

# Selecting Tropical and Subtropical Tree Species for Wind Resistance<sup>1</sup>

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## Introduction

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 the next hurricane season and to rebuild a healthy urban forest by selecting proper species.

This fact sheet presents the research and methodology that lead to lists of relative wind resistance for tropical and subtropical tree species (Chapter 8 reports on coastal

plain tree species). It also discusses in detail its results and additional recommendations for selecting and establishing tropical and subtropical species for a healthier and more wind-resistant urban forest.

## Study

Since 1992 when Hurricane Andrew struck south Florida, we have been studying the impacts of hurricanes on urban forests (Duryea et al. 1996; Duryea et al. 2007a; Duryea et al. 2007b). In 1998 when Hurricane Georges (177 km/h) crossed over the entire island of Puerto Rico, and in 2004 when Hurricanes Jeanne (193 km/h) and Charley (233 km/h) struck south Florida, we continued with these measurements. Hurricanes striking the subtropical and tropical regions of Florida and Puerto Rico, with their varied wind speeds, gave us the opportunity to study over 60 species and their comparable responses to wind. This study utilizes our results from hurricanes and incorporates results from a survey and the scientific literature to present lists of relative wind resistance for tropical and subtropical tree species.

## Methods

Urban tree damage was measured within 3 to 10 days of the two hurricanes that struck Florida (Charley and Jeanne 2004) and the one that struck Puerto Rico (Georges 1998). In this study, we also included the hurricane response of

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some tropical/subtropical species, such as live oak (*Quercus virginiana*) and sabal palm (*Sabal palmetto*), that occur throughout Florida and were impacted by Hurricanes Erin (1995), Opal (1995), and Ivan (2004) in the Florida panhandle (Figure 2).

Hurricane Andrew measurements involved a survey of 128 homeowners in Dade County, Florida who measured and reported to us about each tree in their yards (Duryea et al. 1996). The methodology for the other hurricanes was the same and is as follows: neighborhoods at the point of landfall of the hurricane were randomly chosen. For each neighborhood, all trees were observed along street transects. For each of the three hurricanes, we sampled 26 neighborhoods and 3,678 trees (Georges), 17 neighborhoods and 2,272 trees (Charley), and 7 neighborhoods and 1,642 trees (Jeanne). (Branch loss measurements for Hurricanes Frances [2005] and Jeanne were combined and made immediately following Hurricane Jeanne).

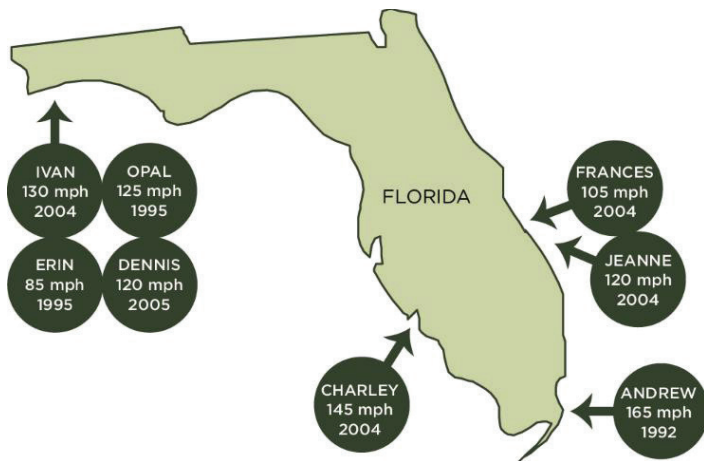


Figure 2. Urban trees were measured following hurricanes striking Florida and Puerto Rico. For each hurricane, the arrow points to the location of landfall. The maximum sustained wind speed (mph) and year are included.

## Results

### Overall Urban Forest Loss

The percent of urban forest loss (mortality) ranged from 13% for Hurricane Georges to 16% for Hurricane Jeanne to 18% for Hurricane Charley. The urban forest loss for these hurricanes combined with hurricanes striking the southeastern coastal plain is reported in EDIS publication FOR118 *Lessons Learned from Hurricanes*. To evaluate tree survival and responses, we divided the species into four categories: palms, dicots, conifers, and Puerto Rico species. We then talk about native versus exotic species

## Tree Survival and Branch Loss

### PALMS

Sabal palms along with the smaller palms such as areca (*Chrysalidocarpus lutescens*), Manila (*Veitchia merrillii*) and pigmy date (*Phoenix roebelenii*), had 89% or greater survival (Table 1). In Hurricane Charley, palm survival was 88% compared to 77% for all other tree species ( $p=0.0001$ ). In Hurricane Jeanne, palm survival was 86% versus 76% for all other tree species ( $p<0.0001$ ). When compared to dicots, palms have often been observed to be more resistant to winds (Francis and Gillespie 1993; Frangi and Lugo 1991). Zimmerman et al. (1994) conclude that palms are wind resistant because they are able to lose all their leaves without losing their terminal meristem. Coconut palm (*Cocos nucifera*), which survived poorly in Hurricane Andrew (Duryea et al. 1996), exhibited intermediate survival in both Charley's and Georges' winds (77% survival) (Table 1). Royal palm (*Roystonea elata*) which had only 63% survival in Andrew, had improved survival (87%) in Hurricane Charley in the deeper soils of the Gulf Coast. Washington palm (*Washingtonia robusta*) survived well in Charley's 233 km/h (145 mph) winds (92%) but less well in Jeanne's winds of 193 km/h (120 mph) (80%). This was perplexing to us until we looked at the height comparisons of the two populations. Washington palms in the Ft. Pierce area that experienced Hurricane Jeanne averaged 11 m in height, with 42% of the palms above 10 m, compared to an average of 4 m and only 7% over 10 m for Charley; perhaps as Washington palms acquire heights of 20 meters and above, their wind resistance starts to decline.

### DICOTS

Of the dicot tree species, the poorest surviving were melaleuca (*Melaleuca quinquenervia*), Australian pine (*Casuarina equisetifolia*), and black olive (*Bucida buceras*) in Hurricane Charley. Dicots with highest survival were camphor (*Cinnamomum camphora*), gumbo limbo (*Bursera simarouba*), sea grape (*Coccoloba uvifera*), strangler fig (*Ficus aurea*), live oak, and laurel oak (*Quercus laurifolia*) (Figure 3).

Trees with large amounts of branch loss in a hurricane (Figure 4) may not be considered as healthy urban trees, so we re-analyzed survival taking into account branches lost. Standing trees with 50% or greater branch loss were called dead and a "new" survival was calculated (named "recalculated survival").

Some species such as camphor, strangler fig, laurel oak, and live oak may continue to stand in hurricane- force winds

but at the same time lose large branches, especially at the 233 km/h (145 mph) winds of Charley (Figure 5).

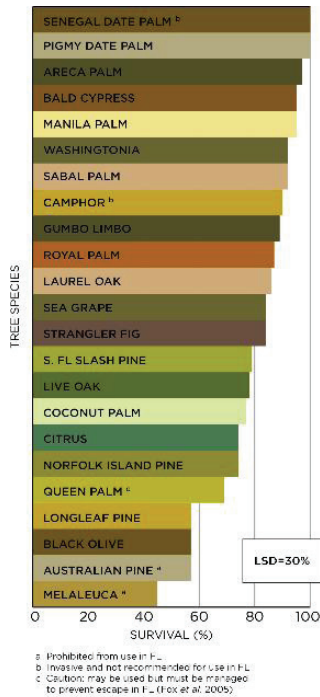


Figure 3. Survival (%) of tree species in Hurricane Charley, which struck at 233 km/h (145 mph)

After intermediate survival in Hurricane Andrew, West Indian mahogany (*Swietenia mahagoni*) and white cedar (*Tabebuia heterophylla*) exhibited higher survival in Hurricane Georges at 177 km/h (110 mph). After relatively poor survival in Andrew, 94% of the royal poinciana (*Delonix regia*) survived the relatively lighter winds of Hurricane Georges. In a study of 24 species of urban trees in San Juan, Puerto Rico after Hurricane Georges, species with the highest survival (lowest failed stems) were West Indian mahogany (100%), mango (*Mangifera indica*) (98%), queen's crape myrtle (*Lagerstroemia speciosa*) (98%), and royal poinciana (98%) (Francis 2000). Species with the poorest survival were African tuliptree (*Spathodea campanulata*) (66%) and weeping banyan (*Ficus benjamina*) (70%) (Francis 2000). Studies summarized in Everham and Brokaw's table of species resistance to catastrophic wind (1996) rank gumbo limbo, mahogany, sea grape, baldcypress (*Taxodium distichum*), live oak, and white cedar with high wind resistance in at least two or more studies. Species that received the lowest wind resistance ratings in two or more studies were Australian pine (*Casuarina equisetifolia*), Honduras mahogany (*Swietenia macrophylla*), swamp mahogany (*Eucalyptus robusta*), and Caribbean pine (*Pinus caribaea*).

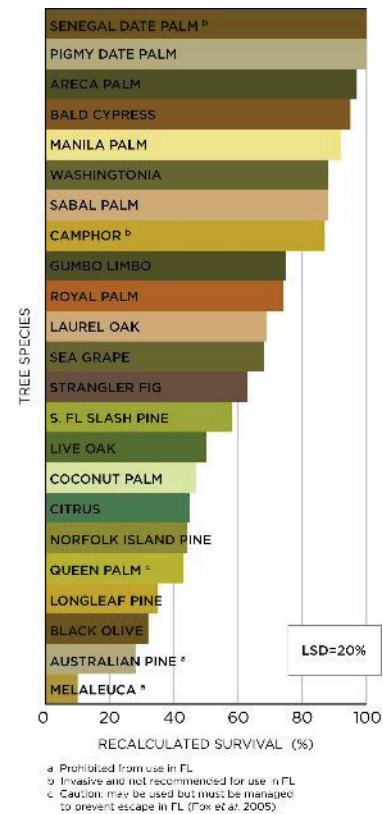


Figure 4. A recalculation of survival (%) after considering trees with greater than or equal to 50% branch loss as dead after Hurricane Charley.

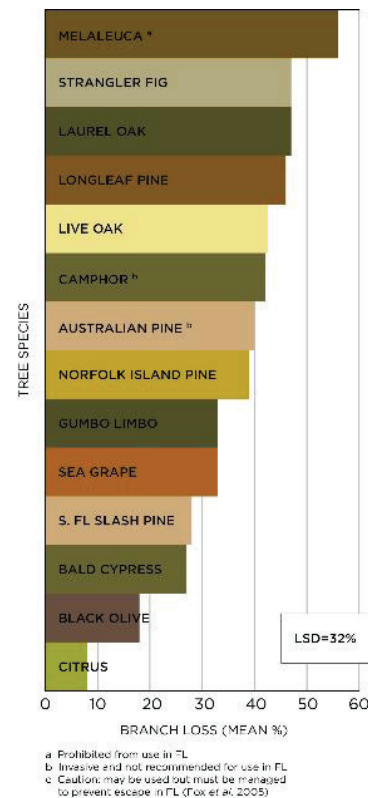


Figure 5. Branch loss (%) for each tree species in Hurricane Charley, which struck land at 233 km/h (130 mph).

In the urban areas of the southeastern coastal plain, laurel oak trees did not survive as well as live oak and sand live oak (*Quercus geminata*) in four hurricanes (Duryea *et al.* 2007b). However, in the two south Florida hurricanes, both survival and branch loss for live and laurel oaks were similar (Figures 4 and 5). We also compared large trees of these species (greater than 50 cm diameter) and found that their survival, branch loss, and re-calculated survival were not significantly different in Jeanne and Charley (Figure 6).

Speculations about the reasons for lack of difference between live oak and laurel oak in south Florida include:

(1) Laurel oak in south Florida may be a different cultivar or variety than those in north Florida and (2) sandier soils in south Florida and their accompanying lower site quality may result in laurel oaks with shorter heights or lower height-to-diameter ratio (as occurs between the north Florida and south Florida varieties of slash pine (*Pinus elliotii* var. *elliotii* and var. *densa*). Still, many authors point to live oak as a tree with strong wood and little failure in hurricanes (Touliatos and Roth 1971; Swain 1979; Hook *et al.* 1991; Barry *et al.* 1993).



Figure 6. When compared to live oaks, laurel oaks in south Florida (above) showed no statistical difference for either survival, branch loss, or re-calculated survival in Hurricanes Charley and Jeanne.

## CONIFERS

Of the conifer species, baldcypress survived Hurricane Charley the best with 95% survival (Figure 3). Baldcypress also suffered little damage after Hurricane Hugo (Putz and Sharitz 1991; Gresham *et al.* 1991). After Hurricane Andrew, cypress trees in the Everglades National Park were still standing on the edges of the hammocks while many hardwoods had failed (Orr and Ogden 1992). Only 4% of the sand pine (*Pinus clausa*) survived Hurricane Jeanne; sand pine's poor survival has been measured in several

other hurricanes (Duryea 1997; Duryea *et al.* 2007a). South Florida slash pine is next best in wind resistance for the conifers across the south Florida hurricanes (Figure 6); however, longleaf pine (*Pinus palustris*), which is usually similar to slash pine in wind resistance in the coastal plain hurricanes (Duryea *et al.* 2007a), had 57% survival in Hurricane Charley. Survival of south Florida slash pine in pine rockland ecosystems ranged from 78% to 88% in Hurricane Andrew. Mortality of the standing pine trees continued for one year with 17% to 25% dying (Platt *et al.* 2000). We returned three months after Hurricane Charley and found that 27% of the standing south Florida slash pines and 48% of the standing longleaf pines had died.



Figure 7. South Florida slash pine had 79% survival rate after Hurricane Charley.

## PUERTO RICO SPECIES

Of the species measured in Puerto Rico, the species with the highest survival and least branch damage were Santa Maria (*Calophyllum calaba*), Caribbean pine, schefflera, West Indian mahogany, and Oriental arborvitae (*Thuja orientalis*) (Table 2).

Many trees had extensive branch loss that reduced survival further with the most notable species being Norfolk Island pine (*Araucaria heterophylla*), Napoleon's plume (*Bauhinia monandra*), apple blossom (*Cassia javanica*), yellow cassia (*Cassia siamea*), swamp mahogany, mahoe (*Hibiscus elatus*), and African tuliptree. The 24 tree species measured in Francis' study (2000) following Hurricane Georges also showed extensive branch damage ranging from 23% to 81%.

Similar to our study, Francis also found that West Indian mahogany was the best survivor (100% survival) and had the least branch loss, while African tuliptree suffered the most crown loss and was one of the poorest survivors (66% survival) (Francis 2000). Results for black olive and royal poinciana were also similar to those in our study, with trees surviving well (98%) but losing nearly half of their branches.

## NATIVE AND EXOTIC SPECIES

Native tree species survived better in Hurricanes Jeanne, Charley, and Andrew but not in Hurricane Georges (Figure 8).

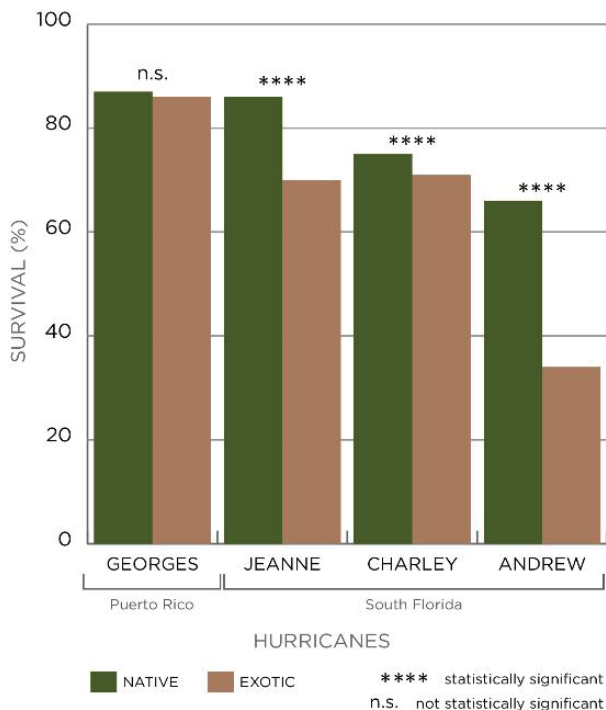


Figure 8. Native trees survived better than exotic trees in three south Florida hurricanes but not in Puerto Rico.

Native species also lost fewer branches than exotic species in Jeanne (21% versus 36%,  $p=0.0001$ ) and Charley (36% versus 39%,  $p=0.0001$ ). Some of the exotic species with low survival were melaleuca, Australian pine, and queen palm, and these can be compared to native species with high survival—live oak, gumbo limbo, and sabal palm. In their extensive review of hurricanes and forest damage, Everham and Brokaw (1996) summarize that there is a trend towards more damage in exotic forest plantations, although they also point out that these exotic forests are often monocultures. Out of the 35 tree species measured after Hurricane Georges in Puerto Rico ( $n=20$ ), only four were native trees to Puerto Rico—Santa Maria, black olive, white cedar, and common calabash tree (*Crescentia cujete*). Santa Maria survived very well (93%), but the other three had 84%, 83%,

and 67% respectively, not surviving better than many of the exotic species (Table 2). Branch loss of exotics and natives in Puerto Rico, too, appeared to be equal (31% for exotics versus 27%, not statistically significant). With few exotic species in the urban forest population, natives also did not survive better in the southeastern US coastal plain during Hurricane Ivan.

## The Survey

Arborists, urban foresters, and scientists confirmed many of our results about wind resistance but also provided new information about some species not frequently seen and measured in the urban forest. Consistent with our results, queen palm was ranked by the experts as the palm with the lowest wind resistance (Table 3). Royal palm and coconut palm were intermediate, again consistent with our results. Sabal palm was ranked high, which is consistent with our results from the tropical and northern areas of Florida (Duryea 1996; Duryea 1997; Duryea *et al.* 2007a). Some of the species with little information from our studies that were ranked high by the experts include pond apple (*Annona glabra*), cocoplum (*Chrysobalanus icaco*), and lignum vitae (*Guaiacum sanctum*). Species with little research information that were ranked with low wind resistance include weeping banyan, jacaranda (*Jacaranda mimosifolia*), and golden trumpet (*Tabebuia chrysotricha*). Species ranked with high wind resistance in agreement with our results were crape myrtle (*Lagerstroemia indica*), dahoon holly (*Ilex cassine*), southern magnolia (*Magnolia grandiflora*), sand live oak, live oak, and both species of cypress (*Taxodium distichum* and *T. ascendens*). One perplexing species is West Indian mahogany, which fared reasonably well in Georges and Andrew (Table 1); however, the survey respondents ranked it with medium to low wind resistance. In agreement with our results but in contrast to the survey results, another study of 24 species experiencing Hurricane Georges found West Indian mahogany had the best survival and the least branch loss (Francis 2000).

## Recommendations

Taking the results from our studies and incorporating the survey results and the scientific literature, we have developed lists of relative wind resistance for tropical and subtropical tree species (Table 4). These lists should be used with caution, with the knowledge that no species and no tree is completely wind proof, and with the consideration of local soil conditions, tree age, structure and health, and other urban forest conditions. In addition, hurricane characteristics other than wind, such as rain amount and storm duration, can also influence the ability of trees to

survive hurricanes. In their thorough review of forest damage from wind, Everham and Brokaw (1996) concluded that species differences do exist and can be explained by differences in wood density, canopy architecture, rooting patterns, susceptibility to diseases, and bole shape. Yet these differences, they say, can also be masked by varied soil conditions, exposure, wind intensity, and cultural practices.

## Important Recommendations

- One of the most important findings reported is the rooting space results: the more rooting space that a tree has, the healthier it is, meaning better anchorage and resistance to wind.
- Another important cultural practice for broadleaved trees is pruning. Pruning conferred more wind resistance to trees and should be considered an important practice for tree health and wind resistance.
- Trees growing in groups or clusters were also more wind resistant compared to individual trees. This might be an especially good strategy for tree establishment in parks or larger yards.
- Especially in south Florida, native trees appear to survive winds better than exotics. When considering species to plant, know which exotic species do not fare well in wind—some of these include melaleuca, Australian pine, queen palm, African tulip tree, and weeping banyan.

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Table 1. Survival of tropical and subtropical tree species after four hurricanes\*

Tree Species	Survival (%) After Each Hurricane (Wind Speed in km/h; mph)			
	Georges (177 km/h; 110 mph)	Jeanne (193 km/h; 120 mph)	Charley (233 km/h; 145 mph)	Andrew (265 km/h; 165 mph)
<b>Dicots</b>				
<i>Araucaria heterophylla</i>	88	—	74	—
<i>Bucida buceras</i>	84	—	57	68
<i>Bursera simarouba</i>	—	—	89	84
<i>Callistemon viminalle</i>	—	—	—	52
<i>Carya floridana</i>	—	83	—	—
<i>Casuarina equisetifolia</i> <sup>a</sup>	—	—	57	4
<i>Cinnamomum camphora</i> <sup>b</sup>	—	—	90	—
<i>Citrus</i> spp.	—	67	74	25 to 66
<i>Coccoloba uvifera</i>	—	—	84	64
<i>Delonix regia</i> <sup>c</sup> (in S. FL)	94	—	—	57
<i>Eugenia foetida</i>	—	—	—	96
<i>Ficus aurea</i>	—	—	84	—
<i>Mangifera indica</i>	76	—	—	60
<i>Melaleuca quinquenervia</i> <sup>a</sup>	65	75	45	79
<i>Persea americana</i>	—	—	—	46
<i>Quercus geminata</i>	—	94	—	—
<i>Quercus laurifolia</i>	—	94	86	—
<i>Quercus virginiana</i>	—	97	78	78
<i>Schefflera actinophylla</i> <sup>b</sup> (in C. and S. FL)	87	—	—	85
<i>Swietenia mahagoni</i>	92	—	—	75
<i>Tabebuia heterophylla</i>	83	—	—	72
<b>Monocots – Palms</b>				
<i>Chrysalidocarpus lutescens</i>	94	—	97	93
<i>Cocos nucifera</i>	77	—	77	41
<i>Phoenix reclinata</i> <sup>b</sup> (in S. FL)	—	—	100	—
<i>Phoenix roebelenii</i>	—	100	100	—
<i>Roystonea elata</i> (R. borinquena in PR)	93	—	87	63
<i>Sabal palmetto</i>	—	92	92	93
<i>Syagrus romanzoffiana</i> <sup>c</sup> (in S. FL)	—	74	69	42
<i>Veitchia merrillii</i>	89	—	95	—
<i>Washingtonia robusta</i>	—	80	92	—
<b>Conifers</b>				
<i>Pinus clausa</i>	—	4	—	—
<i>Pinus elliottii</i> var. <i>densa</i> ( <i>P. caribaea</i> in PR)	89	90	79	73
<i>Pinus palustris</i>	—	—	57	—
<i>Taxodium distichum</i>	—	—	95	—

<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 (Fox et al. 2005)

\*Survival is defined as the percentage of trees still standing after the hurricane. Numbers are only presented for tree species having a sample size greater than 20 trees for each hurricane. Least Significant Differences at  $p=0.05$  are 16% for Georges, 35% for Jeanne, and 30% for Charley; Andrew survival percentages are from Duryea et al. 1996.



Table 2. Survival and branch loss of tree species in Puerto Rico after Hurricane Georges (110 mph)\*

Tree Species	Sample Size	Survival (%)	Branch Loss (%)	Re-calculated Survival (%)
<i>Araucaria heterophylla</i>	25	88	41	52
<i>Bauhinia monandra</i>	31	71	41	39
<i>Bucida buceras</i>	286	84	33	59
<i>Callistemon citrinus</i>	42	81	12	69
<i>Calophyllum calaba</i> <sup>c</sup> (in S. FL)	295	93	20	81
<i>Cassia javanica</i>	28	86	42	57
<i>Cassia siamea</i>	94	85	53	30
<i>Crescentia cujete</i>	21	67	12	62
<i>Cupressus sempervirens</i>	31	29	7	29
<i>Delonix regia</i> <sup>c</sup> (in S. FL)	194	94	33	68
<i>Enterolobium cyclocarpum</i>	20	100	23	85
<i>Eucalyptus robusta</i>	69	86	59	28
<i>Ficus benjamina</i>	65	83	25	63
<i>Ficus macrocarpa</i>	33	76	18	67
<i>Ficus microcarpa</i> <sup>c</sup> (in C. & S. FL)	22	100	25	73
<i>Hibiscus elatus</i>	25	100	63	20
<i>Lagerstroemia speciosa</i>	138	88	28	70
<i>Mangifera indica</i>	76	76	36	51
<i>Melaleuca quinquenervia</i> <sup>a</sup>	37	65	21	57
<i>Melicoccus bijugatus</i>	22	82	25	64
<i>Pinus caribaea</i>	53	89	16	85
<i>Pterocarpus indicus</i>	32	97	29	75
<i>Pterocarpus macrocarpus</i>	43	95	33	77
<i>Schefflera actinophylla</i> <sup>b</sup> (in C. & S. FL)	24	88	17	79
<i>Spathodea campanulata</i>	24	67	52	37
<i>Swietenia mahagoni</i>	146	92	21	80
<i>Swietenia macrophylla</i>	69	74	28	64
<i>Swietenia macrophylla</i> x <i>mahagoni</i>	36	89	43	58
<i>Tabebuia heterophylla</i>	334	83	26	65
<i>Terminalia cattapa</i> <sup>c</sup> (in S. FL)	44	89	35	52
<i>Thuja orientalis</i>	36	92	16	86
Least Significant Difference, p=0.05	—	16	21	23

<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 (Fox et al. 2005)

\*Reported rates exclude Palms (see Table 1). Re-calculated survival was calculated by subtracting trees with = 50% branch loss. Numbers are only presented for tree species having a sample size greater than 20 trees for each hurricane.

Table 3. Survey results for wind resistance of tropical and subtropical tree species\*

Scientific Name	Common Name	Wind Resistance						p-value	Total N
		High		Medium		Low			
		N	%	N	%	N	%		
<i>Acer rubrum</i>	red maple	12	<b>20</b>	32	<b>52</b>	17	<b>28</b>	0.0049	61
<i>Annona glabra</i>	pond apple	10	<b>71</b>	4	<b>29</b>	0	<b>0</b>	n.s.	14
<i>Araucaria heterophylla</i>	Norfolk Island pine	8	<b>18</b>	14	<b>31</b>	23	<b>51</b>	0.0224	45
<i>Averrhoa carambola</i>	star-fruit or carambola	3	<b>18</b>	6	<b>35</b>	8	<b>47</b>	n.s.	17
<i>Bauhinia blakeana</i>	Hong Kong orchid	1	<b>5</b>	9	<b>41</b>	12	<b>54</b>	0.0122	22
<i>Bucida buceras</i>	black olive	8	<b>30</b>	14	<b>52</b>	5	<b>18</b>	0.0538	27
<i>Bursera simarouba</i>	gumbo limbo	21	<b>64</b>	10	<b>30</b>	2	<b>6</b>	0.0007	33
<i>Callistemon</i> spp	bottlebrush	8	<b>21</b>	23	<b>61</b>	7	<b>18</b>	0.0018	38
<i>Calophyllum calaba</i> <sup>c</sup> (in S. FL)	Brazilian beautyleaf	6	<b>38</b>	8	<b>50</b>	2	<b>12</b>	n.s.	16
<i>Cassia fistula</i>	golden shower	4	<b>18</b>	7	<b>32</b>	11	<b>50</b>	n.s.	22
<i>Ceiba</i> (or <i>Chorisia</i> ) <i>speciosa</i>	floss-silk	4	<b>18</b>	12	<b>55</b>	6	<b>27</b>	0.0498	22
<i>Chrysobalanus icaco</i>	cocoplum	18	<b>78</b>	5	<b>22</b>	0	<b>0</b>	0.0067	23
<i>Chrysophyllum oliviforme</i>	satinleaf	11	<b>61</b>	7	<b>39</b>	0	<b>0</b>	n.s.	18
<i>Citrus</i> spp.	citrus (lime, orange, etc.)	18	<b>44</b>	18	<b>44</b>	5	<b>12</b>	0.0162	41
<i>Coccoloba diversifolia</i>	pigeon plum	11	<b>58</b>	8	<b>42</b>	0	<b>0</b>	n.s.	19
<i>Coccoloba uvifera</i>	sea grape	18	<b>50</b>	12	<b>33</b>	6	<b>17</b>	0.0498	36
<i>Conocarpus erectus</i>	buttonwood	11	<b>35</b>	17	<b>55</b>	3	<b>10</b>	0.0084	31
<i>Cordia sebestena</i>	geiger tree	8	<b>33</b>	13	<b>54</b>	3	<b>12</b>	0.0439	24
<i>x Cupressocyparis leylandii</i>	leyland cypress	7	<b>22</b>	13	<b>41</b>	12	<b>37</b>	n.s.	32
<i>Delonix regia</i> <sup>c</sup> (in S. FL)	royal poinciana	2	<b>6</b>	20	<b>63</b>	10	<b>31</b>	0.0005	32
<i>Enterolobium cyclocarpum</i>	ear tree	1	<b>5</b>	7	<b>33</b>	13	<b>62</b>	0.0058	21
<i>Eriobotrya japonica</i> <sup>c</sup> (in S. & C. FL)	loquat	9	<b>24</b>	24	<b>63</b>	5	<b>13</b>	0.0004	38
<i>Eucalyptus cinerea</i>	silver dollar eucalyptus	2	<b>13</b>	9	<b>56</b>	5	<b>31</b>	n.s.	16
<i>Eugenia axillaris</i>	white stopper	7	<b>64</b>	3	<b>27</b>	1	<b>9</b>	n.s.	11
<i>Eugenia foetida</i>	boxleaf, Spanish stopper	7	<b>64</b>	2	<b>18</b>	2	<b>18</b>	n.s.	11
<i>Ficus aurea</i>	strangler fig	4	<b>36</b>	5	<b>46</b>	2	<b>18</b>	n.s.	11
<i>Ficus benjamina</i>	weeping banyan	0	<b>0</b>	2	<b>18</b>	9	<b>82</b>	0.0348	11
<i>Grevillea robusta</i>	silk oak	1	<b>4</b>	8	<b>32</b>	16	<b>64</b>	0.0012	25
<i>Guaiacum sanctum</i>	lignumvitae	10	<b>83</b>	2	<b>17</b>	0	<b>0</b>	0.0209	12
<i>Ilex cassine</i>	dahoon holly	35	<b>76</b>	10	<b>22</b>	1	<b>2</b>	0.0001	46
<i>Jacaranda mimosifolia</i>	jacaranda, black poui	1	<b>7</b>	2	<b>13</b>	12	<b>80</b>	0.0006	15
<i>Juniperus silicicola</i>	SE red cedar	14	<b>28</b>	18	<b>35</b>	19	<b>37</b>	n.s.	51

Scientific Name	Common Name	Wind Resistance						p-value	Total N
		High		Medium		Low			
		N	%	N	%	N	%		
<i>Kigelia pinnata</i>	sausage tree	7	<b>41</b>	6	<b>35</b>	4	<b>24</b>	n.s.	17
<i>Koelreuteria paniculata</i>	golden raintree	11	<b>37</b>	11	<b>37</b>	8	<b>26</b>	n.s.	30
<i>Krugiodendron ferreum</i>	ironwood	10	<b>77</b>	3	<b>23</b>	0	<b>0</b>	n.s.	13
<i>Lagerstroemia indica</i>	crape myrtle	55	<b>83</b>	11	<b>17</b>	0	<b>0</b>	0.0001	66
<i>Ligustrum japonicum</i>	privet	30	<b>75</b>	9	<b>23</b>	1	<b>2</b>	0.0001	40
<i>Liquidambar styraciflua</i>	sweetgum	19	<b>43</b>	22	<b>50</b>	3	<b>7</b>	0.0013	44
<i>Litchi chinensis</i>	lychee	8	<b>57</b>	5	<b>36</b>	1	<b>7</b>	n.s.	14
<i>Lysiloma latisiliqua</i>	wild tamarind	9	<b>50</b>	6	<b>33</b>	3	<b>17</b>	n.s.	18
<i>Magnolia grandiflora</i>	SE magnolia	45	<b>82</b>	9	<b>16</b>	1	<b>2</b>	0.0001	55
<i>Mangifera indica</i>	mango tree	6	<b>20</b>	16	<b>53</b>	8	<b>27</b>	n.s.	30
<i>Peltophorum pterocarpa</i>	yellow poinciana	1	<b>5</b>	15	<b>68</b>	6	<b>27</b>	0.0010	22
<i>Persea americana</i>	avocado tree	1	<b>3</b>	20	<b>63</b>	11	<b>34</b>	0.0002.	32
<i>Pinus clausa</i>	sand pine	3	<b>7</b>	7	<b>16</b>	34	<b>77</b>	0.0001	44
<i>Pinus elliotii</i> var. <i>densa</i>	FL slash pine	18	<b>38</b>	25	<b>52</b>	5	<b>10</b>	0.0016	48
<i>Pinus palustris</i>	longleaf pine	23	<b>56</b>	13	<b>32</b>	5	<b>12</b>	0.0017	41
<i>Podocarpus</i> spp.	podocarpus	24	<b>75</b>	7	<b>22</b>	1	<b>3</b>	0.0001	32
<i>Prunus caroliniana</i>	carolina laurel cherry	5	<b>16</b>	15	<b>48</b>	11	<b>36</b>	n.s.	31
<i>Quercus geminata</i>	sand live oak	36	<b>92</b>	2	<b>5</b>	1	<b>3</b>	0.0001	39
<i>Quercus laurifolia</i>	laurel oak	3	<b>4</b>	27	<b>39</b>	39	<b>57</b>	0.0001	69
<i>Quercus nigra</i>	water oak	3	<b>8</b>	14	<b>36</b>	22	<b>56</b>	0.0009	39
<i>Quercus stellata</i>	post oak	5	<b>33</b>	10	<b>67</b>	0	<b>0</b>	n.s.	15
<i>Quercus virginiana</i>	live oak	64	<b>89</b>	8	<b>11</b>	0	<b>0</b>	0.0001	72
<i>Sideroxylon foetidissimum</i>	mastic tree	3	<b>30</b>	6	<b>60</b>	1	<b>10</b>	n.s.	10
<i>Simarouba glauca</i>	paradise tree	5	<b>42</b>	5	<b>42</b>	2	<b>16</b>	n.s.	12
<i>Spathodea campanulata</i>	African tuliptree	0	<b>0</b>	6	<b>38</b>	10	<b>62</b>	n.s.	16
<i>Swietenia mahagoni</i>	West Indian mahagony	2	<b>9</b>	13	<b>56</b>	8	<b>35</b>	n.s.	23
<i>Tabebuia aurea</i>	silver trumpet	0	<b>0</b>	4	<b>33</b>	8	<b>67</b>	n.s.	12
<i>Tabebuia chrysotricha</i>	golden trumpet	2	<b>7</b>	5	<b>18</b>	21	<b>75</b>	0.0001	28
<i>Tabebuia heterophylla</i>	white cedar	0	<b>0</b>	6	<b>55</b>	5	<b>45</b>	n.s.	11
<i>Tabebuia impetiginosa</i>	purple tabebuia, ipe	3	<b>12</b>	12	<b>50</b>	9	<b>38</b>	n.s.	24
<i>Tecoma stans</i>	yellow elder	0	<b>0</b>	8	<b>73</b>	3	<b>27</b>	n.s.	11
<i>Terminalia catappa</i> <sup>c</sup> (in S. FL)	tropical almond	3	<b>20</b>	8	<b>53</b>	4	<b>27</b>	n.s.	15

Scientific Name	Common Name	Wind Resistance						p-value	Total N
		High		Medium		Low			
		N	%	N	%	N	%		
<i>Taxodium distichum</i>	baldcypress	59	<b>91</b>	6	<b>9</b>	0	<b>0</b>	0.0001	65
<i>Taxodium ascendens</i>	pondcypress	41	<b>91</b>	4	<b>9</b>	0	<b>0</b>	0.0001	45
<b>Palms</b>									
<i>Butia capitata</i>	pindo	34	<b>79</b>	7	<b>16</b>	2	<b>5</b>	0.0001	43
<i>Caryota mitis</i>	fishtail	8	<b>38</b>	6	<b>29</b>	7	<b>33</b>	n.s.	21
<i>Chrysalidocarpus lutescens</i>	areca	19	<b>63</b>	11	<b>37</b>	0	<b>0</b>	n.s.	30
<i>Coccothrinax argentata</i>	FL silver, silver thatch	21	<b>95</b>	1	<b>5</b>	0	<b>0</b>	0.0001	22
<i>Cocos nucifera</i>	coconut	22	<b>63</b>	13	<b>37</b>	0	<b>0</b>	n.s.	35
<i>Hyophorbe lagenicaulis</i>	bottle	13	<b>81</b>	3	<b>19</b>	0	<b>0</b>	0.0124	16
<i>Hyophorbe verschaffeltii</i>	spindle	11	<b>79</b>	2	<b>14</b>	1	<b>7</b>	0.0015	14
<i>Latania loddigesii</i>	blue latan	8	<b>67</b>	3	<b>25</b>	1	<b>8</b>	0.0388	12
<i>Livistona chinensis</i> c (in S. & C. FL)	chinese fan	29	<b>71</b>	9	<b>22</b>	3	<b>7</b>	0.0001	41
<i>Neodypsis decaryi</i>	triangle	14	<b>58</b>	6	<b>25</b>	4	<b>17</b>	0.0302	24
<i>Phoenix canariensis</i>	Canary Island date	49	<b>89</b>	4	<b>7</b>	2	<b>4</b>	0.0001	55
<i>Phoenix dactylifera</i>	date	33	<b>94</b>	2	<b>6</b>	0	<b>0</b>	0.0001	35
<i>Phoenix reclinata</i> <sup>b</sup> (in S. FL)	Senegal date	29	<b>85</b>	5	<b>15</b>	0	<b>0</b>	0.0001	34
<i>Phoenix roebelenii</i>	pygmy date	40	<b>98</b>	1	<b>2</b>	0	<b>0</b>	0.0001	41
<i>Ptychosperma elegans</i>	Alexander, solitary	16	<b>73</b>	6	<b>27</b>	0	<b>0</b>	0.0330	22
<i>Roystonea elata</i>	Florida royal	19	<b>56</b>	10	<b>29</b>	5	<b>15</b>	0.0118	34
<i>Roystonea regia</i>	Cuban royal	17	<b>61</b>	10	<b>36</b>	1	<b>4</b>	0.0010	28
<i>Sabal palmetto</i>	cabbage	71	<b>99</b>	1	<b>1</b>	0	<b>0</b>	0.0001	72
<i>Syagrus romanzoffiana</i> <sup>c</sup> (in S. FL)	queen	5	<b>10</b>	17	<b>33</b>	29	<b>57</b>	0.0002	51
<i>Thrinax morrisii</i>	Key thatch	13	<b>87</b>	2	<b>13</b>	0	<b>0</b>	0.0045	15
<i>Thrinax radiata</i>	Florida thatch	17	<b>89</b>	2	<b>11</b>	0	<b>0</b>	0.0006	19
<i>Veitchia merrillii</i>	Manila, Christmas	13	<b>81</b>	3	<b>19</b>	0	<b>0</b>	0.0124	16
<i>Washingtonia robusta</i>	Washington fan	29	<b>54</b>	16	<b>30</b>	9	<b>17</b>	0.0033	54

<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 (Fox et al. 2005)

\*Results of the survey of arborists, scientists, and urban foresters in Florida with their rankings for wind resistance of tropical and subtropical tree species. N is the number of respondents for each species, out of a total of 85 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 4. Wind resistance of tropical and subtropical tree species\*

Highest Wind Resistance	Medium–High Wind Resistance
<b>Dicots</b>	<b>Dicots</b>
<p><i>Bursera simaruba</i>, gumbo limbo  <i>Carya Floridaana</i>, Florida scrub hickory  <i>Conocarpus erectus</i>, buttonwood  <i>Chrysobalanus icaco</i>, cocoplum  <i>Cordia sebestena</i>, geiger tree  <i>Eugenia axillaris</i>, white stopper  <i>Eugenia confusa</i>, redberry  <i>Eugenia foetida</i>, boxleaf stopper  <i>Guaiacum sanctum</i>, lignum vitae  <i>Ilex cassine</i>, dahoon holly  <i>Krugiodendrum ferreum</i>, ironwood  <i>Lagerstroemia indica</i>, crape myrtle  <i>Magnolia grandiflora</i>, southern magnolia  <i>Podocarpus</i> spp, <i>podocarpus Quercus virginiana</i>, live oak  <i>Quercus geminata</i>, sand live oak</p>	<p><i>Annona glabra</i>, pond apple  <i>Calophyllum calaba</i>, Brazilian beautyleaf<sup>f</sup>  <i>Chrysophyllum oliviforme</i>, satinleaf  <i>Coccoloba uvifera</i>, sea grape  <i>Coccoloba diversifolia</i>, pigeon plum  <i>Liquidambar styraciflua</i>, sweetgum  <i>Lysiloma latsiliqua</i>, wild tamarind  <i>Magnolia virginiana</i>, sweetbay magnolia  <i>Nyssa sylvatica</i>, black tupelo  <i>Sideroxylon foetidissimum</i>, mastic  <i>Simarouba glauca</i>, paradise tree  <i>Swietenia mahagoni</i>, mahogany</p>
<b>Conifers</b>	<b>Conifers</b>
<p><i>Taxodium ascendens</i>, pondcypress  <i>Taxodium distichum</i>, baldcypress</p>	N/A
<b>Palms</b>	<b>Palms</b>
<p><i>Butia capitata</i>, pindo or jelly  <i>Dypsis lutescens</i>, areca  <i>Coccothrinax argentata</i>, Florida silver  <i>Hyophorbe lagenicaulis</i>, bottle  <i>Hyophorbe verschaffeltii</i>, spindle  <i>Latania loddigesii</i>, blue latan  <i>Livistona chinensis</i>, Chinese fan<sup>p</sup>  <i>Phoenix canariensis</i>, Canary Island date  <i>Phoenix dactylifera</i>, date  <i>Phoenix reclinata</i>, Senegal date<sup>p</sup>  <i>Phoenix roebelenii</i>, pygmy date  <i>Ptychoesperma elegans</i>, Alexander  <i>Sabal palmetto</i>, cabbage, <i>sabal</i>  <i>Thrinax morrisii</i>, key thatch  <i>Thrinax radiata</i>, Florida thatch  <i>Veitchia merrillii</i>, Manila</p>	<p><i>Caryota mitis</i>, fishtail  <i>Cocos nucifera</i>, coconut  <i>Dypsis decaryi</i>, triangle  <i>Roystonea elata</i>, royal</p>
<b>Fruit Trees</b>	<b>Fruit Trees</b>
N/A	<i>Litchi chinensis</i> , lychee
Medium–Low Wind Resistance	Lowest Wind Resistance
<b>Dicots</b>	<b>Dicots</b>
<p><i>Acer rubrum</i>, red maple  <i>Bauhinia blakeana</i>, Hong-Kong orchid  <i>Bucidas buceras</i>, black olive  <i>Callistemon</i> spp, bottlebrush  <i>Cinnamomum camphora</i>, camphor<sup>b</sup>  <i>Delonix regia</i>, royal poinciana<sup>c</sup>  <i>Enterolobium cyclocarpum</i>, ear tree  <i>Eriobotrya japonica</i>, loquat<sup>c</sup>  <i>Eucalyptus cinerea</i>, silverdollar eucalyptus  <i>Ficus aurea</i>, strangler fig  <i>Kigelia pinnata</i>, sausage tree  <i>Myrica cerifera</i>, wax myrtle  <i>Persea borbonia</i>, redbay  <i>Platanus occidentalis</i>, sycamore  <i>Quercus laurifolia</i>, laurel oak  <i>Tabebuia heterophylla</i>, pink trumpet tree  <i>Terminalia catappa</i>, tropical almond<sup>c</sup></p>	<p><i>Casuarina equisetifolia</i>, Australian pine<sup>a</sup>  <i>Cassia fistula</i>, golden shower  <i>Chorisia speciosa</i>, floss-silk tree  <i>Ficus benjamina</i>, weeping banyan  <i>Grevillea robusta</i>, silk oak  <i>Jacaranda mimosifolia</i>, jacaranda  <i>Melaleuca quinquenervia</i>, melaleuca<sup>a</sup>  <i>Quercus nigra</i>, water oak  <i>Peltophorum pterocarpa</i>, yellow poinciana  <i>Prunus caroliniana</i>, Carolina laurelcherry  <i>Sapium sebiferum</i>, Chinese tallow<sup>a</sup>  <i>Spathodea campanulata</i>, African tuliptree  <i>Tabebuia caraiba</i>, silver trumpet tree  <i>Ulmus parvifolia</i>, Chinese elm</p>

<b>Conifers</b>	<b>Conifers</b>
<i>Pinus elliottii</i> , slash pine <i>Pinus palustris</i> , longleaf pine	<i>Araucaria heterophylla</i> , Norfolk Island pine <i>Cupressocyparis leylandii</i> , Leyland cypress <i>Juniperus silicicola</i> , southern red cedar <i>Pinus clausa</i> , sand pine
<b>Palms</b>	<b>Palms</b>
N/A	<i>Syagnus romanzoffiana</i> , queen <sup>c</sup> <i>Washingtonia robusta</i> , Washington fan
<b>Fruit trees</b>	<b>Fruit trees</b>
<i>Averrhoa carambola</i> , star-fruit, carambola <i>Citrus spp</i> , oranges, limes, grapefruits <i>Mangifera indica</i> , mango	<i>Persea americana</i> , avocado
<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 (Fox et al. 2005) *Wind resistance of tropical and subtropical tree species as estimated utilizing the hurricane measurements and the survey results in this study, and the scientific literature cited throughout this publication.	