. Some applicants did not qualify for assistance either because their land did not have sufficient damage or because they could not afford to pay their 25% share of the cost-share.

Generally, HIP participants received three visits from a field forester. The first was the initial needs-check to make sure the applicant qualified and to decide which methods of reforestation should be used. When natural regeneration was not an option, foresters recommended the lowest cost artificial regeneration method available. On the second visit, the project forester checked the land to make sure it had been prepared for planting properly. If the land met specifications, the landowner could receive partial payment. On the third visit, the forester checked the planted trees. At that point, the landowner received the remainder of the cost-share payment. HIP provided no up-front payments; that is, the landowner initially paid for the work, and when the work was completed, the landowner was reimbursed. In most instances, landowners received cost-share assistance for 100 acres or less. Most landowners were able to use a combination of natural regeneration and artificial regeneration on their lands.

In April 1992, another official signup period was held.[44] SCFC received another 160 applications. The SCFC estimated that it would be able to fund most of the applicants because some already-approved applicants had not reforested as much land as they had planned, leaving some surplus funds. By June 1992, approximately 1000 landowners had been assisted. Cost-share assistance covered work on 31,000 acres with landowners, on average, receiving assistance to reforest 31 acres.[45]

Congress appropriated another $3 million for this program in the 1991-92 budget, bringing the total federal contribution to $11 million. This money should allow SCFC to provide assistance to all landowners who qualified, using the $10,000 cap.

PART 3B: CONCLUSIONS

The success of the reforestation effort in South Carolina can be evaluated on the basis of several measures. One measure is the numbers of acres reforested. The Reforestation Committee and SCFC's management objective was to encourage reforestation and growth in order to restore South Carolina's forested land to its pre-Hugo condition. The extent of reforestation efforts on Hugo-damaged timberland may not be reflected fully in the (relatively low) rates of participation in either the GIMME GREEN campaign or HIP.[46] The foresters performing GIMME GREEN site checks emphasized natural regeneration whenever it was a viable option, and, in general, HIP only funded artificial regeneration. Consequently, the 31,000 acres of cost-share funded reforestation greatly underestimates the total reforestation activity (natural and artificial) in the Hugo affected area. Educational efforts of the Reforestation Committee and SCFC designed to teach NIPF landowners successful natural regeneration techniques may have greatly enhanced the forest recovery process.

Another measure of the effectiveness of the reforestation effort is the number of landowners participating in either GIMME GREEN or HIP. This measure allows policy makers to evaluate the success of forestry assistance policy in disbursing forestry assistance equitably across landowners. Many industry and state personnel have commented that the majority of landowners participating in GIMME GREEN and HIP had previously participated in forestry assistance programs, or were part of a cooperative forest management agreement with industry, or had an established relationship with a forester. According to this line of reason, landowners who were unfamiliar with forestry assistance or who had no

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[44] The terminology here is a bit confusing. Signups were never actually closed; "official" signups were simply publicized more.
[45] SCFC personnel, personal communication, November 1992.
[46] There was a great deal of overlap in landowner participation in Gimme Green and HIP. Thus, enrollment in both programs may only account for 5% of over 40,000 NIPF landowners in the Hugo area. (Clemson University personnel, personal communication, December 1992).

relationship or association with a forester were helped much less often.

Active forest managers generally made several forestry management decisions prior to Hugo that facilitated their participation in HIP. Prior to Hugo, these landowners were more likely to have: (1) obtained forestry advice from a consulting or industry forester; (2) reforested their lands by artificial means; and (3) kept undergrowth to a minimum through prescribed burning. As a result, after Hugo, these landowners were more likely to readily make contact with a logger (because of their previous connection to forestry organizations) and to have successful salvage on at least some of their damaged timberland.[47] In turn, salvaged timberland made artificial regeneration less costly (due to less site preparation) and more successful. In contrast, landowners who had no established relationship with a forester were at a disadvantage when competing for scarce salvage loggers and quickly allocated forestry assistance funds. Even if they were interested, these landowners may have found Hugo assistance programs difficult to pursue.

Landowners also differ in their land management objectives. Active forest managers tend to: (1) place greater value on timber production; and (2) invest in more intensive reforestation and management practices (site prep costs after Hugo approached $250/acre[48]) over the short term. Other landowners: (1) may place more value on non-forest benefits; and (2) may have less intensive forest management plans. Landowners characterized by the second group of objectives may have participated less often in the assistance programs for at least three reasons. First, they may have intended to use natural regeneration from the beginning and decided that applying for HIP assistance was not worth the time. Second, landowners interested in natural regeneration may not feel the need for forestry advice. Third, these landowners may have gotten sufficient information about regeneration techniques through alternative sources, such as pamphlets, news programs, and magazines.

Landowners who place greater value on nontimber outputs engaged in passive natural regeneration at the very least, but also may have decided to more actively reforest at a later date (after taking care of other, perhaps more pressing, losses) or participated in other incentive programs. In particular, the Forest Stewardship Program (FSP) and the Stewardship Incentive Program (SIP) emphasize management for multiple resources. Through FSP, landowners can obtain help to write a formal stewardship management plan. SIP, which began in May 1992, provides cost-share assistance for implementing the plan. Both programs enable landowners to address, in addition to timber management, management of fish and wildlife habitat, recreation, and soil and water quality. Because of this multiple resource management emphasis, both programs may be attracting NIPF landowners who did not want to take advantage of Gimme Green or HIP.

In South Carolina, over 550 landowners have requested help in developing a stewardship management plan (see Table 1). Throughout the South, 75% of the landowners participating in FSP are, for the first time, managing their land under a written plan. Many of these landowners, throughout the South and in South Carolina, may be participating in an assistance program for the first time.

Table 1--Summary of the Forest Stewardship Plan Requests by District.

District	Number of Requests	Acres
Camden	114	49,077
Florence	33	8,322
Kingstree	86	40,510
Newberry	110	25,305
Orangeburg	91	34,842
Spartanburg	66	18,969
Walterboro	54	32,018
TOTALS	554	209,043

[47] Salvage was generally more successful and easier on lands managed with prescribed burning because the undergrowth was scarce and did not contribute to the difficulty of logging fallen and twisted trees (industry personnel, personal communication, November 1992).
[48] South Carolina Forestry Commission personnel, interview, May 1992.

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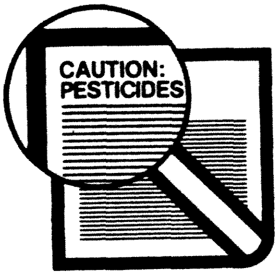

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This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

Haymond, Jacqueline L.; Harms, William R., eds. 1996. Hurricane Hugo: South Carolina forest land research and management related to the storm. Gen. Tech. Rep. SRS-5. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 540 p.

This compilation includes 69 published and previously unpublished articles relating to the effects of Hurricane Hugo, a Category 4 storm, on forests primarily in South Carolina. The articles record the response of the forests to the storm and the activities of those who care for these forests. Broad topics include historical background, damage assessment, forest restoration, and evaluation of recovery programs.