

# Selecting Coastal Plain Species for Wind Resistance<sup>1</sup>

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Wind damage to urban trees increases with storm intensity, but not all tree species withstand high winds to the same degree, 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) studied 10 hurricanes to determine their effect on the urban forest. One of the major goals of this study was to assemble lists of relative wind resistance for different urban tree species to help communities better prepare for future hurricane seasons by selecting proper species. (Chapter 9 reports on tropical and subtropical tree 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.

## 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 plant hardiness zones 8 and 9).

## 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

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top of lists for hurricane-related wind resistance (Touliatos and Roth 1971; Swain 1979; Barry et al. 1993).

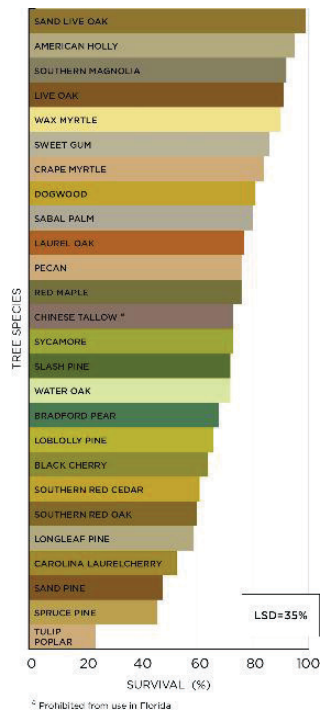


Figure 2. Survival (percentage of trees still standing) of species in Hurricane Ivan, which struck at 209 km/h (130 mph). The LSD (Least Significant Difference) is at the 0.05 level.

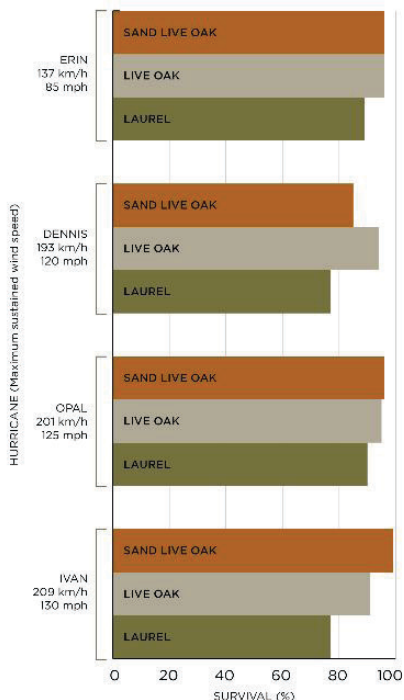


Figure 3. In a statistical comparison of sand live oak, live oak, and laurel oak survival in four Florida panhandle hurricanes, laurel oak survival was significantly less than the other two oaks ( $p < 0.001$ ). There was no difference between sand live oak and live oak survival.

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. Sweetgum, 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*).

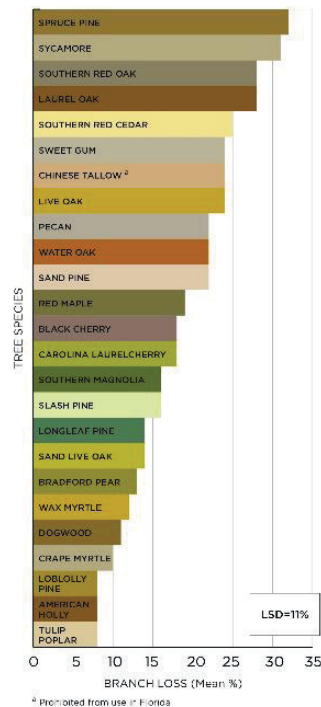


Figure 4. Average branch loss (%) for each tree species in Hurricane Ivan, which struck land at 209 km/h (130 mph). The LSD (Least Significant Difference) is at the 0.05 level.

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 5. A recalculation of survival (%) after declaring trees with <sup>3</sup> 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 also 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).



Figure 6. By readily losing its leaves right after a hurricane, sand live oak is one of the species that survives hurricanes well.

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 arboreum*), and the hollies (*Ilex* spp.) (Table 2).

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).



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.

Respondents rated sweetgum's wind resistance as medium to high; in a summary table of wind resistance by Everham and Brokaw (1996), seven studies rated sweetgum 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, sweetgum was listed as one of the best survivors, but also the tree with the most branch damage (Glitzenstein and Harcombe 1988). In a study after Hurricane Kate in 1985, sweetgum 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 sweetgum 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.

## 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.

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

Tree Species		Survival (%) After Each Hurricane (Wind Speed in km/h)					
		Erin (137)	Jeanne (193)	Opal (201)	Ivan (209)	Charley (233)	Andrew (265)
<b>Dicots</b>							
<i>Acer rubrum</i>	Red maple	—	—	93	76	—	—
<i>Acer saccharinum</i>	Silver maple	—	—	93	—	—	—
<i>Carya floridana</i>	Florida scrub hickory	—	83	—	—	—	—
<i>Carya illinoensis</i>	Pecan	97	—	93	76	—	—
<i>Carya glabra</i>	Pignut hickory	100	—	—	—	—	—
<i>Cinnamomum camphora</i> <sup>a</sup>	Camphor	—	—	—	—	90	—
<i>Cornus florida</i>	Flowering dogwood	100	—	96	81	—	—
<i>Ilex opaca</i>	American holly	—	—	—	95	—	—
<i>Lagerstroemia indica</i>	Crape myrtle	—	—	—	84	—	—
<i>Liquidambar styraciflua</i>	Sweet gum	—	—	93	86	—	—
<i>Liriodendron tulipifera</i>	Tulip poplar	—	—	—	24	—	—
<i>Magnolia grandifolia</i>	Southern magnolia	96	—	97	92	—	—
<i>Magnolia virginiana</i>	Sweet bay magnolia	97	—	—	—	—	—
<i>Myrica cerifera</i>	Wax myrtle	—	—	—	90	—	—
<i>Platanus occidentalis</i>	Sycamore	—	—	92	73	—	—
<i>Prunus caroliniana</i>	Carolina laurelcherry	76	—	74	53	—	—
<i>Prunus serotina</i>	Black cherry	—	—	—	64	—	—
<i>Pyrus calleryana</i>	Bradford pear	—	—	—	68	—	—
<i>Quercus falcata</i>	Southern red oak	—	—	—	60	—	—
<i>Quercus virginiana</i>	Live oak	96	97	95	91	78	78
<i>Quercus geminata</i>	Sand live oak	96	94	96	99	—	—
<i>Quercus laurifolia</i>	Laurel oak	89	94	90	77	85	—
<i>Quercus laevis</i>	Turkey oak	83	—	89	—	—	—
<i>Quercus nigra</i>	Water oak	—	—	—	72	—	—
<i>Sapium sebiferum</i> <sup>a</sup>	Chinese tallow	97	—	83	73	—	—
<b>Monocots—Palms</b>							
<i>Butia capitata</i>	Jelly palm	97	—	—	—	—	—
<i>Sabal palmetto</i>	Sabal palm	97	92	100	80	92	93
<i>Washingtonia robusta</i>	Washington palm	—	80	—	—	92	—
<b>Conifers</b>							

Tree Species		Survival (%) After Each Hurricane (Wind Speed in km/h)					
		Erin (137)	Jeanne (193)	Opal (201)	Ivan (209)	Charley (233)	Andrew (265)
<i>Juniperus virginiana</i> var. <i>silicicola</i>	Southern red cedar	92	—	60	61	—	—
<i>Pinus clausa</i>	Sand pine	61	4	58	48	—	—
<i>Pinus elliottii</i> var. <i>elliottii</i> and var. <i>densa</i>	Slash pine (and south Florida slash pine)	95	90 ( <i>densa</i> )	96	72	79 ( <i>densa</i> )	73 ( <i>densa</i> )
<i>Pinus glabra</i>	Spruce pine	—	—	—	46	—	—
<i>Pinus palustris</i>	Longleaf pine	90	—	94	59	57	—
<i>Pinus taeda</i>	Loblolly pine	—	—	82	66	—	—
<i>Taxodium distichum</i>	Baldcypress	—	—	—	—	95	—

<sup>a</sup> 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

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									
<i>Acer negundo</i>	boxelder	1	8	6	50	5	42	n.s.	12
<i>Acer palmatum</i>	Japanese maple	6	50	6	50	0	0	n.s.	12
<i>Acer rubrum</i>	red maple	12	20	32	52	17	28	0.0049	61
<i>Acer saccharinum</i>	silver maple	0	0	10	45	12	55	n.s.	22
<i>Acer saccharum</i> subsp <i>floridanum</i>	Florida sugar maple	2	11	11	61	5	28	0.0302	18
<i>Betula nigra</i>	river birch	11	39	16	57	1	4	0.0019	28
<i>Carpinus caroliniana</i>	ironwood	7	50	6	43	1	7	n.s.	14
<i>Carya glabra</i>	pignut hickory	11	41	14	52	2	7	0.0131	27
<i>Carya illinoensis</i>	pecan	6	21	9	32	13	47	n.s.	28
<i>Carya tomentosa</i>	mockernut hickory	6	50	6	50	0	0	n.s.	12
<i>Celtis laevigata</i>	sugarberry	4	15	18	70	4	15	0.0005	26
<i>Celtis occidentalis</i>	common hackberry	2	18	5	46	4	36	n.s.	11
<i>Cercis canadensis</i>	red bud	14	48	8	28	7	24	n.s.	29
<i>Chionanthus virginicus</i>	fringe tree	7	50	5	36	2	14	n.s.	14
<i>Cornus florida</i>	flowering dogwood	9	60	6	40	0	0	n.s.	15
x <i>Cupressocyparis leylandii</i>	leyland cypress	7	22	13	41	12	37	n.s.	32
<i>Diospyros virginiana</i>	common persimmon	14	56	9	36	2	8	0.0128	25
<i>Eucalyptus cinerea</i>	silver dollar eucalyptus	2	13	9	56	5	31	n.s.	16
<i>Eriobotrya japonica</i> <sup>c</sup>	loquat	9	24	24	63	5	13	0.0004	38
<i>Fraxinus americana</i>	white ash	3	30	6	60	1	10	n.s.	10
<i>Fraxinus pennsylvanica</i>	green ash	3	24	5	38	5	38	n.s.	13
<i>Ilex cassine</i>	dahoon holly	34	76	10	22	1	2	0.0001	46
<i>Ilex opaca</i>	American holly	21	75	6	21	1	4	0.0001	28
<i>Ilex vomitoria</i>	yaupon holly	28	81	7	19	0	0	0.0004	37
<i>Juniperus virginiana</i> var. <i>silicicola</i>	southern red cedar	14	28	18	35	19	37	n.s.	51
<i>Lagerstroemia indica</i>	crape myrtle	55	83	11	17	0	0	0.0001	66
<i>Liriodendron tulipifera</i>	tulip poplar	2	8	14	58	8	33	0.0111	24
<i>Liquidambar styraciflua</i>	sweetgum	18	43	21	50	3	7	0.0013	42
<i>Magnolia grandiflora</i>	southern magnolia	45	82	9	16	1	2	0.0001	55

Scientific Name	Common Name	Wind Resistance						p-value	Total N
		High		Medium		Low			
		N	%	N	%	N	%		
<i>Magnolia virginiana</i>	sweetbay magnolia	15	42	17	47	4	11	0.0169	36
<i>Magnolia x soulangiana</i>	saucer magnolia	8	44	9	50	1	6	0.0421	18
<i>Morus rubra</i>	red mulberry	6	23	14	54	6	23	n.s.	26
<i>Myrica cerifera</i>	wax myrtle	18	33	15	28	21	39	n.s.	54
<i>Nyssa aquatica</i>	water tupelo	7	58	5	42	0	0	n.s.	12
<i>Nyssa sylvatica</i>	black tupelo	14	58	9	38	1	4	0.0469	24
<i>Ostrya virginiana</i>	American hophornbeam	8	67	4	33	0	0	n.s.	12
<i>Pinus glabra</i>	spruce pine	7	54	1	8	5	38	n.s.	13
<i>Pinus elliotii</i> var. <i>elliotii</i>	slash pine	16	25	36	57	11	18	0.0002	63
<i>Pinus palustris</i>	longleaf pine	23	56	13	32	5	12	0.0017	41
<i>Pinus taeda</i>	loblolly pine	7	20	19	54	9	26	0.0289	35
<i>Platanus occidentalis</i>	sycamore	17	38	21	48	6	14	n.s.	44
<i>Prunus angustifolia</i>	chickasaw plum	12	50	8	33	4	17	n.s.	24
<i>Prunus caroliniana</i>	Carolina laurelcherry	5	16	15	48	11	36	n.s.	31
<i>Prunus serotina</i>	black cherry	4	18	10	46	8	36	n.s.	22
<i>Pyrus calleryana</i>	Bradford pear	5	21	5	21	14	58	0.0342	24
<i>Quercus alba</i>	white oak	6	55	5	45	0	0	0.0539	11
<i>Quercus falcata</i>	southern red oak	4	20	15	75	1	5	0.0003	20
<i>Quercus geminata</i>	sand live oak	36	92	2	5	1	3	0.0001	39
<i>Quercus laevis</i>	turkey oak	17	47	16	45	3	8	0.0062	36
<i>Quercus laurifolia</i>	laurel oak	3	4	27	39	39	57	0.0001	69
<i>Quercus michauxii</i>	swamp chestnut oak	8	50	8	50	0	0	n.s.	16
<i>Quercus myrtifolia</i>	myrtle oak	13	76	4	24	0	0	0.0290	17
<i>Quercus nigra</i>	water oak	3	8	14	36	22	56	0.0009	39
<i>Quercus phellos</i>	willow oak	1	8	8	67	3	25	0.0388	12
<i>Quercus shumardii</i>	shumard oak	13	52	10	40	2	8	0.0207	25
<i>Quercus stellata</i>	post oak	5	33	10	67	0	0	n.s.	15
<i>Quercus virginiana</i>	live oak	64	89	8	11	0	0	0.0001	72
<i>Salix x sepulcralis</i>	weeping willow	2	12	8	50	6	38	n.s.	16
<i>Taxodium distichum</i>	baldcypress	59	91	6	9	0	0	0.0001	65
<i>Taxodium ascendens</i>	pondcypress	41	91	4	9	0	0	0.0001	45
<i>Tilia americana</i>	basswood	5	38	4	31	4	31	n.s.	13
<i>Ulmus alata</i>	winged elm	15	53	12	43	1	4	0.0030	28
<i>Ulmus americana</i>	American elm	6	30	12	60	2	10	0.0224	20
<i>Ulmus parvifolia</i>	Chinese elm	7	23	11	35	13	42	n.s.	31

Scientific Name	Common Name	Wind Resistance						p-value	Total N
		High		Medium		Low			
		N	%	N	%	N	%		
<i>Vaccinium arboreum</i>	sparkleberry	11	85	2	15	0	0	0.0126	13
Palms									
<i>Butia capitata</i>	pindo, jelly	34	79	7	16	2	5	0.0001	43
<i>Phoenix canariensis</i>	Canary Island date palm	49	89	4	7	2	4	0.0001	55
<i>Phoenix dactylifera</i>	date palm	33	94	2	6	0	0	0.0001	35
<i>Sabal palmetto</i>	cabbage, sabal palm	71	99	1	1	0	0	0.0001	72
<i>Washingtonia robusta</i>	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 (UF/IFAS, 2018)									
* 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 3. Wind resistance of southeastern US coastal plain tree species.\*

Highest Wind Resistance	<p><b>DICOTS</b></p> <p><i>Carya floridana</i>, Florida scrub hickory  <i>Cornus florida</i>, dogwood  <i>Ilex cassine</i>, dahoon holly  <i>Ilex glabra</i>, inkberry  <i>Ilex opaca</i>, American holly  <i>Ilex vomitoria</i>, yaupon holly  <i>Lagerstroemia indica</i>, crape myrtle  <i>Magnolia grandiflora</i>, southern magnolia  <i>Podocarpus</i> spp, podocarpus  <i>Quercus geminata</i>, sand live oak  <i>Quercus laevis</i>, turkey oak  <i>Quercus myrtiflora</i>, myrtle oak  <i>Quercus virginiana</i>, live oak  <i>Vaccinium arboreum</i>, sparkleberry</p> <p><b>CONIFERS</b></p> <p><i>Taxodium ascendens</i>, pondcypress  <i>Taxodium distichum</i>, baldcypress</p>
Medium-High Wind Resistance	<p><b>DICOTS</b></p> <p><i>Acer saccharum</i>, Florida sugar maple  <i>Acer palmatum</i>, Japanese maple  <i>Betula nigra</i>, river birch  <i>Carpinus caroliniana</i>, ironwood  <i>Carya glabra</i>, pignut hickory  <i>Carya tomentosa</i>, mockernut hickory  <i>Cercis canadensis</i>, red bud  <i>Chionanthus virginicus</i>, fringe tree  <i>Diospyros virginiana</i>, common persimmon  <i>Fraxinus americana</i>, white ash  <i>Liquidambar styraciflua</i>, sweetgum  <i>Magnolia virginiana</i>, sweetbay magnolia  <i>Magnolia x soulangiana</i>, saucer magnolia  <i>Nyssa aquatica</i>, water tupelo  <i>Nyssa sylvatica</i>, black tupelo  <i>Ostrya virginiana</i>, American hophonbeam  <i>Prunus angustifolia</i>, chickasaw plum  <i>Quercus michauxii</i>, swamp chestnut oak  <i>Quercus shumardii</i>, Shumard oak  <i>Quercus stellata</i>, post oak  <i>Ulmus alata</i>, winged elm</p>

Medium-low Wind Resistance	<p><b>DICOTS</b></p> <p><i>Acer negundo</i>, boxelder  <i>Acer rubrum</i>, red maple  <i>Acer saccharinum</i>, silver maple  <i>Celtis laevigata</i>, sugarberry  <i>Celtis occidentalis</i>, hackberry  <i>Cinnamomum camphora</i>, camphor<sup>b</sup>  <i>Eriobotrya japonica</i>, loquat<sup>c</sup>  <i>Eucalyptus cinerea</i>, silverdollar eucalyptus  <i>Fraxinus pennsylvanica</i>, green ash  <i>Morus rubra</i>, red mulberry  <i>Myrica cerifera</i>, wax myrtle  <i>Persea borbonia</i>, redbay  <i>Platanus occidentalis</i>, sycamore  <i>Prunus serotina</i>, black cherry  <i>Quercus alba</i>, white oak  <i>Quercus phellos</i>, willow oak  <i>Salix x sepulcralis</i>, weeping willow  <i>Ulmus americana</i>, American elm</p> <p><b>CONIFERS</b></p> <p><i>Pinus elliottii</i>, slash pine  <i>Pinus palustris</i>, longleaf pine  <i>Pinus taeda</i>, loblolly pine</p>
Lowest Wind Resistance	<p><b>DICOTS</b></p> <p><i>Carya illinoensis</i>, pecan  <i>Liriodendron tulipifera</i>, tulip poplar  <i>Prunus caroliniana</i>, Carolina laurelcherry  <i>Pyrus calleryana</i>, Bradford pear  <i>Quercus falcata</i>, southern red oak  <i>Quercus laurifolia</i>, laurel oak  <i>Quercus nigra</i>, water oak  <i>Sapium sebiferum</i>, Chinese tallow<sup>a</sup>  <i>Ulmus parvifolia</i>, Chinese elm</p> <p><b>CONIFERS</b></p> <p><i>Juniperus virginiana</i> var. <i>silicicola</i>, southern red cedar  x <i>Cupressocyparis leylandii</i>, Leyland cypress  <i>Pinus clausa</i>, sand pine  <i>Pinus glabra</i>, spruce pine</p> <p><b>PALMS</b></p> <p><i>Washingtonia robusta</i>, Washington fan palm</p>
<p><sup>a</sup> Prohibited from use in Florida  <sup>b</sup> Invasive and not recommended for use in Florida  <sup>c</sup> Caution: may be used but must be managed to prevent escape in Florida (UF/IFAS 2018)  * 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.</p>	

Table 4. New Trees

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

Table 5. Established Trees

<b>Likewise, recommendations for managing established trees include:</b>
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).