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Selecting Tropical and Subtropical Tree Species for Wind Resistance[1]

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Caryota mitis

View Assessment

South

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

Casuarina equisetifolia

View Assessment

North, Central, South

Prohibited

Prohibited from use in Florida according to the Federal Noxious Weed List, the Florida Department of Agriculture and Consumer Services (FDACS) 5B-64.011 Prohibited Aquatic Plants, or FDACS 5B-57.007 Noxious Weed List.

Chrysalidocarpus lutescens

View Assessment

South

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

Cinnamomum camphora

View Assessment

North, Central

Invasive

Invasive and not recommended by IFAS. Will be reassessed every 10 years. Specified and limited uses may be considered by the IFAS Invasive Plants Working Group

South

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

Cocos nucifera

View Assessment

South

Invasive

Invasive and not recommended by IFAS. Will be reassessed every 10 years. Specified and limited uses may be considered by the IFAS Invasive Plants Working Group

Central

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

Delonix regia

View Assessment

South

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

Eriobotrya japonica

View Assessment

Central, South

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

Eucalyptus cinerea

View Assessment

North, Central, South

High Invasion Risk

Predicted to be invasive and not recommended by IFAS. Will be reassessed every 10 years. In particular cases, this species may be considered for use under specific management practices that have been approved by the IFAS Invasive Plant Working Group.

Eucalyptus robusta

View Assessment

North, Central, South

High Invasion Risk

Predicted to be invasive and not recommended by IFAS. Will be reassessed every 10 years. In particular cases, this species may be considered for use under specific management practices that have been approved by the IFAS Invasive Plant Working Group.

Ficus microcarpa

View Assessment

Central, South

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

Ligustrum japonicum

View Assessment

North, Central, South

High Invasion Risk

Predicted to be invasive and not recommended by IFAS. Will be reassessed every 10 years. In particular cases, this species may be considered for use under specific management practices that have been approved by the IFAS Invasive Plant Working Group.

Livistona chinensis

View Assessment

North, Central, South

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

Mangifera indica

View Assessment

Central, South

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

Melaleuca quinquenervia

View Assessment

North, Central, South

Prohibited

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Callistemon citrinus *(Melaleuca citrina)*

View Assessment

North, Central, South

High Invasion Risk

Predicted to be invasive and not recommended by IFAS. Will be reassessed every 10 years. In particular cases, this species may be considered for use under specific management practices that have been approved by the IFAS Invasive Plant Working Group.

Phoenix reclinata

View Assessment

South

Invasive

Invasive and not recommended by IFAS. Will be reassessed every 10 years. Specified and limited uses may be considered by the IFAS Invasive Plants Working Group

Ptychosperma elegans

View Assessment

Central, South

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

Spathodea campanulata

View Assessment

South

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

Syagrus romanzoffiana

View Assessment

North, Central, South

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

Tabebuia heterophylla

View Assessment

South

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

Tecoma stans

View Assessment

North, Central, South

High Invasion Risk

Predicted to be invasive and not recommended by IFAS. Will be reassessed every 10 years. In particular cases, this species may be considered for use under specific management practices that have been approved by the IFAS Invasive Plant Working Group.

Bucida buceras *(Terminalia buceras)*

View Assessment

South

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

Terminalia catappa

View Assessment

South

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

Washingtonia robusta (Washingtonia filifera var. robusta)

View Assessment

South

Caution

Caution - manage to prevent escape. May be recommended by IFAS. Will be reassessed in two years.

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 led to lists of relative wind resistance for tropical and subtropical 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.



Figure 1.
Credit: UF/IFAS

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 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).

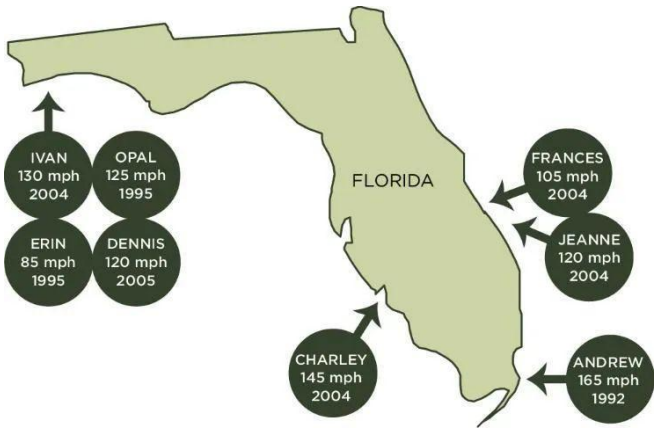


Figure 2. Urban trees were measured following hurricanes striking Florida and Puerto Rico. For each hurricane, the arrow points to the location of landfall. The maximum sustained wind speed (mph) and year are included.
Credit: UF/IFAS

Results

Overall Urban Forest Loss

The percentage 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 Ask IFAS 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 non-native species

Tree Survival and Branch Loss

Palms

Sabal palms along with the smaller palms such as areca (*Chrysalidocarpus lutescens*), Manila (*Veitchia merrilii*), and pygmy 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 can 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 (36 ft) in height, with 42% of the palms above 10 m (32 ft), compared to an average of 4 m (13 ft) and only 7% over 10 m for Charley; perhaps as Washington palms acquire heights of 20 meters (65 feet) and above, their wind resistance starts to decline.

Tree Suvival and Branch Loss: Dicots

Of the dicot tree species, the poorest surviving were melaleuca (*Melaleuca quinquenervia*), Australian pine (*Casuarina equisitifolia*), 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).

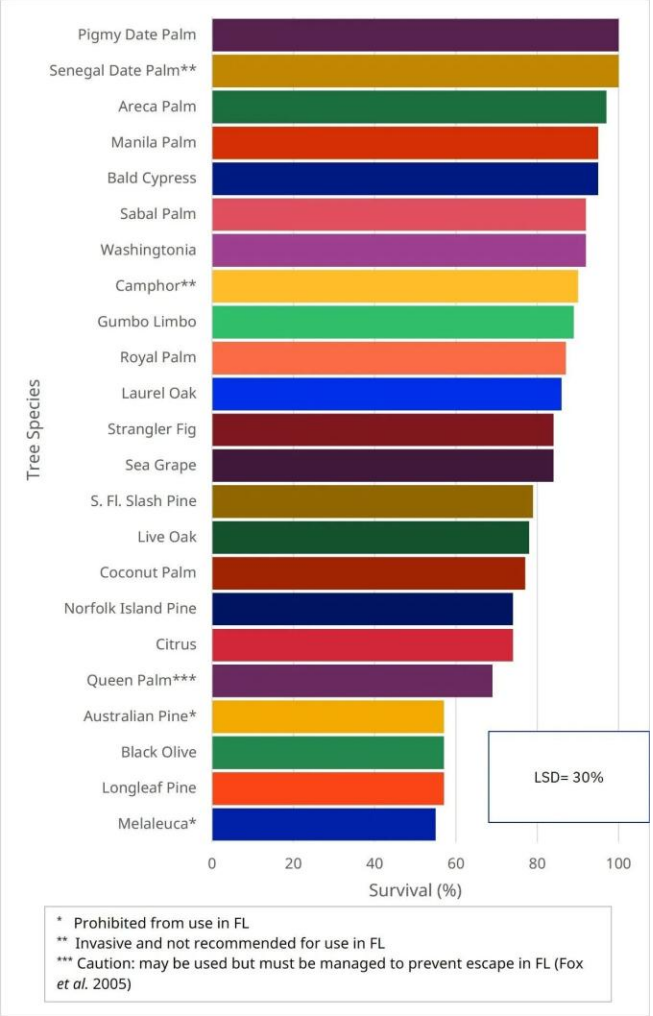


Figure 3. Survival (%) of tree species in Hurricane Charley, which struck at 233 km/h (145 mph).

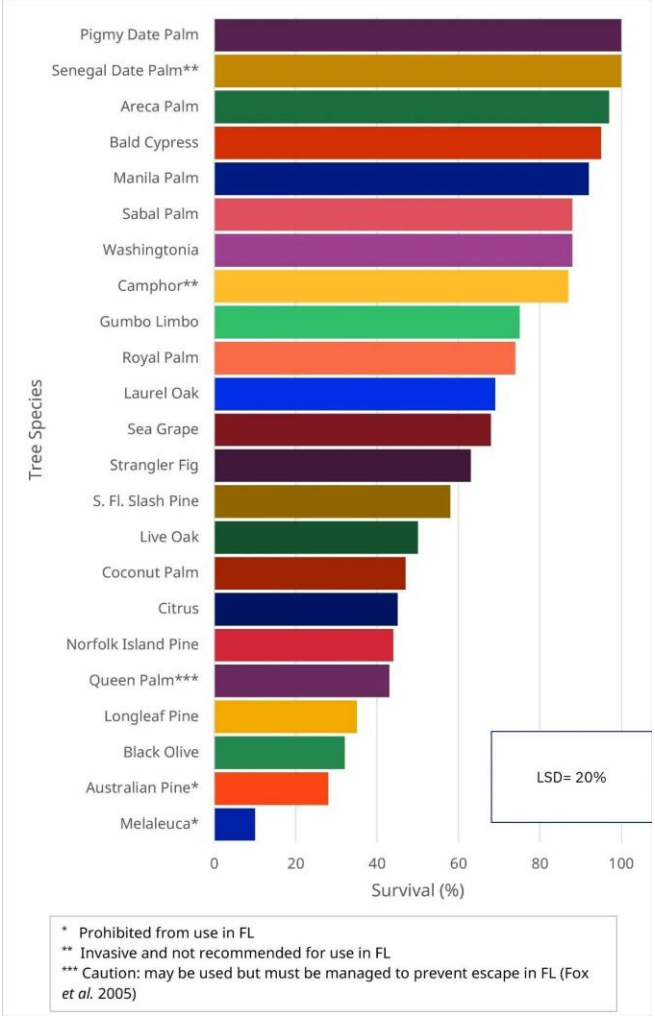


Figure 4. A recalculation of survival (%) after considering trees with greater than or equal to 50% branch loss as dead after Hurricane Charley.

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 considering 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).

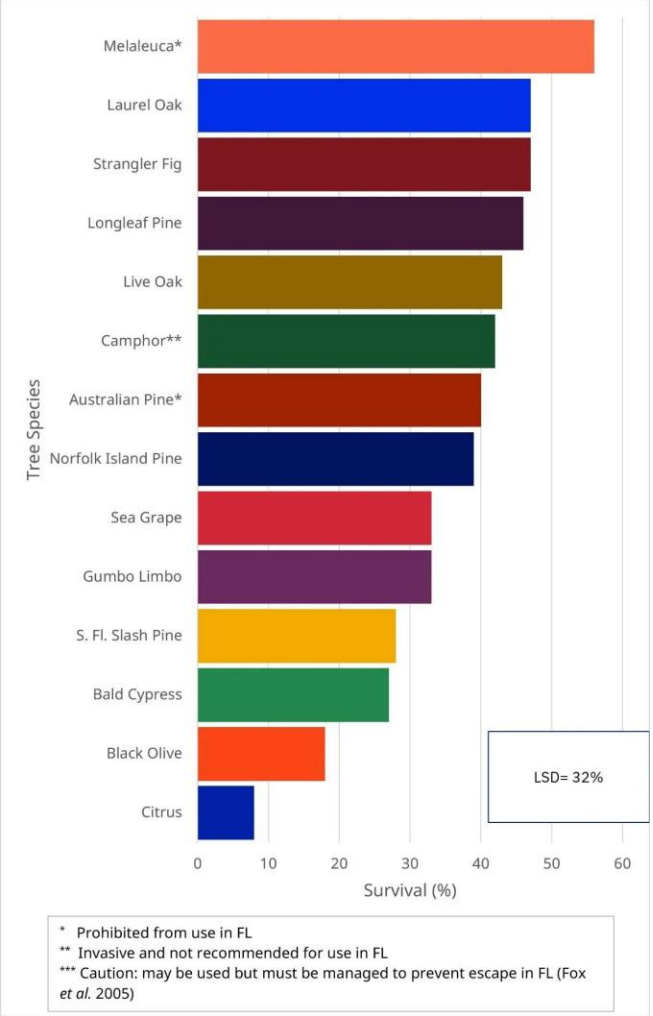


Figure 5. Branch loss (%) for each tree species in Hurricane Charley, which struck land at 233 km/h (130 mph).

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)*.

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 recalculated 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 from 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 elliottii* var. *elliottii* 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).

Tree Survival and Branch Loss: 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.

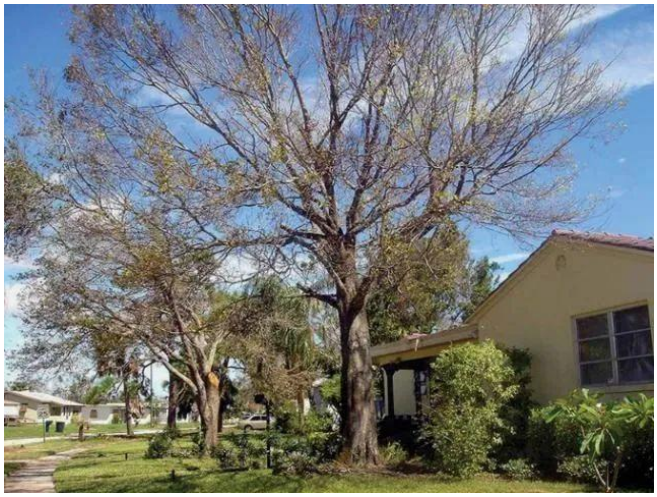


Figure 6. When compared to live oaks, laurel oaks in south Florida (above) showed no statistical difference for either survival, branch loss, or recalculated survival in Hurricanes Charley and Jeanne.
Credit: UF/IFAS



Figure 7. South Florida slash pine had 79% survival rate after Hurricane Charley.
Credit: UF/IFAS

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 Chinese arborvitae (*Platycladus 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 like those in our study, with trees surviving well (98%) but losing nearly half of their branches.

Tree Survival and Branch Loss: Native and Non-Native Species

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

Native species also lost fewer branches than non-native species in Jeanne (21% versus 36%, p=0.0001) and Charley (36% versus 39%, p=0.0001). Some of the non-native 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 non-native forest plantations, although they also point out that these non-native 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 non-native species (Table 2). Branch loss of non-natives and natives in

Puerto Rico, too, appeared to be equal (31% for non-natives versus 27%, not statistically significant). With few non-native species in the urban forest population, natives also did not survive better in the southeastern US coastal plain during Hurricane Ivan.

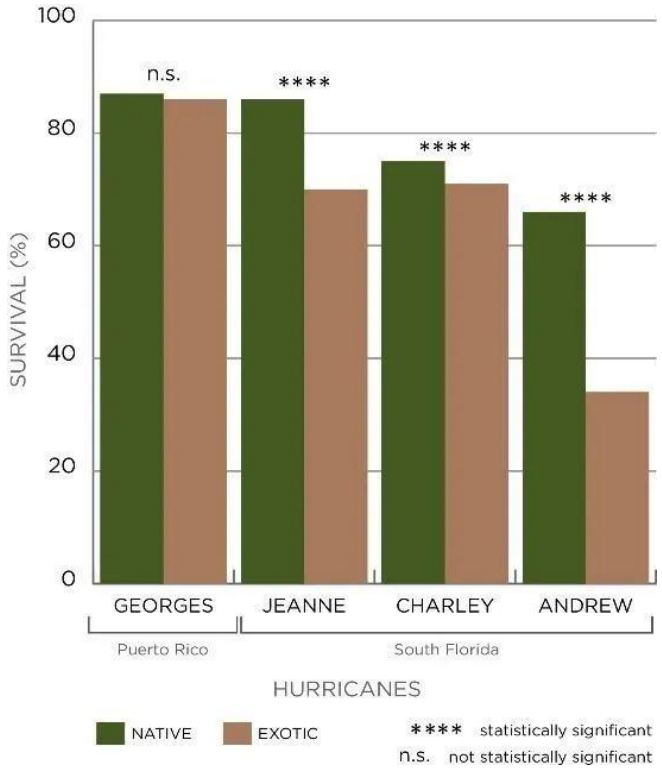


Figure 8. Native trees survived better than non-native trees in three south Florida hurricanes but not in Puerto Rico.

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 windproof, 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 total rainfall 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.

Wind resistance of tropical and subtropical tree species*

[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 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.

Highest Wind Resistance

Dicots

- *Bursera simaruba,* gumbo limbo
- *Carya Floridana,* Florida scrub hickory
- *Conocarpus erectus*, buttonwood
- *Chrysobalanus icaco*, cocoplum
- *Cordia sebestena*, geiger tree
- *Eugenia axillaris,* white stopper
- *Eugenia confusa,* redberry
- *Eugenia foetida*, boxleaf stopper
- *Guaiacum sanctum*, lignum vitae
- *Ilex cassine,* dahoon holly
- *Krugiodendrum ferreum*, ironwood
- *Lagerstroemia indica*, crape myrtle
- *Magnolia grandiflora*, southern magnolia
- *Podocarpus* spp. *podocarpus Quercus virginiana*, live oak
- *Quercus geminata*, sand live oak

Conifers

- *Taxodium ascendens*, pondcypress
- *Taxodium distichum*, baldcypress

Palms

- *Butia capitata*, pindo or jelly
- *Coccothrinax argentata*, Florida silver
- *Dypsis lutescens*, areca
- *Hyophorbe lagenicaulis*, bottle
- *Hyophorbe verschaffeltii,* spindle
- *Latania loddigesii*, blue latan
- *Livistona chinensis*, Chinese fan[b]
- *Phoenix canariensis*, Canary Island date
- *Phoenix dactylifera*, date
- *Phoenix reclinata*, Senegal date[b]
- *Phoenix roebelenii,* pygmy date
- *Ptychoesperma elegans*, Alexander
- *Sabal palmetto,* cabbage, *sabal*
- *Thrinax morrisii,* key thatch
- *Thrinax radiata*, Florida thatch
- *Veitchia merrillii*, Manila

Fruit Trees

- N/A

Medium–High Wind Resistance

Dicots

- *Annona glabra*, pond apple
- *Calophyllum calaba*, Brazilian beautyleaf[c]
- *Chrysophyllum oliviforme*, satinleaf
- *Coccoloba diversifolia*, pigeon plum
- *Coccoloba uvifera,* sea grape
- *Liquidambar styraciflua*, sweetgum
- *Lysiloma latsiliqua,* wild tamarind
- *Magnolia virginiana*, sweetbay magnolia
- *Nyssa sylvatica*, black tupelo
- *Sideroxylon foetidissimum*, mastic
- *Simarouba glauca*, paradise tree
- *Swietenia mahagoni,* mahogany

Conifers

- N/A

Palms

- *Caryota mitis*, fishtail
- *Cocos nucifera,* coconut
- *Dypsis decaryi,* triangle
- *Roystonea elata*, royal

Fruit Trees

- *Litchi chinensis*, lychee

Medium–Low Wind Resistance

Dicots

- *Acer rubrum,* red maple
- *Bauhinia blakeana*, Hong Kong orchid
- *Bucidas buceras*, black olive
- *Callistemon* spp., bottlebrush
- *Cinnamomum camphora,* camphor[b]
- *Delonix regia*, royal poinciana[c]
- *Enterolobium cyclocarpum*, ear tree
- *Eriobotrya japonica*, loquat[c]
- *Eucalyptus cinerea,* silverdollar eucalyptus
- *Ficus aurea*, strangler fig
- *Kigelia pinnata*, sausage tree
- *Myrica cerifera,* wax myrtle
- *Persea borbonia,* redbay
- *Platanus occidentalis,* sycamore
- *Quercus laurifolia,* laurel oak
- *Tabebuia heterophylla*, pink trumpet tree

- *Terminalia catappa*, tropical almond[c]

Conifers

- *Pinus elliottii,* slash pine
- *Pinus palustris,* longleaf pine

Palms

- N/A

Fruit trees

- *Averrhoa carambola*, star-fruit, carambola
- *Citrus* spp., oranges, limes, grapefruits
- *Mangifera indica*, mango

Lowest Wind Resistance

Dicots

- *Casuarina equisetifolia*, Australian pine[a]
- *Cassia fistula*, golden shower
- *Chorisia speciosa*, floss-silk tree
- *Ficus benjamina*, weeping banyan
- *Grevillea robusta*, silk oak
- *Jacaranda mimosifolia*, jacaranda
- *Melaleuca quinquenervia*, melaleuca[a]
- *Peltophorum pterocarpa*, yellow poinciana
- *Prunus caroliniana*, Carolina laurelcherry
- *Quercus nigra*, water oak
- *Sapium sebiferum,* Chinese tallow[a]
- *Spathodea campanulata*, African tuliptree
- *Tabebuia caraiba*, silver trumpet tree
- *Ulmus parvifolia*, Chinese elm

Conifers

- *Araucaria heterophylla*, Norfolk Island pine
- *x Cupressocyparis leylandii,* Leyland cypress
- *Juniperus silicicola*, southern red cedar
- *Pinus clausa*, sand pine

Palms

- *Syagnus romanzoffiana*, queen[c]
- *Washingtonia robusta,* Washington fan

Fruit trees

- *Persea americana*, avocado

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 on 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 non-natives. When considering species to plant, know which non-native species do not fare well in wind—some of these include melaleuca, Australian pine, queen palm, African tuliptree, 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)**
Dicots				
Araucaria heterophylla	88	—	74	—
Bucida buceras	84	—	57	68
Bursera simarouba	—	—	89	84
Callistemon viminalle	—	—	—	52
Carya floridana	—	83	—	—
Casuarina equisitifolia[a]	—	—	57	4
Cinnamomum camphora[b]	—	—	90	—
Citrus spp.	—	67	74	25 to 66
Coccoloba uvifera	—	—	84	64
Delonix regia[c] (in S. FL)	94	—	—	57
Eugenia foetida	—	—	—	96
Ficus aurea	—	—	84	—
Mangifera indica	76	—	—	60
Melaleuca quinquenervia[a]	65	75	45	79
Persea americana	—	—	—	46
Quercus geminata	—	94	—	—
Quercus laurifolia	—	94	86	—
Quercus virginiana	—	97	78	78
Schefflera actinophyla[b] (in C. and S. FL)	87	—	—	85
Swietenia mahagoni	92	—	—	75
Tabebuia heterophylla	83	—	—	72
Monocots—Palms				
Chrysalidocarpus lutescens	94	—	97	93
Cocos nucifera	77	—	77	41
Phoenix reclinata[b] (in S. FL)	—	—	100	—
Phoenix roebelenii	—	100	100	—
Roystonea elata (*R. borinquena* in PR)	93	—	87	63
Sabal palmetto	—	92	92	93
Syagrus romanzoffiana[c] (in S. FL)	—	74	69	42
Veitchia merrilii	89	—	95	—
Washingtonia robusta	—	80	92	—

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)
Conifers				
Pinus clausa	—	4	—	—
Pinus elliottii var. *densa* (*P. caribaea* in PR)	89	90	79	73
Pinus palustris	—	—	57	—
Taxodium distichum	—	—	95	—

[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)

*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 (%)	Recalculated Survival (%)
Araucaria heterophylla	25	88	41	52
Bauhinia monandra	31	71	41	39
Bucida buceras	286	84	33	59
Callistemon citrinus	42	81	12	69
Calophyllum calaba[c] (in S. FL)	295	93	20	81
Cassia javanica	28	86	42	57
Cassia siamea	94	85	53	30
Crescentia cujete	21	67	12	62
Cupressus sempervirens	31	29	7	29
Delonix regia[c] (in S. FL)	194	94	33	68
Enterolobium cyclocarpum	20	100	23	85
Eucalyptus robusta	69	86	59	28
Ficus benjamina	65	83	25	63
Ficus macrocarpa	33	76	18	67
Ficus microcarpa[c] (in C. & S. FL)	22	100	25	73
Hibiscus elatus	25	100	63	20
Lagerstroemia speciosa	138	88	28	70
Mangifera indica	76	76	36	51
Melaleuca quinquenervia[a]	37	65	21	57
Melicoccus bijugatus	22	82	25	64

Tree Species	Sample Size	Survival (%)	Branch Loss (%)	Recalculated Survival (%)
Pinus caribaea	53	89	16	85
Pterocarpus indicus	32	97	29	75
Pterocarpus macrocarpus	43	95	33	77
Schefflera actinophylla[b] (in C. & S. FL)	24	88	17	79
Spathodea campanulata	24	67	52	37
Swietenia mahagoni	146	92	21	80
Swietenia macrophylla	69	74	28	64
Swietenia macrophylla x *mahagoni*	36	89	43	58
Tabebuia heterophylla	334	83	26	65
Terminalia cattapa[c] (in S. FL)	44	89	35	52
Thuja orientalis	36	92	16	86
Least Significant Difference, p=0.05	—	16	21	23

[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)

*Reported rates exclude Palms (see Table 1). Recalculated 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	%		
Acer rubrum	red maple	12	**20**	32	**52**	17	**28**	0.0049	61
Annona glabra	pond apple	10	**71**	4	**29**	0	**0**	n.s.	14
Araucaria heterophylla	Norfolk Island pine	8	**18**	14	**31**	23	**51**	0.0224	45
Averrhoa carambola	star-fruit or carambola	3	**18**	6	**35**	8	**47**	n.s.	17
Bauhinia blakeana	Hong Kong orchid	1	**5**	9	**41**	12	**54**	0.0122	22
Bucida buceras	black olive	8	**30**	14	**52**	5	**18**	0.0538	27
Bursera simarouba	gumbo limbo	21	**64**	10	**30**	2	**6**	0.0007	33
Callistemon spp.	bottlebrush	8	**21**	23	**61**	7	**18**	0.0018	38
Calophyllum calaba[c] (in S. FL)	Brazilian beautyleaf	6	**38**	8	**50**	2	**12**	n.s.	16
Cassia fistula	golden shower	4	**18**	7	**32**	11	**50**	n.s.	22
Ceiba (or *Chorisia) speciosa*	floss-silk	4	**18**	12	**55**	6	**27**	0.0498	22
Chrysobalanus icaco	cocoplum	18	**78**	5	**22**	0	**0**	0.0067	23
Chrysophyllum oliviforme	satinleaf	11	**61**	7	**39**	0	**0**	n.s.	18
Citrus spp.	citrus (lime, orange, etc.)	18	**44**	18	**44**	5	**12**	0.0162	41
Coccoloba diversifolia	pigeon plum	11	**58**	8	**42**	0	**0**	n.s.	19

Scientific Name	Common Name	Wind Resistance						p-value	Total N
		High		Medium		Low			
		N	%	N	%	N	%		
Coccoloba uvifera	sea grape	18	**50**	12	**33**	6	**17**	0.0498	36
Conocarpus erectus	buttonwood	11	**35**	17	**55**	3	**10**	0.0084	31
Cordia sebestena	geiger tree	8	**33**	13	**54**	3	**12**	0.0439	24
x *Cupressocyparis leylandii*	leyland cypress	7	**22**	13	**41**	12	**37**	n.s.	32
Delonix regia [c] (in S. FL)	royal poinciana	2	**6**	20	**63**	10	**31**	0.0005	32
Enterolobium cyclocarpum	ear tree	1	**5**	7	**33**	13	**62**	0.0058	21
Eriobotrya japonica [c] (in S. & C. FL)	loquat	9	**24**	24	**63**	5	**13**	0.0004	38
Eucalyptus cinerea	silver dollar eucalyptus	2	**13**	9	**56**	5	**31**	n.s.	16
Eugenia axillaris	white stopper	7	**64**	3	**27**	1	**9**	n.s.	11
Eugenia foetida	boxleaf, Spanish stopper	7	**64**	2	**18**	2	**18**	n.s.	11
Ficus aurea	strangler fig	4	**36**	5	**46**	2	**18**	n.s.	11
Ficus benjamina	weeping banyan	0	**0**	2	**18**	9	**82**	0.0348	11
Grevillea robusta	silk oak	1	**4**	8	**32**	16	**64**	0.0012	25
Guaiacum sanctum	lignum vitae	10	**83**	2	**17**	0	**0**	0.0209	12
Ilex cassine	dahoon holly	35	**76**	10	**22**	1	**2**	0.0001	46
Jacaranda mimosifolia	jacaranda, black poui	1	**7**	2	**13**	12	**80**	0.0006	15
Juniperus silicicola	SE red cedar	14	**28**	18	**35**	19	**37**	n.s.	51
Kigelia pinnata	sausage tree	7	**41**	6	**35**	4	**24**	n.s.	17
Koelreuteria paniculata	golden raintree	11	**37**	11	**37**	8	**26**	n.s.	30
Krugiodendron ferreum	ironwood	10	**77**	3	**23**	0	**0**	n.s.	13
Lagerstroemia indica	crape myrtle	55	**83**	11	**17**	0	**0**	0.0001	66
Ligustrum japonicum	privet	30	**75**	9	**23**	1	**2**	0.0001	40
Liquidambar styraciflua	sweetgum	19	**43**	22	**50**	3	**7**	0.0013	44
Litchi chinensis	lichee	8	**57**	5	**36**	1	**7**	n.s.	14
Lysiloma latisiliqua	wild tamarind	9	**50**	6	**33**	3	**17**	n.s.	18
Magnolia grandiflora	SE magnolia	45	**82**	9	**16**	1	**2**	0.0001	55
Mangifera indica	mango tree	6	**20**	16	**53**	8	**27**	n.s.	30
Peltophorum pterocarpa	yellow poinciana	1	**5**	15	**68**	6	**27**	0.0010	22
Persea americana	avocado tree	1	**3**	20	**63**	11	**34**	0.0002	32
Pinus clausa	sand pine	3	**7**	7	**16**	34	**77**	0.0001	44
Pinus elliottii var. *densa*	FL slash pine	18	**38**	25	**52**	5	**10**	0.0016	48
Pinus palustris	longleaf pine	23	**56**	13	**32**	5	**12**	0.0017	41
Podocarpus spp.	podocarpus	24	**75**	7	**22**	1	**3**	0.0001	32
Prunus caroliniana	Carolina laurel cherry	5	**16**	15	**48**	11	**36**	n.s.	31
Quercus geminata	sand live oak	36	**92**	2	**5**	1	**3**	0.0001	39

Scientific Name	Common Name	Wind Resistance						p-value	Total N
		High		Medium		Low			
		N	%	N	%	N	%		
Quercus laurifolia	laurel oak	3	**4**	27	**39**	39	**57**	0.0001	69
Quercus nigra	water oak	3	**8**	14	**36**	22	**56**	0.0009	39
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
Sideroxylon foetidissimum	mastic tree	3	**30**	6	**60**	1	**10**	n.s.	10
Simarouba glauca	paradise tree	5	**42**	5	**42**	2	**16**	n.s.	12
Spathodea campanulata	African tuliptree	0	**0**	6	**38**	10	**62**	n.s.	16
Swietenia mahagoni	West Indian mahogany	2	**9**	13	**56**	8	**35**	n.s.	23
Tabebuia aurea	silver trumpet	0	**0**	4	**33**	8	**67**	n.s.	12
Tabebuia chrysotricha	golden trumpet	2	**7**	5	**18**	21	**75**	0.0001	28
Tabebuia heterophylla	white cedar	0	**0**	6	**55**	5	**45**	n.s.	11
Tabebuia impetiginosa	purple tabebuia, ipe	3	**12**	12	**50**	9	**38**	n.s.	24
Tecoma stans	yellow elder	0	**0**	8	**73**	3	**27**	n.s.	11
Terminalia catappa [c] (in S. FL)	tropical almond	3	**20**	8	**53**	4	**27**	n.s.	15
Taxodium distichum	baldcypress	59	**91**	6	**9**	0	**0**	0.0001	65
Taxodium ascendens	pondcypress	41	**91**	4	**9**	0	**0**	0.0001	45
Palms									
Butia capitata	pindo	34	**79**	7	**16**	2	**5**	0.0001	43
Caryota mitis	fishtail	8	**38**	6	**29**	7	**33**	n.s.	21
Chrysalidocarpus lutescens	areca	19	**63**	11	**37**	0	**0**	n.s.	30
Coccothrinax argentata	FL silver, silver thatch	21	**95**	1	**5**	0	**0**	0.0001	22
Cocos nucifera	coconut	22	**63**	13	**37**	0	**0**	n.s.	35
Hyophorbe lagenicaulis	bottle	13	**81**	3	**19**	0	**0**	0.0124	16
Hyophorbe verschaffeltii	spindle	11	**79**	2	**14**	1	**7**	0.0015	14
Latania loddigesii	blue latan	8	**67**	3	**25**	1	**8**	0.0388	12
Livistona chinensis [c] (in S. & C. FL)	chinese fan	29	**71**	9	**22**	3	**7**	0.0001	41
Neodypsis decaryi	triangle	14	**58**	6	**25**	4	**17**	0.0302	24
Phoenix canariensis	Canary Island date	49	**89**	4	**7**	2	**4**	0.0001	55
Phoenix dactylifera	date	33	**94**	2	**6**	0	**0**	0.0001	35
Phoenix reclinata [b] (in S. FL)	Senegal date	29	**85**	5	**15**	0	**0**	0.0001	34
Phoenix roebelenii	pygmy date	40	**98**	1	**2**	0	**0**	0.0001	41
Ptychosperma elegans	Alexander, solitary	16	**73**	6	**27**	0	**0**	0.0330	22
Roystonea elata	Florida royal	19	**56**	10	**29**	5	**15**	0.0118	34
Roystonea regia	Cuban royal	17	**61**	10	**36**	1	**4**	0.0010	28
Sabal palmetto	cabbage	71	**99**	1	**1**	0	**0**	0.0001	72

Scientific Name	Common Name	Wind Resistance						p-value	Total N
		High		Medium		Low			
		N	%	N	%	N	%		
Syagrus romanzoffiana [c] (in S. FL)	queen	5	**10**	17	**33**	29	**57**	0.0002	51
Thrinax morrisii	Key thatch	13	**87**	2	**13**	0	**0**	0.0045	15
Thrinax radiata	Florida thatch	17	**89**	2	**11**	0	**0**	0.0006	19
Veitchia merrillii	Manila, Christmas	13	**81**	3	**19**	0	**0**	0.0124	16
Washingtonia robusta	Washington fan	29	**54**	16	**30**	9	**17**	0.0033	54

[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)

*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).

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