

Impact of Hurricane Hugo on the South Carolina Coastal Plain Forest

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ABSTRACT



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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.

ADDITIONAL INDEX WORDS: *Wind resistance, wind damage, salt damage.*

INTRODUCTION

Hurricane Hugo came ashore across Sullivan's Island, South Carolina, at midnight EDT, 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 wide¹. 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 downgraded 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)²) 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 Carolina during the 20-year peak exploitation period 1909-1929, was approximately 30.8 million m^3 (6.4 billion bf)³. As of this writing, intensive efforts

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¹Powell, M.D.; Dodge, P., and Black, M., 1990. The landfall of Hurricane Hugo in the Carolinas. In preparation for Weather and Forecasting.

²A board foot (bf) is equivalent to a plank 1 inch thick and 12 inches square.

³Reference to timber harvest of 1909-1929.

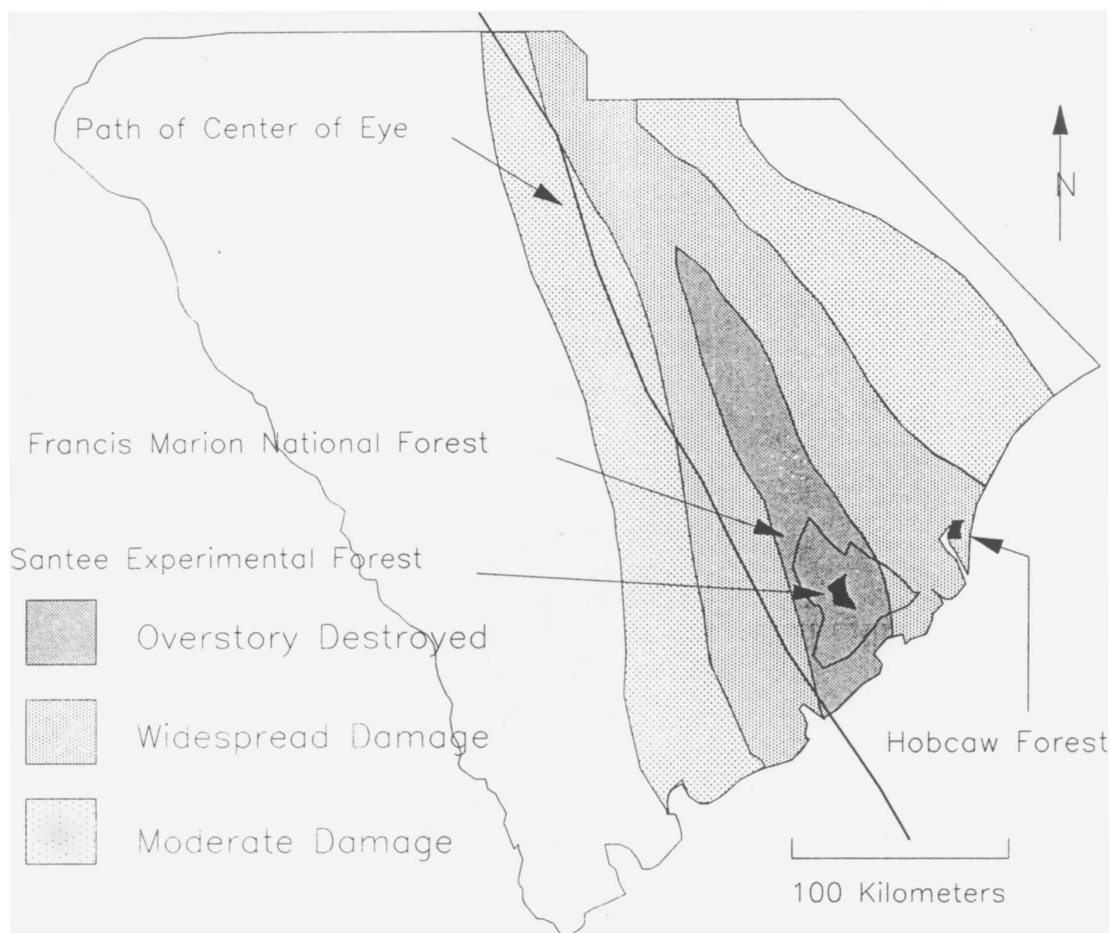


Figure 1. Map of South Carolina showing the path of Hurricane Hugo, the area impacted by it, and the locations of the Santee Experimental Forest and the Hobcaw Forest.

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 rainbands⁴.

⁴Powell, et al. *The landfall of Hurricane Hugo in the Carolinas*.

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 FMNF⁵. Hobcaw Forest (Hobcaw) is approximately 90 km northeast of Charleston, near Georgetown, SC, positioned

⁵The 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.

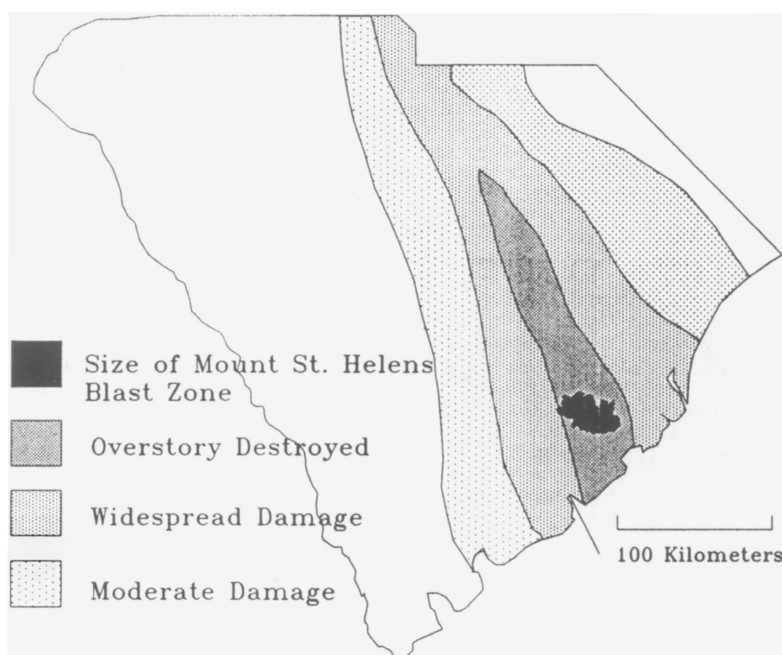


Figure 2. (a) Map of South Carolina showing the area impacted by Hurricane Hugo with the area impacted by the eruption of Mount St. Helens superimposed.

along the coast and immediately to the west of the North Inlet salt marsh (Figure 1)⁶. 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.

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 evi-

dence 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 D. 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).

⁶The 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.

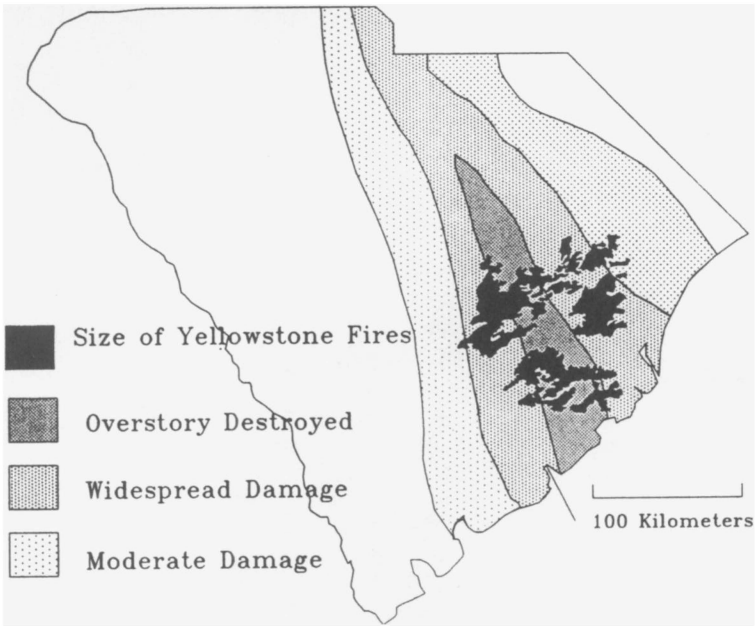


Figure 2. (b) Map of South Carolina showing the area impacted by Hurricane Hugo with the area impacted by the 1988 Yellowstone fires superimposed.

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,

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

Forest Type	Area (ha)	
	Santee Experimental Forest	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

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.

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 m³ (15,000 bf/acre). Current estimates are that less than 24 m³/ha (2000 bf/acre) were left standing after the storm (Photo A1). 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 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, 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



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 $\geq 45^\circ$	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

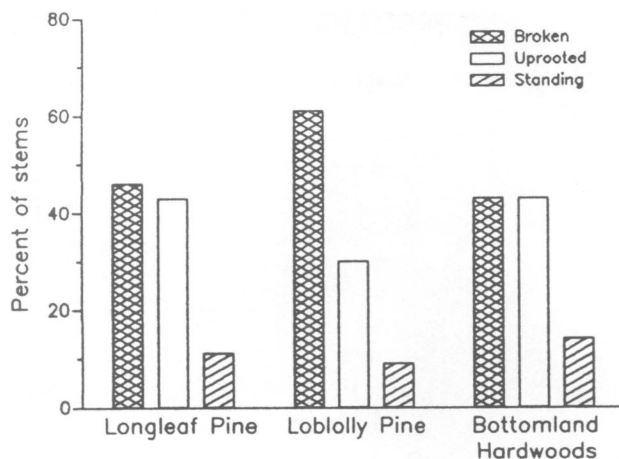
^aCherrybark oak and Shumard oak.

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.

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



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.

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 m³ (26.1 million bf) of pine sawtimber and 35,900 m³ (18,000 cords) of pulpwood based on a 1986 inventory. Hardwood stands occur on 489 ha and contained 15,000 m³ (3.1 million bf) of hardwood sawtimber and 31,500 m³ (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 m³ (3.9 million bf) of pine sawtimber (10.9%), 1365 m³ (684 cords) of pine pulpwood (4.5%), 4650 m³ (912 thousand bf) of hardwood sawtimber (25.9%), and 15,130 m³

(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 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 m²/ha (40 to 80 ft²/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 bottom-land 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 wind-blown 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 m³ (4.6 million bf) of pine sawtimber (13%), 11,400 m³ (5700 cords) of pine pulpwood (33%), 1050 m³ (226 thousand bf) of hardwood sawtimber (6.4%) and 4200 m³ (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 infiltra-

tion 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/ha⁷, 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 area⁸. Attacks of these insects are

⁷South Carolina Forestry Commission. Hurricane Hugo Update. April, 1990.

⁸Barry, Patrick J. Trip report on bark beetle and other pest 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.

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

^aTrip report on bark beetle and other pest activity in Hugo damaged timber, Francis Marion Nation Forest, South Carolina. Patrick J. Barry, State and Private Forestry. May 18, 1990.

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.

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