WIND AND TREES: A SURVEY OF HOMEOWNERS AFTER HURRICANE ANDREW[1]

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Abstract. The destructive winds of Hurricane Andrew dramatically changed the urban forest in Dade County, Florida on August 24, 1992. Overnight, the tree canopy was replaced by a landscape of broken, uprooted, defoliated and severely damaged trees. To assist communities in reforestation efforts, scientists at the University of Florida conducted a homeowner survey to determine how different tree species responded to strong winds. Native tree species, such as box leaf stopper, sabal palm gumbo limbo, and live oak were the best survivors of the winds. Other palms such as areca, cabada, and Alexander were also highly wind resistant. In general, fruit trees such as navel orange, mango, avocado and grapefruit were severely damaged. Black olive, live oak, and gumbo limbo trees that were pruned survived the hurricane better than unpruned trees. Only 18% of all the trees that fell caused property damage. Hurricane-susceptible communities should consider wind resistance as one of their criteria in tree species selection.

On August 24, 1992 when Hurricane Andrew swept away many of the homes, schools, and businesses of the people in Dade County, Florida, it also affected another valuable part of the metropolitan area, the urban forest. Trees along streets, in parks, in backyards were stripped of branches, uprooted or broken off by the 145 mph sustained winds. People cared about the trees they lost and immediately started cleaning up and replanting. Many asked questions about what species to replant.

Scientists at the School of Forest Resources and Conservation, University of Florida in cooperation with the Florida Division of Forestry began a project to determine how different tree species responded to the strong winds. Preliminary observations four days after the hurricane revealed that damage was not uniform but appeared to vary by species, size, and previous cultural practices. To collect further information for characterizing tree response to the strong winds, we developed a survey of homeowners in Dade County. This report summarizes the results of the homeowner survey and provides some insight into which tree species were best at resisting the hurricane-force winds.

The Survey

From January through April, 1993 the University of Florida Hurricane Andrew survey was sent directly to 371 homeowners in Dade County, Florida. Mailing list for homeowners were obtained from the Florida Urban Forestry Council, Trees for Dade, and Florida Master Gardeners Program. Thirty-five additional surveys were distributed to homeowners personally by Rick Vasquez, Florida Division of Forestry and David Ettman, Department of Environmental Resources Management. Survey recipients were chosen because of their knowledge and familiarity with tree species in Dade County. Of the 406 surveys distributed or mailed, 128 surveys (32%) were returned (Figure 1). Homeowners filled out one form for each tree "that fell down during the hurricane" and one for each tree that was "still standing after the hurricane." Additional questions were asked about the location of the tree (a map of the property), tree height and diameter, previous pruning practices, and whether the tree damaged property.

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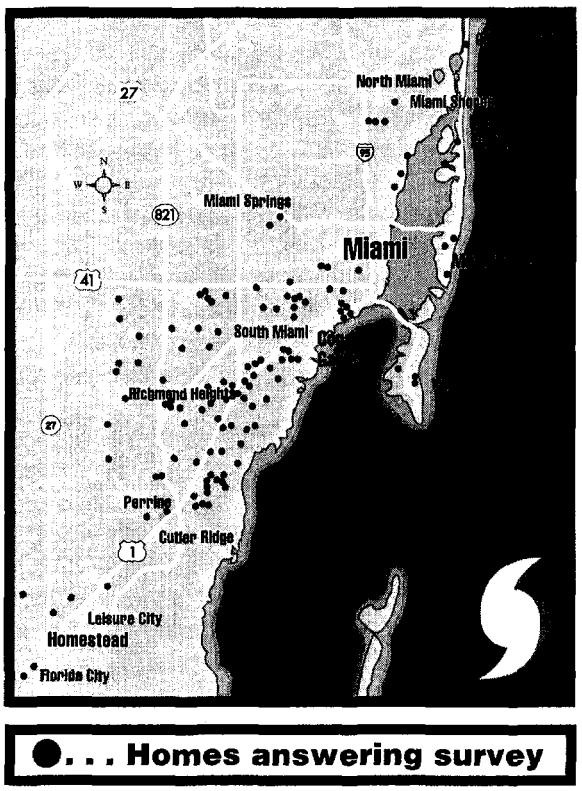

Figure 1. A map of Dade County, Florida showing the location of homeowners responding to the Hurricane Andrew Survey.

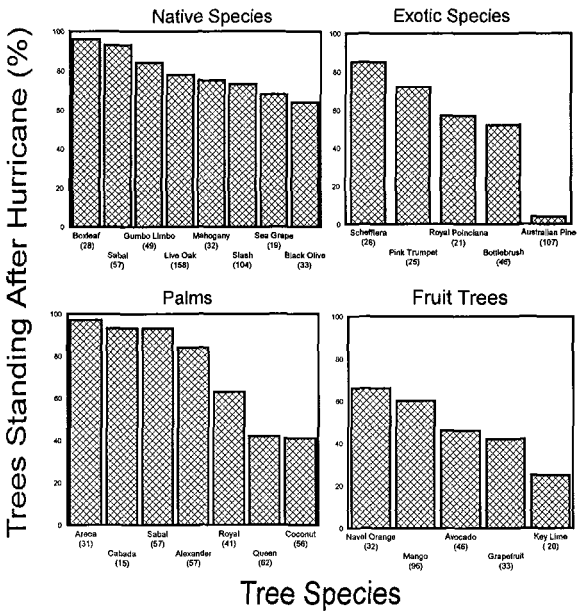

Figure 2. The percentage of native, exotic, palm and fruit tree species standing after Hurricane Andrew. (Number in parentheses denotes the number of observations.)

Results

What Tree Species Fell? Response data were obtained on 1,947 trees located on 128 residential properties in Dade County, Florida. Of the 1947 total trees, 202 tree species were represented including 167 gymnosperms and angiosperms (dicots) (25 native species and 12 fruit species), and 35 palms (monocots) (2 native). Thirty-eight percent (38%) of the trees were uprooted or broke at the main stem and 62% remained standing after the hurricane. The number of trees observed for each species varied. Sample sizes for some species such as live oak, South Florida slash pine and casuarina exceeded 100 trees. Other species were represented by eight to fourteen trees.

Native Trees. Native tree species survived the hurricane better than exotics; chi-square analysis showed that 34% of exotic trees were still standing after the hurricane while 66% of native trees were standing ($n21/1\ p<0.0001$). Of the natives, boxleaf stopper (*Eugenia foetida*), sabal palm (*Sabal palmetto*), and gumbo limbo (*Bursera simaruba*) were the best survivors with 96, 93, and 84% still standing after the hurricane (Figure 2). Live oak (*Quercus virginiana*), manogany (*Swietenia mahagoni*) and South Florida slash pine (*Pinus elliottii* var. *densa*) comprised a second group (78,75, and 73% still standing) and black olive (*Bucida buceras*) and sea grape (*Coccoloba uvifera*) were in the third group with 68 and 64% standing. Three other natives, white stopper (*Eugenia axillaris*), red bay (*Persea borbonia*) and paradise tree (*Simarouba glauca*) even though they were represented by only 10 trees each, also demonstrated wind resistance with 100, 100, and 80% still standing after the hurricane (Table 1). Although represented by six or seven trees, two other natives, redberry stopper (*Eugenia confus*) and lignumvitae (*Guaiacum sanctum*) were all standing after the hurricane.

Exotics. Schefflera (*Brassaia actinophylla*) (85%) and pink trumpet (*Tabebuia pallida*) (72%) were the only two exotic dicot species with relatively high numbers of trees still standing; in com-

Table 1. The percentage of trees still standing after the hurricane for species with a smaller sample (8 to 14 trees). (* signifies a tree native to south Florida.)

Name		Sample	%
Scientific	Common	size	standing
Dicots			
Euginia axillaris*	White stopper	10	100
Persea borbonia*	Red bay	10	100
Simarouba glauca*	Paradise tree	10	80
Melaleuca quinquenervia	Melaleuca	14	79
Manilkara zapota	Sapodilla	9	67
Litchi chinensis	Lychee	8	63
Ilex cassine*	Dahoon holly	9	56
Kigelia pinnata	Sausage tree	13	46
Bauhinia blakeana	Hong-Kong orchid tree	9	44
Chrysophyllum oliviforme	Satinleaf	14	36
Ficus benjamina	Weeping banyan	10	10
Palms			
Phoenix roebelenii	Pygmy date palm	13	100
Livistona chinensis	Chinese fan palm	10	80
Washingtonia robusta	Washingtonia	10	80
Gaussia attenuata	Maya palm	11	73
Heterospathe elata	Sagasi palm	11	73
Veitchia merrillii	Manila palm	13	55
Fruit Trees			
Citrus reticulata Blanco	Tangerine	9	33
Eriobotrya japonica	Loquat	11	9

parison, the lowest native tree species had 64% (Figure 2). Royal poinciana (*Delonix regina*) and bottlebrush (*Callistemon viminalis*) were next (57 and 52%). Australian pine (*Causarina equisetifolia*) demonstrated poor wind resistance with only 4% standing after the hurricane. Exotic dicots with smaller sample sizes showed variable responses with melaleuca (*Malaleuca quinquenervia*) surviving fairly well (79%) and several other species, sausage tree (*Kigelia pinnata*), Hong-Kong orchid (*Bauhinia blakeana*), and weeping banyan (*Ficus benjamina*), having less than 50% standing (Table 1). One other exotic with a small sample (n 6 trees) evidenced extreme sensitivity to wind stress: Floss-silk tree (*Chorisia speciosa*) had 0% standing after the hurricane.

Palms. Palm species did not respond uniformly to the wind stress. Cabada (*Chrysalidocarpus cabadae*), areca (*Chrysalidocarpus lutescens*), sabal (*Sabal palmetto*) and Alexander palms (*Ptychosperma elegans*) tolerated the strong winds extremely well (97, 93, 93, 84% still standing) (Figure 2). However, royal (*Roystonea regia*), queen (*Arecastrum remanzoffianum*) and coconut palms (*Cocus nucifera*) were less resistant (63, 42, and 41% standing). Pygmy date palm (*Phoenix roebelenii*), Chinese fan palm (*Lisistona chinensis*), and Washington (*Washingtonia robusta*) palms had smaller sample sizes but survived the winds very well (100, 80, 80%) Table 1). While Senegal date palm (*Phoenix reclinata*) had a very small sample (n = 5 trees), all of them were still standing.

Fruit Trees. Of the fruit trees, navel orange (*Citrus sinensis*) and mango (*Mangifera indica*) exhibited the highest levels of wind tolerance (66 and 60% standing). Avocado (*Persea americana*), grapefruit (*Citrus paradisi*) and key lime (*Citrus aurantiifolia*) were frequently uprooted or broken by the winds (46, 42, and 25% standing) (Figure 2). Tangerine and loquat, two fruit tree species with smaller samples, also showed poor wind tolerance (33 and 9% surviving (Table 1).

How Did Trees Fall? When trees fell, they were either uprooted, broken at he trunk or both (Table 2). Uprooting was the most common type of failure for black olive and live oak while slash pine typically broke at the trunk. Coconut, queen and royal palms were most often uprooted. Grapefruit, navel orange, mango and avocado trees were uprooted while key lime exhibited both types of failure.

Pruning. Did pruning help trees to withstand wind stress? Of the trees with a large enough sample size of fallen trees (> 10 fallen) a common pattern was evident. Coconut, queen and royal palms were not affected by pruning — the same percentage of trees fill whether pruned or not. However, unpruned black olives, live oaks and gumbo limbos were more likely to fail in the winds compared to pruned trees (Figure 3). Pruning grapefruit, navel orange, and avocado did not seem to help.

Property Damage. Eighteen percent of the fallen trees damaged property. Of the total trees surveyed only 7% damaged property. The species causing the most damage were queen palm, royal palm, black olive, sea grape and mango; greater

Table 2. The type of failure (uprooted, broken at the main stem, or both) associated with fallen trees. (For species with a sample size of 10 or more fallen trees.)

Name	Sample size	Broken (%)	Uprooted (%)	Both (%)
Palms				
Coconut palm, Cocos nucifera	31	29	68	3
Queen palm, Cocos plumosa	36	30	67	3
Royal palm, Roystonea regia	13	15	85	0
Dicots				
Black olive, Bucida buceras	10	20	80	0
Bottlebrush, Callistemon viminalis	25	48	44	8
Live oak, *Quercus virginiana*	41	19	71	10
Slash pine, Pinus elliotii	12	92	8	0
Fruit Trees				
Key lime, Citrus aurantifolia	19	47	47	6
Grapefruit, Citrus paradisi	17	24	76	0
Navel orange, Citrus sinensis	11	0	100	0
Mango, Magnifera indica	39	15	82	3
Avocado, Persae americana	49	22	78	0

than 25% of each species damaged property (Table 3). The species causing the least property damage were cabada, areca, coconut, Alexander, and sabal palms, casuarina, royal poinsiana, navel orange, box leaf stopper, love oak, mahogany. Twenty-four percent (24%) of the damage was to homes, 8% was to utility lines, 8% to vehicles and the rest of the damage was to minor structures

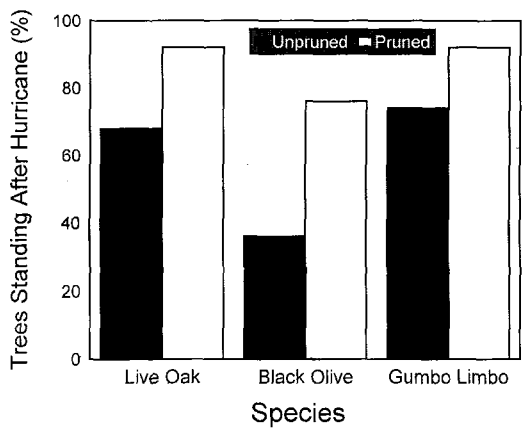

Figure 3. The percentage of pruned and unpruned live oak, black olive and gumbo limbo trees standing after Hurricane Andrew.

such as signs, fences and concrete.

Tree Size and Damage. Larger trees within a species were more likely to fall than samller trees. For example, the average height of fallen royal Palms was 15 m while the height of standing royal palms was 10 m. Fallen slash pines averaged 20 m high and 53 cm in diameter while standing pines were 17 m and 45 cm. Few exceptions to this size-failure relationship wee live oak and pink trumpet. Other studies in forests have shown that three with larger diameters and heights were more likely to be damaged by hurricane winds (3,4). In Hurricane Hugo (South Carolina, 1989), large diameter trees were more often uprooted in high winds (7).

Notes About Specific Species. Live oak was placed at the top of wind-resistance lists developed after hurricanes such as Camille (1969) and Frederick (1979) (1,6). Live oaks are well known to have exceedingly strong and resilient wood (1). In our study the few live oaks that failed wee uprooted and not broken at the stem. In addition, unlike most of the other trees species large live oaks were not preferentially damaged, indicating

Table 3. Property damage caused by tree failure during Hurricane Andrew. (For sample sizes with greater than 10 fallen trees.)

Name	% that fell	% of fallen causing property damage
Palms		
Coconut palm	59	3
Queen palm	58	27
Royal palm	37	60
Dicots		
Black olive	36	42
Bottlebrush	48	27
Australian pine	98	2
Live oak	22	9
Slash pine	27	21
Fruit trees		
Key lime	75	7
Grapefruit	58	21
Navel orange	34	9
Mango	40	42
Avocado	54	20

their exceptional resistance to wind stress.

Wind-resistance lists generated after previous hurricanes place palms second, just below live oak (1,6). Palms were noted to have little surface available to the wind because their crowns do not extend laterally (1). This appears to be true for most of the palms exposed to Hurricane Andrew; exceptions include royal, queen and coconut palms. Typically, royal palms are quite tall, thereby increasing the likelihood of property damage when they do fall. Care should be taken to plant them in deep soils and in locations where they are less likely to damage property if they fall.

Over the years, hurricanes such as Camille, Frederick and Hugo have helped people to observe hurricane effects on southern pine forests. Southern pines have been placed relatively low on hurricane-resistance lists due to their propensity for stem breakage (1,5). Pine forests in New England were found to be more susceptible to catastrophic winds than hardwood forests (2). Hurricane Andrew caused stem breakage to South Florida slash pine. Hurricane damage to forests can also initiate outbreaks of pests such as bark beetles, ambrosia beetles, sawyers, and blue stain fungi that preferentially attack stem-damaged trees (1,5). High insect populations in the damaged trees can than increase exposure of nearby healthy trees or trees with little evidence of storm damage.

After Hurricane Andrew, many individual pines did not show immediate damage but dies during the following year. Even though a relatively high percentage of slash pine were standing after the hurricane (73%), it may be that hidden structural and root damage caused additional mortality. This damage and the associated stress to trees may also have predisposed them to insect attack. Therefore, even though South Florida slash pine is placed in the medium-resistant category, its ability to survive hurricane level stresses may be less than other species with the same percentage of standing trees after the hurricane.

Conclusions

From this survey we ranked tree species according to observed wind resistance (Figure 4). Many of the species that are planted in the Dade

Wind Resistance To Hurricane Andrew			
Greatest Resistance (>75% standing after Hurricane)			
Natives	**Exotics**	**Palms**	**Fruit Trees**
Boxleaf stopper	Melaleuca	Alexander	(None)
Gumbo limbo	Schefflera	Areca	
Lignum vitae		*Cabada*	
Live oak		Chinese fan	
Paradise tree		Pygmy date	
Red bay		Sabal	
Red berry stopper		Senegal date	
Sabal palm		Washington	
White stopper			
Intermediate Resistance (50 to 75% standing after Hurricane)			
Natives	**Exotics**	**Palms**	**Fruit Trees**
Black olive	Bottlebrush	Manila	Mango
Dahoon holly	Pink Trumpet	Maya	Navel orange
Mahogany	Royal Poinciana	Royal	
Sea grape		Sagasi	
S. Florida slash pine			
Least Resistance (<50% standing after Hurricane)			
Natives	**Exotics**	**Palms**	**Fruit Trees**
Satinleaf	Australian pine	Coconut	Avocado
	Floss-silk tree	Queen	Grapefruit
	Hong-Kong orchid		Key lime
	Lychee		Loquat
	Sausage tree		Tangerine
	Sapodilla		
	Weeping banyan		

Figure 4. Wind resistance of native, exotic, palm and fruit trees as determined by frequency of failure following Hurricane Andrew.

County area are not on this list because of the limited sample size in our data set. We therefore, encourage you to use this last as a starting point for forming a list based on your observations.

Native dicots were more tolerant of high winds than exotics. This is not surprising since South Florida native trees have long been subjected to hurricanes, providing a natural selection for wind resistance. Native trees should receive strong consideration when selecting planting stock for reforesting the urban forest. Other benefits of utilizing native species include their values for wildlife and native ecosystem conservation. The two exotic tree species that demonstrated good wind tolerance (melaleuca and shefflera) are Category 1 species of the Florida Exotic Pest Plant Council, a designation noting their ability to invade and disrupt native plant communities in Florida. Australian pine and weeping banyan which are also Category 1 and 2 species did not survive the hurricane well.

Several palms tolerated the hurricane force winds. Palms appear well-suited for use in hurricane-prone areas. Royal, queen and coconut appear to be less well suited than other species such as sabal and cabada. We recommend planting these palms on deep soils in locations

where they will be less likely to damage property if they fall.

Most uprooted fruit trees reflected shallow soils and/or poor rooting properties of the trees. Planting these species in deeper soils or in more protected situations would be helpful in increasing their wind resistance. A large proportion (42%) of mango trees that fell caused property damage. When planting mangos in yards, their location relative to structures should be considered.

Except for slash pine, most trees were uprooted and not broken off by the winds. This emphasizes the importance of soil properties and rooting space for trees. Adequate soil depth, lack of soil compaction, a deep water table, and adequate rooting space improve root system development and anchorage which contribute to wind firmness.

Maintaining healthy urban trees is critical to reducing damage in hurricanes. In this study, it was evident that pruning can improve wind resistance and reduce tree failure. Live oak and gumbo limbo, two of the most wind tolerant species, did even better with pruning. Pruning, however, does not include the practice of topping which misshapes and destroys branching structure, not does it include excessive crown thinning. To maintain a healthy urban forest, homeowners and communities should remove hazard trees immediately; homeowners may seek advice from certified arborists who are trained at detecting hazard trees.

This study illustrates that numerous species possess the wind-firmness and structural strength needed to tolerate exposure to high winds. Species diversity can enhance aesthetic beauty while limiting losses to species-specific diseases or insect attacks. Native trees also offer practical advantages including adaptation to local environments. Judicious use of exotics may also contribute to diversity. Regardless of origin, all species must be considered for wind resistance, especially in hurricane-prone areas. Wind damage is also related to tree size. This illustrates the importance of having both age and size diversity in cities to ensure that some undamaged trees remain after a hurricane.

There is danger after a hurricane for urban citizens to think that trees are a problem and are undesirable in cities due to their damage potential. We found that only 7% of the trees studied caused damage to property. While damage is undesirable at any level, impact on property can be balanced against the many other benefits of urban trees including energy conservation, reduction of stormwater runoff, wildlife habitat, and aesthetics. Programs to teach urban citizens more about proper tree care, selection and maintenance can contribute to an urban forest with greater tolerance to hurricanes and storms.

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Résumé. Les vents destructeurs de l'ouragan Andrew ont dramatiquement changé la forêt urbaine du comté de Dade en Floride le 24 août 1992. Afin d'assister la communauté locale dans le processus de replantation, les scientifiques de l'Université de la Floride ont mis sur pied un inventaire maison pour évaluer la réaction de différentes espèces d'arbres aux vents violents. Les espèces indigènes d'arbres ont été celles qui ont le plus survécus aux vents. En plus du palmier sabal, les autres espèces qui ont très bien survécu sont les palmiers areca, acabada et d'Alexander. En général, les arbres fruitiers comme la navel, le manguier, l'avocatier et le pamplemoussier ont mal résisté. Les arbres ayant été élagués ont mieux survécu que ceux non élagués. Seulement 18% de tous les arbres qui sont tombés ont causé des dommages à la propriété.

Zusammenfassung. Die zerstörerischen Winde des Orkans Andreas vom 24. August 1992 veränderten den Stadtwald von Dade County, Florida ganz dramatisch. Um die Kommunen in ihren Bemühungen, neu anzupflanzen zu unterstützen, entwickelten die Wissenschaftler der Universität Florida einen Erhebungsbogen für Eigenheimbesitzer, um die Auswirkungen der starken Winde auf die einzelnen Baumarten zu bestimmen. Die einheimischen Baumarten waren die besten Überlebenden des Sturmes. Zusätzlich zu der Sabalpalme überlebten auch die anderen Palmen, einschließlich Areca-, Acabada- und Alexanderpalme sehr gut. Im allgemeinen reagierten die Fruchtbäume, wie Navalorange, Mango, Avocado und Grapefruit eher schlecht. Beschnittene Bäume überlebten eher als ungeschnittene. Nur 18% der umgestürzten Bäume beschädigten Eigentum.