CHAPTER 8

SELECTING SOUTHEASTERN COASTAL PLAIN TREE SPECIES FOR WIND RESISTANCE

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Introduction

Wind damage to urban trees increases with storm intensity, but not all tree species withstand high winds the same way, making some trees better choices than others for including in coastal landscapes. A team of scientists at the University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS) has been tracking and studying major hurricanes since Hurricane Andrew in 1992 to determine their effect on the urban forest. One of the major goals of this study is to assemble lists of relative wind resistance for different urban tree species. These lists can assist communities to better prepare for future hurricane seasons and to rebuild a healthy urban forest by selecting proper species. This fact sheet presents the research and methodology that lead to these lists of relative wind resistance. It also discusses in detail the results and additional recommendations for selecting and establishing trees for a healthier and more wind-resistant urban forest.

Contents

I. The Study

In 2004, four hurricanes struck Florida with maximum sustained winds ranging from 169 to 233 km/h (105 to 145 mph). In 2005, Hurricane Dennis struck the Florida panhandle at 193 km/h (120 mph). The impacts of these five hurricanes were widespread. They affected urban areas, agricultural croplands and Florida's natural ecosystems (Duryea *et al*. 2007). Since 1992 when Hurricane Andrew struck south Florida, we have been studying the impacts of hurricanes on the urban forest (Duryea *et al*. 1996). We continued with measurements of hurricane wind damage to urban neighborhoods again in 1995 when two hurricanes struck the Pensacola area (Duryea 1997) and then again in 1998 when Hurricane Georges crossed over the entire island of Puerto Rico. These nine hurricanes with their varied wind speeds gave us the opportunity to study over eighty tree species and their comparable responses to hurricanes. This study reports on the relative wind resistance of southeastern coastal plain species in urban forests (including hardiness zones 8 and 9).

II. Methods

Urban Tree Damage Measurements

Urban tree damage was measured within three to six days following each hurricane that struck the Florida panhandle: Erin, Opal, Ivan and Dennis (Figure 1). We also report the hurricane response of coastal plain species such as live oak (*Quercus virginiana*) and sabal palm (*Sabal palmetto*) that occur throughout Florida and were impacted by Hurricanes Andrew, Charley, Frances, and Jeanne. Hurricane Andrew results were collected in a survey of 128 homeowners in Dade County, Florida who reported the impacts of the hurricane on trees in their yards (Duryea *et al*. 1996). The methodology for the other eight hurricanes was the same and was as follows. Neighborhoods at the point of landfall of the hurricane were randomly chosen on the strong side of the storm. For each neighborhood, all trees in front yards were observed along street transects. (If invited, we also measured trees in backyards.) Overall we sampled 100 neighborhoods and 18,200 trees. Each tree's diameter at breast height (for dicots and conifers) or height (for palms) was measured (estimated for height) and then it was determined if the tree was standing, leaning or had fallen. Leaning trees were those that were leaning as a result of the storm at less than a 45 degree angle. Fallen trees were either broken at the main stem or lying on the ground. All fallen trees were assessed as either broken or uprooted. Percent survival was calculated for each species using trees that were standing after the hurricane (Trees were considered not surviving if they had fallen or if they were leaning at less than a 45 degree angle.)

Crowns of all standing trees were first assessed for percent branch loss and then for leaf loss from the hurricane. For palms, only percent leaf loss was assessed. Then for dicots and conifers, if a tree had 50% or greater branch loss from the hurricane, it was declared dead and a new second survival percentage was calculated. This is called the "recalculated survival" throughout this document.

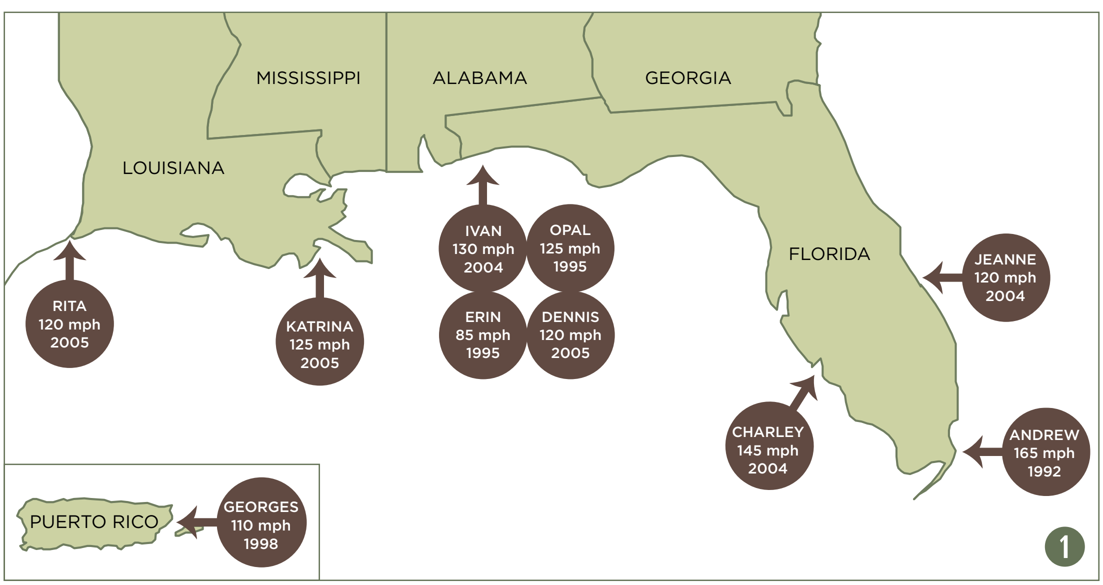


Figure 1

Urban trees were measured following hurricanes striking Florida, the Gulf Coast, and Puerto Rico. For each hurricane, the arrow points to the location of landfall. The maximum sustained wind speed (mph) and year are included.

The Survey

After four hurricanes struck Florida in 2004, we concluded that urban forest professionals in the state were a resource of knowledge about wind resistance. In June 2005, we sent out 240 surveys to arborists, urban foresters, and forest scientists who were members of the International Society of Arboriculture (Florida chapter) or the Florida Urban Forestry Council or who were faculty at the University of Florida. We asked them to rank the wind resistance (high, medium or low) of those urban tree species they observed after hurricanes. Eighty-five (85) surveys (35%) were returned. We report these numbers and percentages in this publication and then use these ratings along with our measurements and analyses and the scientific literature to formulate wind resistance lists for tree species in urban areas.

III. Results

Tree Survival and Branch Loss

Tree species in the Southeastern Coastal Plain respond differently to hurricanes. Response of species to Hurricane Ivan in 2004 illustrates differences at 209 km/h (130 mph) wind speeds (Figure 2). Tree species demonstrating the highest survival in these winds were sand live oak (*Quercus geminata*), American holly (*Ilex opaca*), southern magnolia (*Magnolia grandiflora*), live oak, wax myrtle (*Myrica cerifera*), sweet gum (*Liquidambar styraciflua*), crape myrtle (*Lagerstroemia indica*), dogwood (*Cornus florida*) and sabal palm. Dogwood, live oak, sabal palm, sand live oak and southern magnolia were also the best survivors in Hurricanes Erin and Opal in 1995 (Duryea 1997).

A more detailed look at live oak and sabal palm demonstrates their repeated resilience to hurricane-force winds (Table 1). However, it can also be seen that in south Florida when the winds reached 233 and 265 km/h (145 and 165 mph) in Hurricanes Charley and Andrew, survival of live oak decreased to 78%.

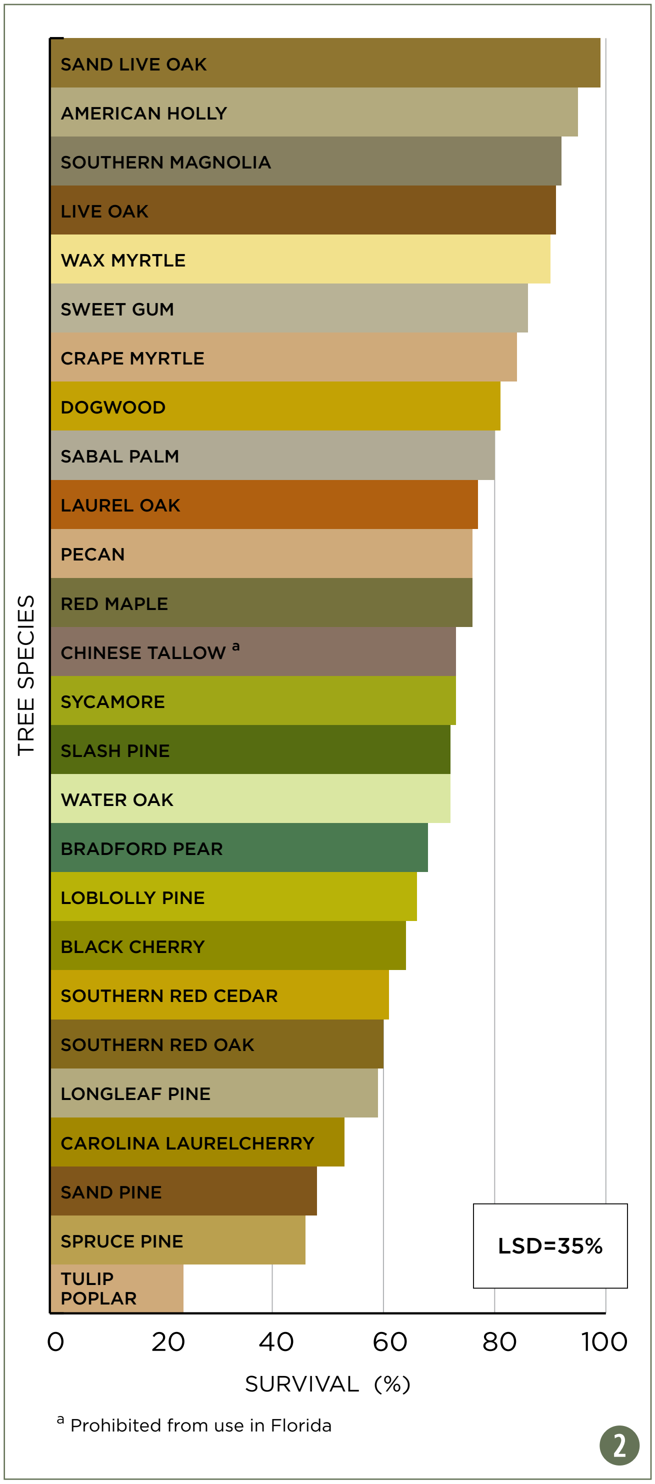


Figure 2

Survival (percentage of trees still standing) of species in Hurricane Ivan, which struck at 209 km/h (130 mph). The LSD (Least Significant Difference) is at the 0.05 level.

Table 1. Survival for Southeastern Coastal Plain tree species after six hurricanes. *

Tree Species		Survival (%) After Each Hurricane (Wind Speed in km/h)					
Dicots		**Erin (137)**	**Jeanne (193)**	**Opal (201)**	**Ivan (209)**	**Charley (233)**	**Andrew (265)**
Acer rubrum	Red maple	—	—	93	76	—	—
Acer saccharinum	Silver maple	—	—	93	—	—	—
Carya floridana	Florida scrub hickory	—	83	—	—	—	—
Carya illinoensis	Pecan	97	—	93	76	—	—
Carya glabra	Pignut hickory	100	—	—	—	—	—
Cinnamomum camphora [a]	Camphor	—	—	—	—	90	—
Cornus florida	Flowering dogwood	100	—	96	81	—	—
Ilex opaca	American holly	—	—	—	95	—	—
Lagerstroemia indica	Crape myrtle	—	—	—	84	—	—
Liquidambar styraciflua	Sweet gum	—	—	93	86	—	—
Liriodendron tulipifera	Tulip poplar	—	—	—	24	—	—
Magnolia grandifolia	Southern magnolia	96	—	97	92	—	—
Magnolia virginiana	Sweet bay magnolia	97	—	—	—	—	—
Myrica cerifera	Wax myrtle	—	—	—	90	—	—
Platanus occidentalis	Sycamore	—	—	92	73	—	—
Prunus caroliniana	Carolina laurelcherry	76	—	74	53	—	—
Prunus serotina	Black cherry	—	—	—	64	—	—
Pyrus calleryana	Bradford pear	—	—	—	68	—	—
Quercus falcata	Southern red oak	—	—	—	60	—	—
Quercus virginiana	Live oak	96	97	95	91	78	78
Quercus geminata	Sand live oak	96	94	96	99	—	—
Quercus laurifolia	Laurel oak	89	94	90	77	85	—
Quercus laevis	Turkey oak	83	—	89	—	—	—
Quercus nigra	Water oak	—	—	—	72	—	—
Sapium sebiferum [a]	Chinese tallow	97	—	83	73	—	—
Monocots—Palms							
Butia capitata	Jelly palm	97	—	—	—	—	—
Sabal palmetto	Sabal palm	97	92	100	80	92	93
Washingtonia robusta	Washington palm	—	80	—	—	92	—
Conifers							
Juniperus virginiana var. *silicicola*	Southern red cedar	92	—	60	61	—	—
Pinus clausa	Sand pine	61	4	58	48	—	—
Pinus elliottii var. *elliottii* and var. *densa*	Slash pine (and south Florida slash pine)	95	90 (*densa*)	96	72	79 (*densa*)	73 (*densa*)
Pinus glabra	Spruce pine	—	—	—	46	—	—
Pinus palustris	Longleaf pine	90	—	94	59	57	—
Pinus taeda	Loblolly pine	—	—	82	66	—	—
Taxodium distichum	Baldcypress	—	—	—	—	95	—

[a] Prohibited from use in Florida

* Survival is defined as the percentage of trees still standing after the hurricane. Numbers are only presented for tree species having a sample greater or equal to n=20 trees for each hurricane. Least Significant Differences at p=0.05 are 35% for Jeanne, 35% for Ivan, and 30% for Charley. Erin and Opal survival percentages are from Duryea 1997; Andrew survival percentages are from Duryea *et al*. 1996.

In a statistical comparison of sand live oak, live oak, and laurel oak, laurel oak had poorer overall survival than both live oak and sand live oak in four panhandle Florida hurricanes ($p<0.001$) (Figure 3). In several publications, live oak, sabal palm, baldcypress (*Taxodium distichum*) and pondcypress (*Taxodium ascendens*) have been ranked at the top of lists for hurricane-related wind resistance (Touliatos and Roth 1971; Swain 1979; Barry *et al*. 1993).

Branch loss in hurricanes may also be an important measure of trees' resilience (Figure 4). In Hurricane Ivan, southern red cedar (*Juniperus virginiana* var. *silicicola*), sycamore (*Platanus occidentalis*), southern red oak (*Quercus falcata*) and laurel oak lost on average over 25% of their branches. Sweet gum, silver maple (*Acer saccharinum*), sycamore and southern red cedar were species losing the most branches in Hurricanes Erin and Opal (Duryea 1997). Species with 10% or less branch loss were crape myrtle, loblolly pine (*Pinus taeda*), American holly, and tulip poplar (*Liriodendron tulipifera*).

When we looked at tree diameter and branch loss, we found that large trees (100-200 cm, 39-79 in diameter) lost the most branches (30%), followed by medium sized trees (50-99 cm, 20-39 in) with 25% loss, smaller trees (20-49 cm, 8-19 in) with 20% loss, and finally the smallest trees (< 20 cm, 8 in), which lost 12% of their branches ($p<0.0001$). Glizenstein and Harcombe (1988) also found that damage was positively correlated with average stem size in a forest stand. In their review, Everham and Brokaw (1996) summarize that most researchers have found a positive correlation between stem size and wind damage. Webb (1989) found that larger trees were more likely to be damaged directly by the wind compared to smaller trees, which were more likely to be indirectly damaged by other falling trees.

Since trees with large amounts of branch loss from a hurricane may not be considered as healthy urban trees, we re-analyzed survival, taking into account branches lost. As mentioned before, standing trees that had 50% or greater branch loss were called dead and a "new" survival was calculated (named "recalculated survival" henceforth) (Figure 5).

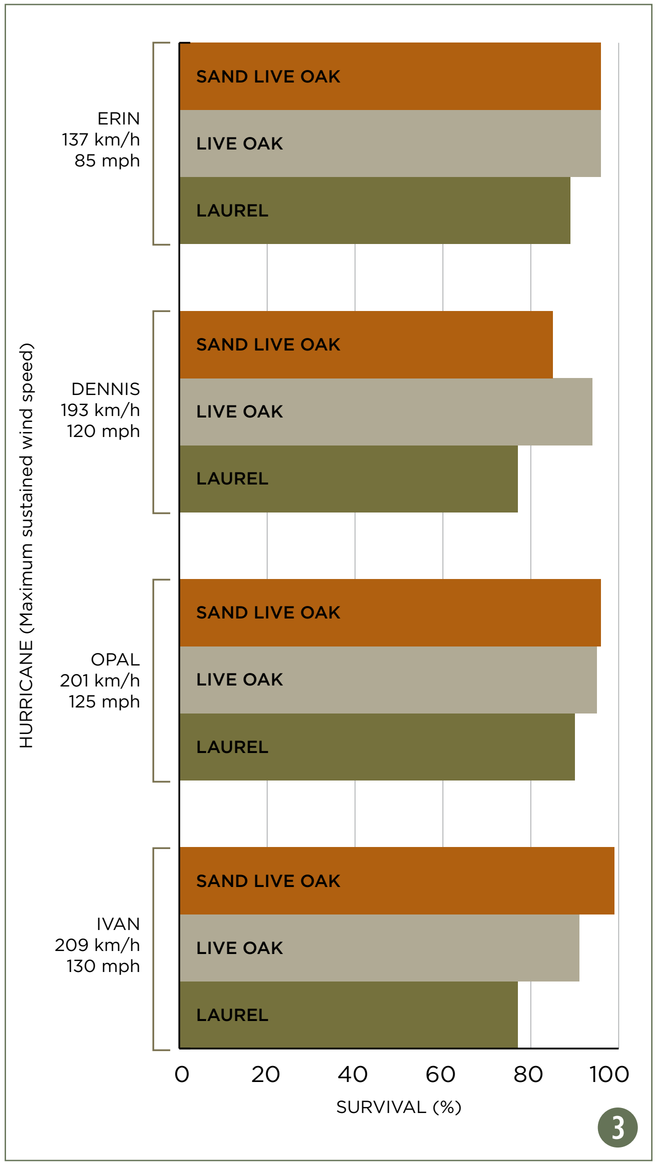
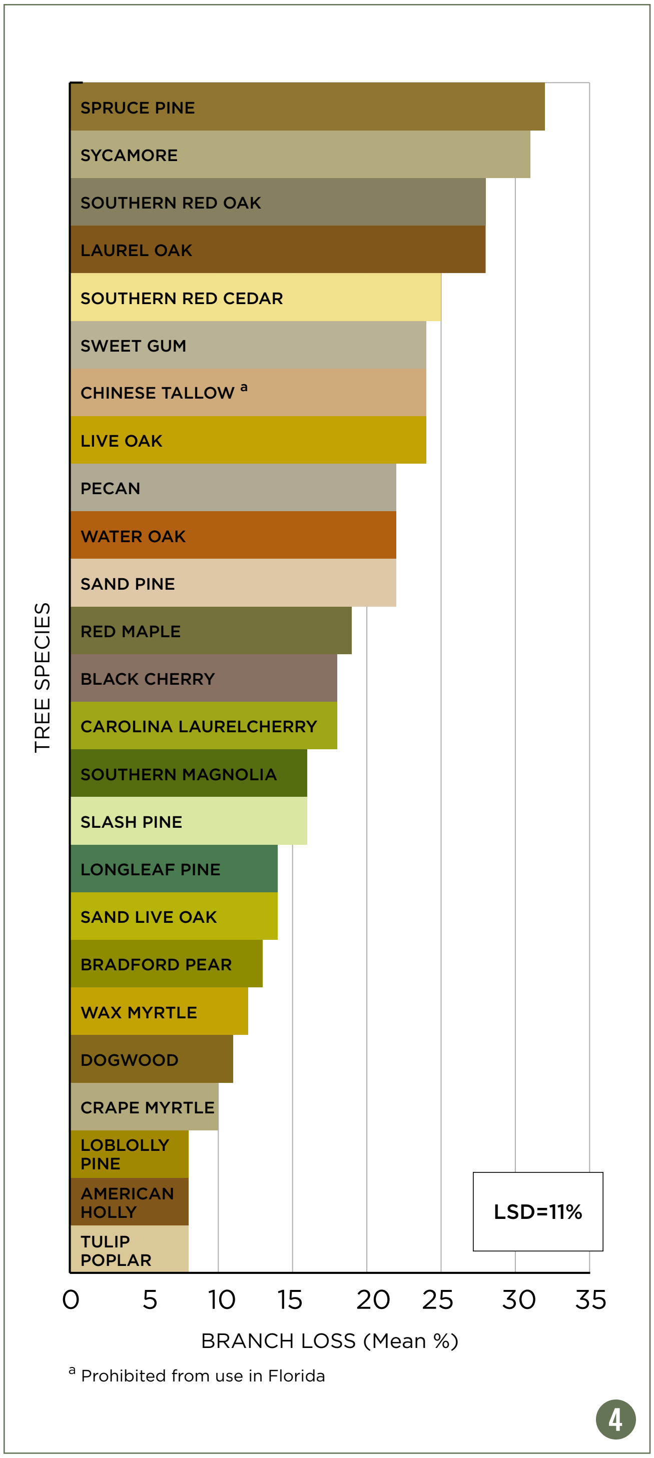


Figure 3

In a statistical comparison of sand live oak, live oak, and laurel oak survival in four Florida panhandle hurricanes, laurel oak survival was significantly less than the other two oaks ($p<0.001$). There was no difference between sand live oak and live oak survival.



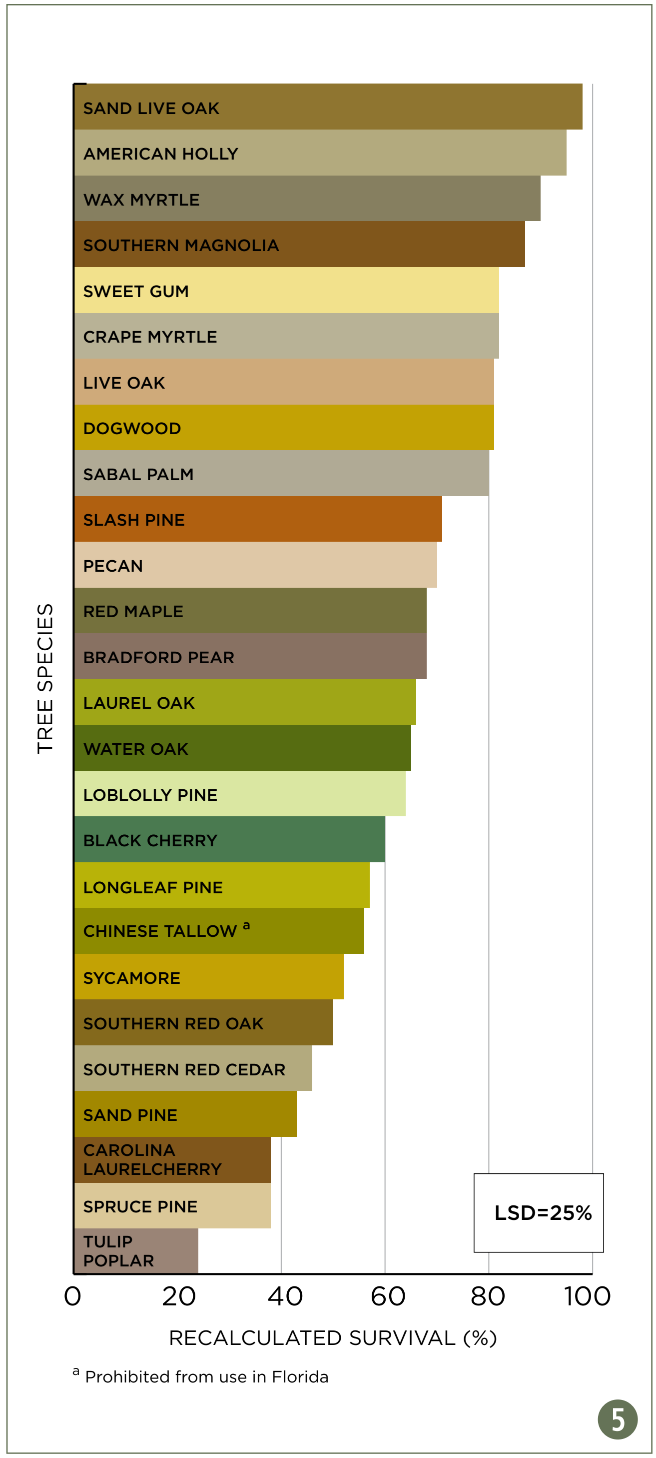


Figure 4

Average branch loss (%) for each tree species in Hurricane Ivan, which struck land at 209 km/h (130 mph). The LSD (Least Significant Difference) is at the 0.05 level.

Figure 5

A recalculation of survival (%) after declaring trees with ≥ 50% branch loss dead after Hurricane Ivan. The LSD (Least Significant Difference) is at the 0.05 level.

Some species with heavy branch loss had significantly lower recalculated survival. Southern red cedar survival was decreased from 61% to 46% due to heavy branch loss. Sycamore survival was reduced from 73% to 52%. Even live oak trees had significant branch loss, and their survival was decreased from 91% to 81%. When we statistically compared the recalculated survival of oak species after Hurricane Ivan, the ranking from greatest to lowest survival was sand live oak (98% survival), live oak (81%), laurel oak (66%), water oak (*Quercus nigra*) (65%) and Southern red oak (50%) (p=0.0001). A study in South Carolina coastal plain forests after Hurricane Hugo found that live oak was less damaged than laurel and water oaks (Gresham *et al*. 1991).

Survival of pine species showed significant differences with greatest survival for slash pine (*Pinus elliottii* var. *elliottii*) (71%), then loblolly (64%), longleaf (*Pinus palustris*) (57%), sand pine (*Pinus clausa*) (43%), and spruce pine (*Pinus glabra*) (38%) (p=0.0014). Three months after Hurricane Ivan, we re-measured pines and found that 2 to 3% of the slash and longleaf standing trees had died and 56% of the standing sand pine had died. In the southeastern coastal plain forest, longleaf pine was less damaged than loblolly during Hurricane Hugo (12% versus 73 % damaged) (Gresham *et al*. 1991), but a tornado in Texas resulted in equal and intense damage to loblolly, longleaf and shortleaf (*Pinus echinata*) pines (Glitzenstein and Harcombe 1988). Two conifer species that have shown repeatedly poor performance in our studies during hurricanes are sand pine and southern red cedar (Duryea 1997) (Table 1).

Defoliation

There were distinct species differences in defoliation during Hurricane Ivan. Species like sand live oak, crape myrtle, and dogwood lost an average of 94%, 88%, and 86% of their leaves compared to southern red cedar, wax myrtle, slash pine, longleaf pine, and loblolly pine, which lost 32%, 31%, 29%, 19%, and 11% of their leaves, respectively (LSD=17%) (Figure 6).

Leaf loss had a positive relationship ($p<0.0001$) with both survival and recalculated survival (trees with ≥ 50% branch loss excluded), which is to say that losing leaves during the hurricane meant higher survival. Francis and Gillespie (1993), reporting on urban trees in Puerto Rico after Hurricane Hugo in 1989, also found that crown damage appeared to be avoided if the crown surface area was reduced quickly with leaf and twig loss during the hurricane. There are some exceptions to defoliation being a strategy for survival; southern magnolia, American holly and sabal palm are all excellent survivors but they only lost 43%, 34%, and 27% of their leaves.

Native and Exotic Species

In the coastal plain area, exotic tree species made up 8% of the trees in the urban forest. The major exotic species were crape myrtle, Chinese tallow (*Sapium sebiferum*)—a prohibited invasive species, camphor tree (*Cinnamomum camphora*)—an invasive species, Bradford pear (*Pyrus calleryana*), and palms such as pindo palm (*Butia capitata*) and Washington fan palm (*Washingtonia robusta*). As a group, native trees survived the same as exotic trees (73% versus 77%, not significantly different [N.S.]) and lost the same amount of branches (20% versus 15%, N.S.) and leaves (58% versus 60%, N.S.). In contrast, after Hurricane Andrew struck south Florida, native trees survived winds better than non-native trees (Duryea *et al*. 1996). Other studies have shown trends toward increased wind damage of exotic species in rural plantation forests (King 1945; Everham and Brokaw 1996).

The Survey

Arborists' and urban foresters' ratings of wind resistance for coastal plain species show a strong agreement with our measurements over several hurricanes. Small trees that were awarded high wind-resistance ratings were fringe tree (*Chionanthus virginicus*), dogwood, persimmon (*Diospyros virginiana*), myrtle oak (*Quercus myrtifolia*), sparkleberry (*Vaccinium arboretum*) and the hollies (*Ilex* spp.) (Table 2).

Figure 6

By readily losing its leaves right after a hurricane, sand live oak is one of the species that survives hurricanes well.

Table 2. Results of survey of arborists, scientists, and urban foresters in Florida.*

Scientific Name	Common Name	Wind Resistance						p-value	Total N
		High		Medium		Low			
		N	%	N	%	N	%		
Dicots and Pines									
Acer negundo	boxelder	1	**8**	6	**50**	5	**42**	n.s.	12
Acer palmatum	Japanese maple	6	**50**	6	**50**	0	**0**	n.s.	12
Acer rubrum	red maple	12	**20**	32	**52**	17	**28**	0.0049	61
Acer saccharinum	silver maple	0	**0**	10	**45**	12	**55**	n.s.	22
Acer saccharum subsp *floridanum*	Florida sugar maple	2	**11**	11	**61**	5	**28**	0.0302	18
Betula nigra	river birch	11	**39**	16	**57**	1	**4**	0.0019	28
Carpinus caroliniana	ironwood	7	**50**	6	**43**	1	**7**	n.s.	14
Carya glabra	pignut hickory	11	**41**	14	**52**	2	**7**	0.0131	27
Carya illinoinensis	pecan	6	**21**	9	**32**	13	**47**	n.s.	28
Carya tomentosa	mockernut hickory	6	**50**	6	**50**	0	**0**	n.s.	12
Celtis laevigata	sugarberry	4	**15**	18	**70**	4	**15**	0.0005	26
Celtis occidentalis	common hackberry	2	**18**	5	**46**	4	**36**	n.s.	11
Cercis canadensis	red bud	14	**48**	8	**28**	7	**24**	n.s.	29
Chionanthus virginicus	fringe tree	7	**50**	5	**36**	2	**14**	n.s.	14
Cornus florida	flowering dogwood	9	**60**	6	**40**	0	**0**	n.s.	15
x *Cupressocyparis leylandii*	leyland cypress	7	**22**	13	**41**	12	**37**	n.s.	32
Diospyros virginiana	common persimmon	14	**56**	9	**36**	2	**8**	0.0128	25
Eucalyptus cinerea	silver dollar eucalyptus	2	**13**	9	**56**	5	**31**	n.s.	16
Eriobotrya japonica [C]	loquat	9	**24**	24	**63**	5	**13**	0.0004	38
Fraxinus americana	white ash	3	**30**	6	**60**	1	**10**	n.s.	10
Fraxinus pennsylvanica	green ash	3	**24**	5	**38**	5	**38**	n.s.	13
Ilex cassine	dahoon holly	34	**76**	10	**22**	1	**2**	0.0001	46
Ilex opaca	American holly	21	**75**	6	**21**	1	**4**	0.0001	28
Ilex vomitoria	yaupon holly	28	**81**	7	**19**	0	**0**	0.0004	37
Juniperus silicicola	southern red cedar	14	**28**	18	**35**	19	**37**	n.s.	51
Lagerstroemia indica	crape myrtle	55	**83**	11	**17**	0	**0**	0.0001	66
Liriodendron tulipifera	tulip poplar	2	**8**	14	**58**	8	**33**	0.0111	24
Liquidambar styraciflua	sweetgum	18	**43**	21	**50**	3	**7**	0.0013	42
Magnolia grandiflora	southern magnolia	45	**82**	9	**16**	1	**2**	0.0001	55
Magnolia virginiana	sweetbay magnolia	15	**42**	17	**47**	4	**11**	0.0169	36
Magnolia xsoulangiana	saucer magnolia	8	**44**	9	**50**	1	**6**	0.0421	18
Morus rubra	red mulberry	6	**23**	14	**54**	6	**23**	n.s.	26
Myrica cerifera	wax myrtle	18	**33**	15	**28**	21	**39**	n.s.	54
Nyssa aquatica	water tupelo	7	**58**	5	**42**	0	**0**	n.s.	12
Nyssa sylvatica	black tupelo	14	**58**	9	**38**	1	**4**	0.0469	24
Ostrya virginiana	American hophornbeam	8	**67**	4	**33**	0	**0**	n.s.	12

[C] Caution: may be used but must be managed to prevent escape in Florida (Fox *et al*. 2005)

* Rankings for wind resistance of southeastern US coastal plain tree species. N is the number of respondents for each species, out of a total of eighty-five experts. P-values from the chi-square test for equal proportions indicate the significance level for one or more of the categories being different from the others; n.s. means that there is no significant difference between the categories of high, medium and low ($p>0.05$).

(Table 2 conntinued)

Scientific Name	Common Name	Wind Resistance						p-value	Total N
		High		Medium		Low			
		N	%	N	%	N	%		
Dicots and Pines									
Pinus glabra	spruce pine	7	**54**	1	**8**	5	**38**	n.s.	13
Pinus elliottii var. elliottii	slash pine	16	**25**	36	**57**	11	**18**	0.0002	63
Pinus palustris	longleaf pine	23	**56**	13	**32**	5	**12**	0.0017	41
Pinus taeda	loblolly pine	7	**20**	19	**54**	9	**26**	0.0289	35
Platanus occidentalis	sycamore	17	**38**	21	**48**	6	**14**	n.s.	44
Prunus angustifolia	chickasaw plum	12	**50**	8	**33**	4	**17**	n.s.	24
Prunus caroliniana	Carolina laurelcherry	5	**16**	15	**48**	11	**36**	n.s.	31
Prunus serotina	black cherry	4	**18**	10	**46**	8	**36**	n.s.	22
Pyrus calleryana	Bradford pear	5	**21**	5	**21**	14	**58**	0.0342	24
Quercus alba	white oak	6	**55**	5	**45**	0	**0**	0.0539	11
Quercus falcata	southern red oak	4	**20**	15	**75**	1	**5**	0.0003	20
Quercus geminata	sand live oak	36	**92**	2	**5**	1	**3**	0.0001	39
Quercus laevis	turkey oak	17	**47**	16	**45**	3	**8**	0.0062	36
Quercus laurifolia	laurel oak	3	**4**	27	**39**	39	**57**	0.0001	69
Quercus michauxii	swamp chestnut oak	8	**50**	8	**50**	0	**0**	n.s.	16
Quercus myrtifolia	myrtle oak	13	**76**	4	**24**	0	**0**	0.0290	17
Quercus nigra	water oak	3	**8**	14	**36**	22	**56**	0.0009	39
Quercus phellos	willow oak	1	**8**	8	**67**	3	**25**	0.0388	12
Quercus shumardii	shumard oak	13	**52**	10	**40**	2	**8**	0.0207	25
Quercus stellata	post oak	5	**33**	10	**67**	0	**0**	n.s.	15
Quercus virginiana	live oak	64	**89**	8	**11**	0	**0**	0.0001	72
Salix x *sepulcralis*	weeping willow	2	**12**	8	**50**	6	**38**	n.s.	16
Taxodium distichum	baldcypress	59	**91**	6	**9**	0	**0**	0.0001	65
Taxodium ascendens	pondcypress	41	**91**	4	**9**	0	**0**	0.0001	45
Tilia americana	basswood	5	**38**	4	**31**	4	**31**	n.s.	13
Ulmus alata	winged elm	15	**53**	12	**43**	1	**4**	0.0030	28
Ulmus americana	American elm	6	**30**	12	**60**	2	**10**	0.0224	20
Ulmus parvifolia	Chinese elm	7	**23**	11	**35**	13	**42**	n.s.	31
Vaccinium arboreum	sparkleberry	11	**85**	2	**15**	0	**0**	0.0126	13
Palms									
Butia capitata	pindo, jelly	34	**79**	7	**16**	2	**5**	0.0001	43
Phoenix canariensis	Canary Island date palm	49	**89**	4	**7**	2	**4**	0.0001	55
Phoenix dactylifera	date palm	33	**94**	2	**6**	0	**0**	0.0001	35
Sabal palmetto	cabbage, sabal palm	71	**99**	1	**1**	0	**0**	0.0001	72
Washingtonia robusta	Washington fan palm	29	**54**	16	**29**	9	**17**	0.0033	54

[C] Caution: may be used but must be managed to prevent escape in Florida (Fox *et al.* 2005)

* Rankings for wind resistance of southeastern US coastal plain tree species. N is the number of respondents for each species, out of a total of eighty-five experts. P-values from the chi-square test for equal proportions indicate the significance level for one or more of the categories being different from the others; n.s. means that there is no significant difference between the categories of high, medium and low (p>0.05).

While live oak and sand live oak were rated as high, other oaks such as southern red oak and swamp chestnut oak (*Quercus michauxii*) were rated as medium and, in agreement with our results, laurel and water oaks were rated as having low wind resistance. Although we have consistently seen low survival or heavy branch damage in southern red cedar, the ratings were even for each of the wind-resistance categories in the survey results. However, 91% of the respondents rated baldcypress and pondcypress with high wind resistance (Figure 7). Both cypresses were stated to have the best wind resistance along with live oak and sabal palm after Hurricanes Camille and Frederick struck the Gulf Coast in 1969 and 1979 (Swain 1979).

In the survey, sand pine received a low rating, which is consistent with our results (Figure 8), while the other pines were mostly rated as medium, again consistent with our results. In their summarizing list of wind resistance for forest species, Everham and Brokaw (1996) cite ten studies where loblolly, slash and longleaf pines are ranked with low to intermediate wind resistance.

Sabal palm received a high wind resistance rating from 99% of the survey respondents in agreement with our ratings and those of Swain (1979). Canary Island date palm (*Phoenix canariensis*), which is being planted more frequently in north Florida, received a high rating from 89% of the respondents (Figure 9).

Respondents rated sweet gum's wind resistance as medium to high; in a summary table of wind resistance by Everham and Brokaw (1996), seven studies rated sweet gum as having medium to high wind resistance. Our studies have shown that it survives well but is prone to some branch breakage. In a Texas study after a tornado, sweet gum was listed as one of the best survivors, but also the tree with the most branch damage (Gliltzenstein and Harcombe 1988). In a study after Hurricane Kate in 1985, sweet gum had low mortality (2%) in a southern mixed hardwood forest compared to spruce pine with 34% mortality (Batista and Platt 2003). They note that wind-firmness of sweet gum is likely due to its underground connections, short and stout branches, and leaves with slender, long petioles that readily detach from branches in wind. On gravelly ridges, hillsides, and upland piedmont sites, sweetgum has been noted to develop a particularly strong taproot and is very resistant to wind (Kormanik 1990).

Tulip poplar had very poor survival in Hurricane Ivan (24%). Survey respondents rated it as having medium to low wind resistance. Everham and Brokaw (1996) summarize two studies in their table with high levels of wind damage for tulip poplar in high intensity storms.

Figure 7
Baldcypress, a species increasingly planted in urban areas, was ranked as a highly wind resistant tree.

Figure 8
Sand pine had a low survival rate of 43% and was also ranked as a low wind resistance species by respondents during the survey.

Figure 9
Canary Island date palm, rated as having high wind resistance, is being planted more frequently in north Florida.

IV. Recommendations

Taking our survival and branch loss results from hurricanes and incorporating results from the survey and from the scientific literature, we have developed lists of relative wind resistance for tree species in the southeastern coastal plain (Table 3). These lists should be used with caution, with the knowledge that no species and no tree is completely wind proof. In addition, local considerations such as soil, cultural practices, tree age and health, and other urban forest health conditions need to be taken into account. In addition to hurricane wind speed, other conditions accompanying hurricanes such as precipitation and the speed with which the storms move through an area appear to influence tree response.

Table 3. Wind resistance of southeastern US coastal plain tree species.*

HIGHEST WIND RESISTANCE	**DICOTS** *Carya floridana*, Florida scrub hickory *Cornus florida*, dogwood *Ilex cassine*, dahoon holly *Ilex glabra*, inkberry *Ilex opaca*, American holly *Ilex vomitoria*, yaupon holly *Lagerstroemia indica*, crape myrtle *Magnolia grandiflora*, southern magnolia	*Quercus geminata*, sand live oak *Quercus laevis*, turkey oak *Quercus myrtiflora*, myrtle oak *Quercus virginiana*, live oak *Podocarpus* spp, podocarpus *Vaccinium arboreum,* sparkleberry **CONIFERS** *Taxodium distichum*, baldcypress *Taxodium ascendens*, pondcypress
MEDIUM-HIGH WIND RESISTANCE	**DICOTS** *Acer saccharum,* Florida sugar maple *Acer palmatum,* Japanese maple *Betula nigra,* river birch *Carpinus caroliniana,* ironwood *Carya glabra,* pignut hickory *Carya tomentosa,* mockernut hickory *Cercis canadensis,* red bud *Chionanthus virginicus,* fringe tree *Diospyros virginiana,* common persimmon *Fraxinus americana,* white ash	*Liquidambar styraciflua,* sweetgum *Magnolia virginiana,* sweetbay magnolia *Magnolia x soulangiana,* saucer magnolia *Nyssa aquatica,* water tupelo *Nyssa sylvatica,* black tupelo *Ostrya virginiana,* American hophorbeam *Prunus angustifolia,* chickasaw plum *Quercus michauxii,* swamp chestnut *Quercus shumardii,* Shumard oak *Quercus stellata,* post oak *Ulmus alata,* winged elm
MEDIUM-LOW WIND RESISTANCE	**DICOTS** *Acer negundo*, boxelder *Acer rubrum*, red maple *Acer saccharinum*, silver mapple *Celtis laevigata*, sugarberry *Celtis occidentalis*, hackberry *Cinnamomum camphora*, camphor [b] *Eriobotrya japonica*, loquat [c] *Eucalyptus cinerea*, silverdollar eucalyptus *Fraxinus pennsylvanica*, green ash *Morus rubra*, red mulberry *Myrica cerifera*, wax myrtle	*Persea borbonia*, redbay *Platanus occidentalis*, sycamore *Prunus serotina*, black cherry *Quercus alba*, white oak *Quercus phellos*, willow oak *Salix* x *sepulcralis*, weeping willow *Ulmus americana*, American elm **CONIFERS** *Pinus elliottii*, slash pine *Pinus palustris*, longleaf pine *Pinus taeda*, loblolly pine
LOWEST WIND RESISTANCE	**DICOTS** *Carya illinoensis,* pecan *Liriodendron tulipifera,* tulip poplar *Prunus caroliniana,* Carolina laurelcherry *Pyrus calleryana,* Bradford pear *Quercus falcata,* southern red oak *Quercus laurifolia,* laurel oak *Quercus nigra,* water oak *Sapium sebiferum,* Chinese tallow [a] *Ulmus parvifolia,* Chinese elm	**CONIFERS** *Juniperus silicicola,* southern red cedar x *Cupressocyparis leylandii,* Leyland cypress *Pinus clausa,* sand pine *Pinus glabra,* spruce pine **PALMS** *Washingtonia robusta,* Washington fan

[a] Prohibited from use in Florida

[b] Invasive and not recommended for use in Florida

[c] Caution: may be used but must be managed to prevent escape in Florida (Fox *et al.* 2005)

* Wind resistance of southeastern coastal plain species as estimated utilizing the hurricane measurements and the survey results in this study, and the scientific literature cited throughout this publication.

These lists do not include all trees that could be wind resistant. They list those species encountered during our studies in large enough numbers to run statistical comparisons.

New Trees

To promote a healthy and more wind-resistant urban forest, additional recommendations for establishing new trees include:

- Plant a mixture of species, ages, and layers (shrubs and trees) to maintain diversity in your community.
- **Plant trees from the "Highest" and "Medium-High" Wind Resistance lists and match these to local site conditions.**
- Give trees adequate rooting space with no obstructions (e.g. sidewalks, buildings, and streets): for small trees, provide at least 3 meters by 3 meters; for large trees, provide at least 10 meters by 10 meters.
- **Consider planting trees in groups as opposed to individually.**
- Consider soil properties when deciding what to plant (e.g. soil depth, water table depth, and compaction).
- **Give trees adequate aerial space considering their crown size when mature.**
- Plant high quality trees with good structure.
- **Establish a structural pruning program early on.**

Established Trees

Likewise, recommendations for managing established trees include:

- Have tree health evaluated and remove hazard trees.
- **Consider removing trees that are on the "Lowest Wind Resistance" list, especially if they are over-mature and endangering life or property.**
- Establish a regular structural pruning program (especially for dicots).
- **Consult with a certified arborist.**
- Do not over-prune palms especially before a hurricane; palms only need to have dead or dying leaves removed.
- **Be aware of possible root damage and lack of anchoring when construction has resulted in sidewalks or trenches near the roots of trees.**
- Avoid damage to the trunk of the tree (e.g. mechanical weed control damage).

Literature Cited

Barry, P.J., C. Doggett, R.L. Anderson, and K.M. Swain, Sr. 1993. How to evaluate and manage storm-damaged forest areas. Management Bulletin R8-MB 63 of the USDA Forest Service, Southern Region. Atlanta, GA. 11 pp.

Batista, W.B. and W.J. Platt. 2003. Tree population responses to hurricane disturbance: syndromes in a south-eastern USA old-growth forest. Ecology 91:197-212.

Duryea, M.L., G.M. Blakeslee, W.G. Hubbard, and R.A. Vasquez. 1996. Wind and trees: A survey of homeowners after Hurricane Andrew. J. Arboric. 22(1):44-50.

Duryea, M.L. 1997. Wind and trees: Surveys of tree damage in the Florida Panhandle after Hurricanes Erin and Opal. Circular 1183 of the University of Florida Cooperative Extension Service (http://edis.ifas.ufl.edu/). Gainesville, FL. 7 pp.

Duryea, M.L., E. Kampf, and R.C. Littell. 2007. Hurricanes and the Urban Forest: I. Effects on Southeastern U.S. Coastal Plain Tree Species. Arboric. & Urban Forestry 33(2):83-97.

Everham III, E.M. and N.V.L. Brokaw. 1996. Forest damage and recovery from catastrophic wind. The Botanical Review 62:113-185.

Fox, A.M., D.R. Gordon, J.A. Dusky, L. Tyson, and R.K. Stocker. 2005. IFAS assessment of the status of non-native plants in Florida's natural areas. SS-AGR-225 of the University of Florida, IFAS Cooperative Extension Service. http://plants.ifas.ufl.edu/assessment/ Gainesville, FL. 27 pp.

Francis, J.K. and A.J.R. Gillespie. 1993. Relating gust speed to tree damage in Hurricane Hugo, 1989. J. Arboric. 19:368-372.

Glitzenstein, J.S. and P.A. Harcombe. 1988. Effects of the December 1983 tornado on forest vegetation of the Big Thicket, southeast Texas, USA. For. Ecol. Managem. 25:269-290.

Gresham, C.A., T.M. Williams, and D.J. Lipscomb. 1991. Hurricane Hugo wind damage to Southeastern U.S. coastal forest tree species. Biotropica 23(4) (Part A. Special Issue: Ecosystem, Plant, and Animal Responses to Hurricanes in the Caribbean):420-426.

King, H.C. 1945. Notes on the three cyclones in Mauritius in 1945: Their effect on exotic plantations, indigenous forest and on some timber buildings. Empire Forest. J. 24: 192-195.

Kormanik, P. 1990. Liquidambar styraciflua, sweetgum. In: Silvics of North America: 2. Hardwoods. Burns, R. M., and B. H. Honkala, Tech. Coords. (http://www.na.fs.fed.us/spfo/pubs/silvics_manual/table_of_contents.htm) Agriculture Handbook 654 Vol. 2 of the U.S.D.A. Forest Service, Washington, DC. 877 pp.

Swain, K.M. 1979. Minimizing timber damage from hurricanes. S. Lumberman 239:107-109.

Touliatos, P. and E. Roth. 1971. Hurricanes and trees: Ten lessons from Camille. J. For. 285-289.

Webb, S.L. 1989. Contrasting windstorm consequences in two forests, Itasca State Park, Minnesota. Ecology 70(4):1167-1180.

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