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

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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 Hole 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 et al. 1991, Whigham et al. 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.

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 et al. 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 & 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 et al. 1990). Rainfall associated with the hurricane was 4-5 inches (Purvis et al. 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

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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 Hole 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 Hole 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 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.

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.

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.

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					Mortality				
			Total	Break	Uprooted	Branches	Bent	Total	Break	Uprooted	Branches	Bent
Water Oak, *Quercus nigra*	47	25	44	17	21	3	3	22	7	15	0	0
Spruce Pine, *Pinus glabra*	43	4	40	31	9	0	0	39	30	9	0	0
Pignut Hickory, *Carya glabra*	26	16	19	10	7	0	2	10	4	5	0	1
Swamp Chestnut Oak, *Quercus michauxii*	24	11	17	4	7	5	1	13	3	7	3	0
American hornbeam, *Carpinus caroliniana*	47	27	31	12	13	5	1	20	7	8	4	1
Elm (American or Winged), *Ulmus* sp.	62	50	41	15	12	11	3	12	5	4	2	1
Sweetgum, *Liquidambar styraciflua*	115	97	63	28	10	22	3	18[2]	7	9	1	0
Red Maple, *Acer rubrum*	65	60	50	18	18	11	3	5	1	4	0	0
Laurel Oak, *Quercus laurifolia*	214	141	141	51	39	30	21	73	35	36	1	1
Ash (all sp. but water ash), *Fraxinus* sp.	70	54	44	25	14	5	0	16[2]	4	11	0	0
Blackgum, *Nyssa sylvatica* var. *biflora*	94	91	43	29	0	11	3	3	3	0	0	0
Baldcypress, *Taxodium distichum*	136	122	63	29	2	32	0	14	12	1	1	0
Water Tupelo, *Nyssa aquatica*	215	212	100	78	1	17	4	3	2	1	0	0
Carolina Ash, *Fraxinus caroliniana*	15	14	5	5	0	0	0	1	1	0	0	0
TOTAL for Dominant Species Only	1,173	924	701	352	153	152	44	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.

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 pre-hurricane 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 Hole 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 Hole Swamp.

Gresham et al. (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 effected were quite similar in our respective studies. They reported that baldcypress, water tupelo, and blackgum were the least effected species, and that pond pine (*Pinus serotina* Michx.), possibly comparable to spruce pine at Four Hole Swamp, and water and laurel oaks were by far the most effected species. They did note that several other upland species, including 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 effected species, suggesting that vulnerability to hurricane impacts is related more to species than generic composition.

Whigham et al. (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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