CHAPTER 9

SELECTING TROPICAL AND SUBTROPICAL TREE SPECIES FOR WIND RESISTANCE

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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.

Contents

I. 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 sixty 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.

II. 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 1).

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.)

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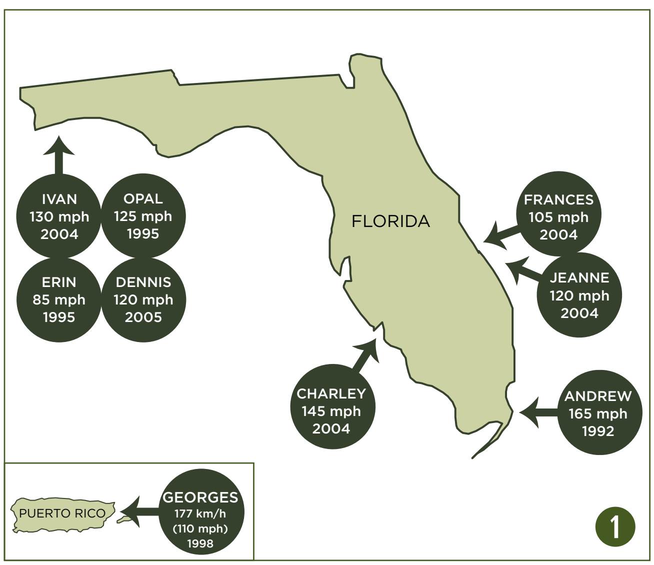


Figure 1

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.

III. 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 *Chapter 5—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

Of the palms, sabal palm along with the smaller palms such as areca (*Chrysalidocarpus lutescens*), Manila (*Veitchia merrilii*) 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 on 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 their heights of 20 meters and above, their wind resistance starts to plummet.

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 actinophylla [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	—
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.

Dicots

Of the dicot tree species, the poorest surviving species 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 2).

Trees with large amounts of branch loss in a hurricane (Figure 3) 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 4).

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, PR 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) (See *Chapter 8—Selecting Southeastern Coastal Plain Tree Species for*

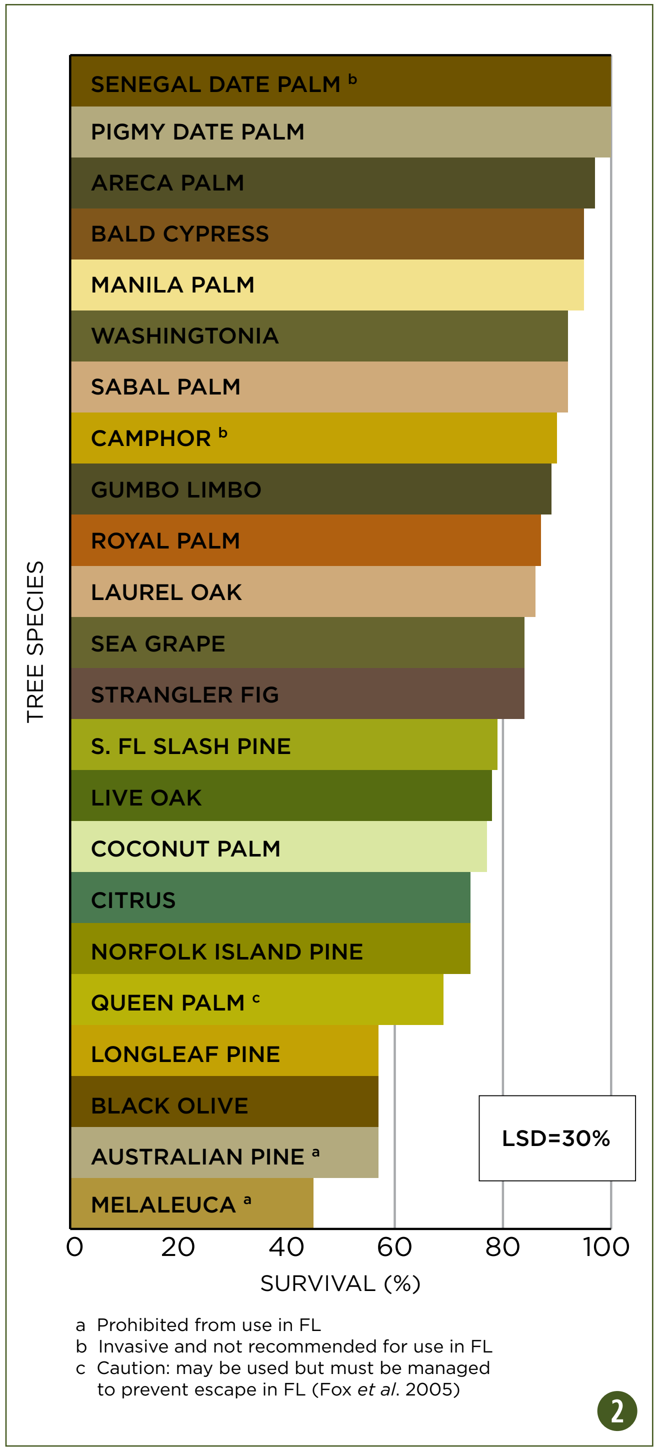
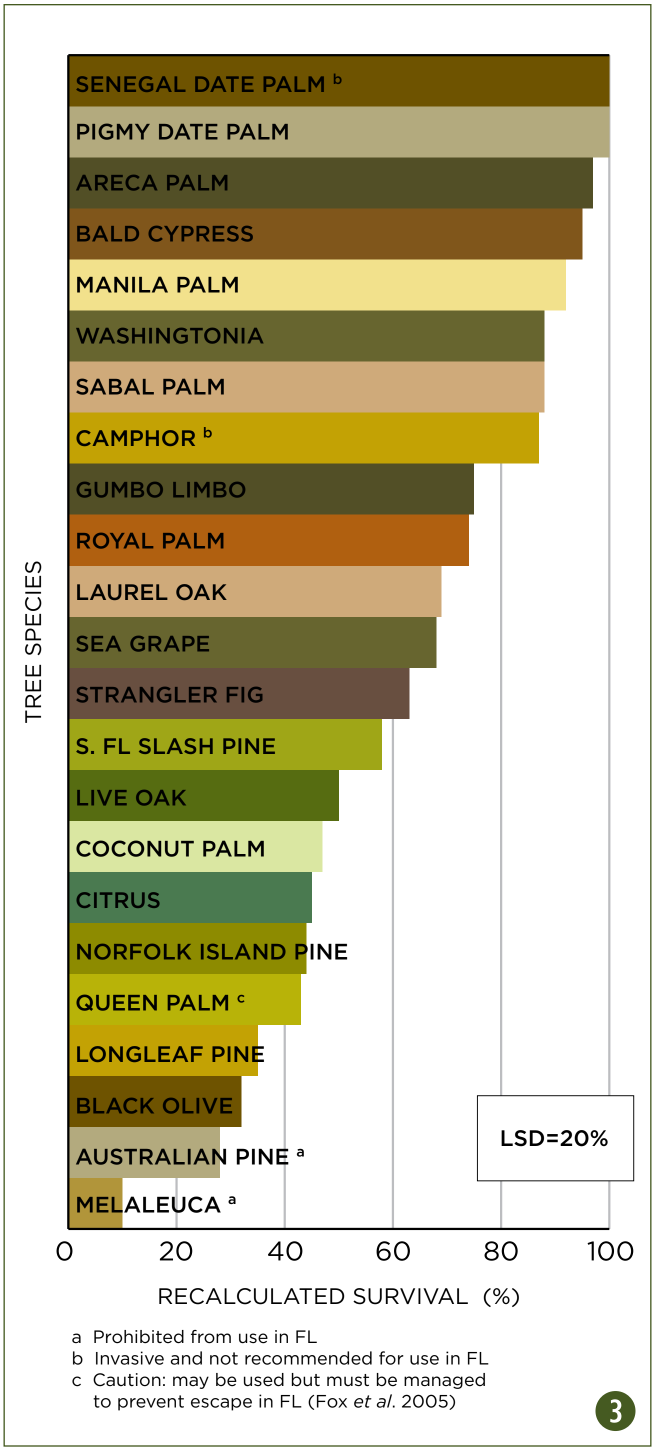


Figure 2

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



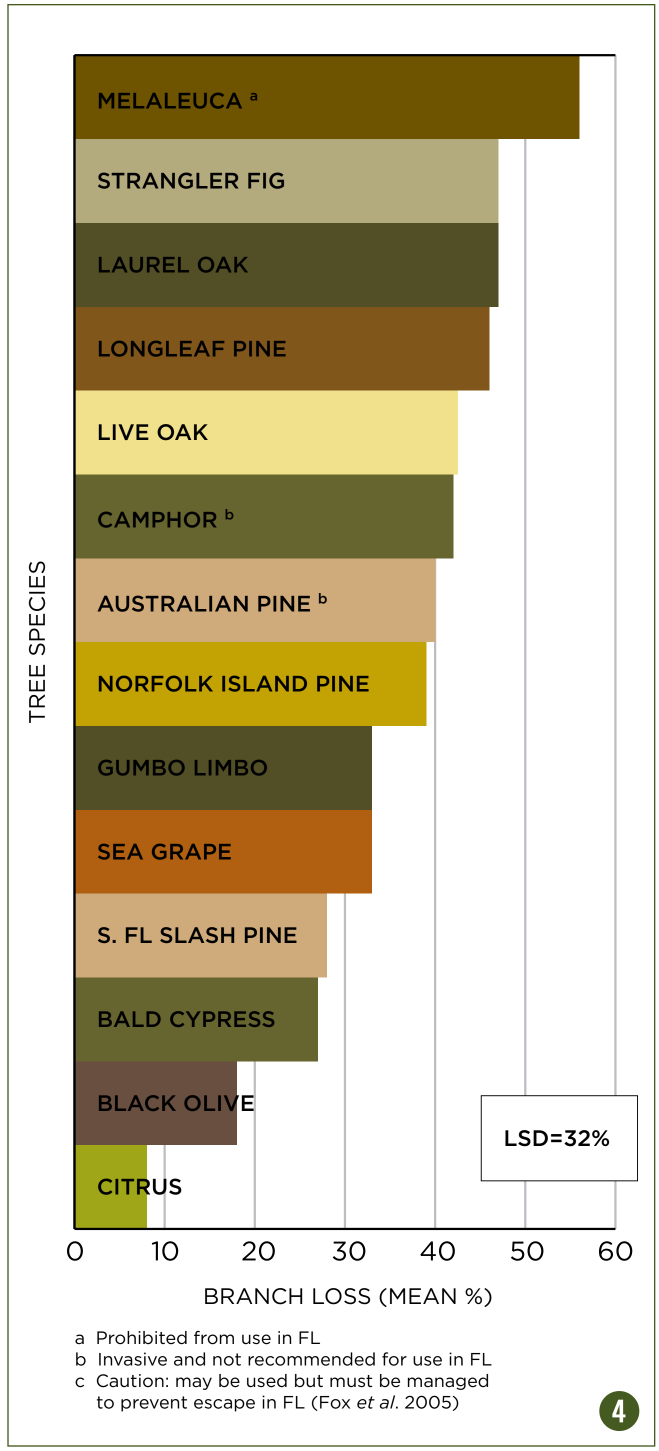


Figure 3

A recalculation of survival (%) after considering trees with ≥ 50% branch loss as dead after Hurricane Charley.

Figure 4

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

Wind Resistance). However in the two south Florida hurricanes, both survival and branch loss for live and laurel oaks were similar (Figures 3 and 4). 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 5).

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 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).

Figure 5

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 1). 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) but 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

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).

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 (%)
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
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). 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.

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 twenty-four 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 7).

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 thirty-five tree species measured after Hurricane Georges in Puerto Rico ($n \geq 20$), 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 U.S. coastal plain during Hurricane Ivan.

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ON SURVIVAL RATES DURING HURRICANE IVAN	CH 8	Selecting Southeastern Coastal Plain Tree Species for Wind Resistance

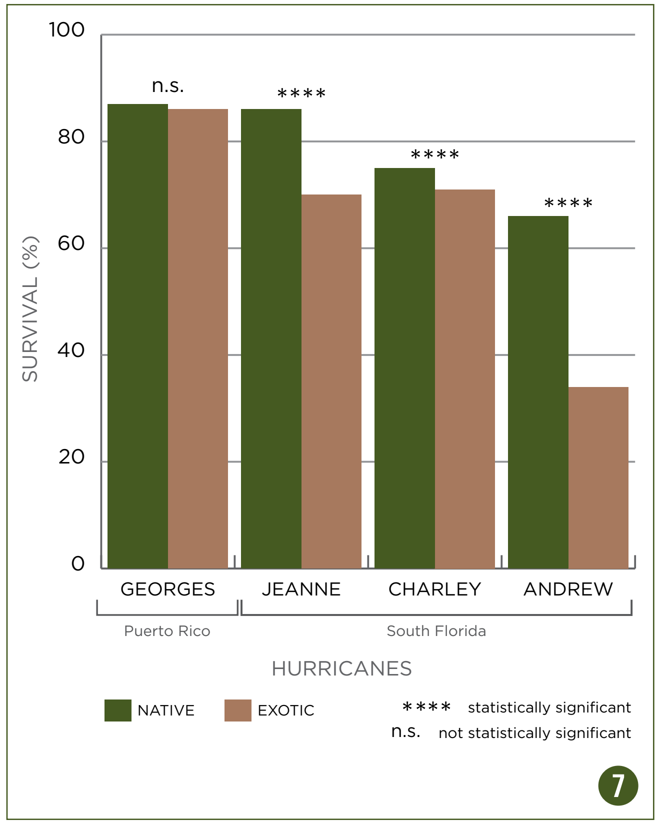

Figure 7

Native trees survived better than exotic 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 some new information about some species not so 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

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
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	lignumvitae	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

[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 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 continued)

Scientific Name	Common Name	Wind Resistance						p-value	Total N
		High		Medium		Low			
		N	%	N	%	N	%		
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
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 mahagony	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

[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 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 continued)

Scientific Name	Common Name	Wind Resistance						p-value	Total N
		High		Medium		Low			
		N	%	N	%	N	%		
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
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 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).

(*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, in another study of twenty-four species experiencing Hurricane Georges, West Indian mahogany had the best survival and the least branch loss (Francis 2000).

IV. 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 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.

Table 4. Wind resistance of tropical and subtropical tree species.*

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
- *Dypsis lutescens,* areca
- *Coccothrinax argentata,* Florida silver
- *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

MEDIUM-HIGH WIND RESISTANCE

DICOTS
- *Annona glabra,* pond apple
- *Calophyllum calaba,* Brazilian beautyleaf [c]
- *Chrysophyllum oliviforme,* satinleaf
- *Coccoloba uvifera,* sea grape
- *Coccoloba diversifolia,* pigeon plum
- *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

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

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]
- *Quercus nigra*, water oak
- *Peltophorum pterocarpa*, yellow poinciana
- *Prunus caroliniana*, Carolina laurelcherry
- *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

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

[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.

Important Recommendations

Some significant findings from this study reported in *Chapter 5—Lessons Learned from Hurricanes*:

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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