Hurricanes and the Urban Forest: II. Effects on Tropical and Subtropical Tree Species

Mary L. Duryea, Eliana Kampf, Ramon C. Littell, and Carlos D. Rodríguez-Pedraza

Abstract. 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, U.S., we measured the impacts of these hurricanes on the urban forest composed of tropical and subtropical species. In addition, we also used previous published data for Hurricane Andrew for some analyses. The percent urban forest loss ranged from 13% for Georges to 16% for Jeanne to 18% for Charley. In Hurricanes Jeanne and Charley, palms survived significantly better than all other trees. Some of the best surviving species in Florida's hurricanes were gumbo limbo (Bursera simarouba), sea grape (Coccoloba uvifera), strangler fig (Ficus aurea), live oak (Quercus virginiana), laurel oak (Quercus laurifolia), and baldcypress (Taxodium distichum). Of the species measured in Puerto Rico, the species with the highest survival and least branch damage were Santa Maria (Calophyllum calaba), Caribbean pine (Pinus caribaea), schefflera (Schefflera actinophylla), and West Indian mahogany (Swietenia mahogani). Losing leaves during these hurricanes had no relationship with how well trees survived. In Hurricanes Jeanne, Charley, and Georges, 3%, 4%, and 11%, respectively, of the trees that fell damaged property. Native tree species survived better than exotic species in Hurricanes Jeanne and Charley but not in Hurricane Georges. Trees growing in groups had greater survival and less branch loss in Hurricane Jeanne than those growing individually. Wood density was not related to survival or branch loss for tree species in Hurricanes Jeanne, Charley, Georges, or Andrew. Two other measurements of wood strength, modulus of elasticity and modulus of rupture, were related to survival and branch loss in Jeanne but not Charley. Tree species with dense crowns had greater survival and less branch loss than moderate- or open-crowned species. Tree species with decrent current growth form survived better than excurrent trees in Hurricane Jeanne with no difference in Charley. Trees with the most rooting space (>7 m²) had the lowest branch loss and the greatest survival in Hurricane Georges. A reanalysis of seven dicot species and their survival in Hurricane Andrew showed that survival for pruned trees was 73% compared with 47% for unpruned trees. A survey of 85 arborists, scientists, and urban foresters ranked species for their wind resistance. Using our results from hurricanes and incorporating results from the survey and the scientific literature, we have developed lists of relative wind resistance for tropical and subtropical tree species. These lists are presented with the caveat that no tree is completely windproof and that other factors such as soil conditions, wind intensity, cultural practices, and tree health and age also contribute to wind firmness.

Key Words. Rooting space; urban trees; wind; wind resistance; wood density.

Since 1992 when Hurricane Andrew struck south Florida, we have been studying the impacts of hurricanes on tropical and subtropical urban forests (Duryea et al. 1996). In 1998 when Hurricane Georges crossed over the entire island of Puerto Rico and then again in 2004 when Hurricanes Jeanne and Charley struck south Florida, we continued with these urban tree measurements. The urban forest loss for these four hurricanes combined with hurricanes striking the southeastern coastal plain is reported in an accompanying article in this issue (Duryea et al. 2007). 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 reports on and synthesizes the types of tree damage, possible reasons for damage, and ways to avert damage in the future for tropical and subtropical tree species in urban forests.

When combined with the coastal plain hurricanes and Hurricane Andrew, urban forest loss for eight hurricanes was positively correlated with wind speed ($r^2 = 0.80$) Duryea et al. (2007). The analysis illustrates a nonlinear relationship between urban forest lost and wind speed. The high $r^2$ value indicates that we are able to reasonably predict the urban forest loss given the maximum sustained wind speed of a hurricane.

Studies of hurricane force winds and their impact on trees have centered on natural and plantation forest ecosystems. A handful of studies have looked at tropical and subtropical urban forest responses to wind (Francis and Gillespie 1993; Duryea et al. 1996; Jim and Liu 1997; Francis 2000). The results have indicated that in addition to species differences in wind resistance, other biophysical factors such as topography, soil characteristics, wind speed, tree health, and age determine the response of an urban forest ecosystem to wind.
The objectives of this study were to analyze the effects of three hurricanes on urban tree species growing in tropical and subtropical regions: (1) to determine if there was species-specific damage over the varied wind speeds, and (2) to determine if damage was related to tree attributes (such as size, leaf loss, wood density, and crown) and site characteristics (rooting space and grouped plantings). We then combined these results with previous results from Hurricane Andrew (Duryea et al. 1996), a survey of arborists, urban foresters, and scientists, and the scientific literature to develop wind-resistant lists and cultural recommendations for tropical and subtropical species.

METHODS

Urban Tree Measurements

Urban tree damage was measured after (within 3 to 10 days) the three hurricanes that struck Florida (Charley and Jeanne 2004) and Puerto Rico (Georges 1998) (Duryea et al. 2007). We also include 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. 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 after Hurricane Jeanne.)

The urban tree measurement methods, the survey methods and the statistical analyses conducted are described in Duryea et al. (2007).

RESULTS AND DISCUSSION

Overall Urban Forest Loss

The percent urban forest loss for these three hurricanes ranged from 13% for Georges to 18% for Jeanne to 18% for Charley. To evaluate tree survival and responses, we divided the species into four categories: palms, dicots, conifers, and Puerto Rico species.

Tree Survival and Branch Loss

Palm

Of the palms, sabal palm along with the smaller palms such as areca (Chrysalidocarpus lutescens), Manila (Veitchia merillii), and pigmy date (Phoenix roebelenii) had 89% or greater survival (Table 1). In Hurricane Charley, palm survival was 88% compared with 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 with dicots, palms have often been observed to be more resistant to winds (Frangi and Lugo 1991; Francis and Gillespie 1993). 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) with 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 (36.3 ft) in height with 42% of the palms above 10 m (33 ft) compared with an average of 4 m (13.2 ft) and only 7% over 10 m (33 ft) for Charley; perhaps when Washington palms acquire their heights of 20 m (66 ft) and above, their wind resistance starts to plummet.

Dicots

Of the dicot tree species, the poorest surviving species were seen in Hurricane Charley’s survival figures with melaleuca (Melaleuca quinquenervia), Australian pine (Casuarina equisetifolia), and black olive (Bucida buceras) (Figures 1A and B). 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). 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 2). 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 crapemyrtle (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 1. Survival (percent of trees standing after the hurricane) of tropical/subtropical tree species after the three hurricanes reported in this study and Hurricane Andrew.

<table>
<thead>
<tr>
<th>Dicots</th>
<th>Survival (%) after each hurricane (wind speed in km/h; mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Georges (177 km/h; 110 mph)</td>
</tr>
<tr>
<td>Araucaria heterophylla</td>
<td>88</td>
</tr>
<tr>
<td>Bucida buceras</td>
<td>84</td>
</tr>
<tr>
<td>Bursera simarouba</td>
<td>—</td>
</tr>
<tr>
<td>Callistemon viminalle</td>
<td>—</td>
</tr>
<tr>
<td>Carya floridana</td>
<td>83</td>
</tr>
<tr>
<td>Casuarina equisitifolia(^x)</td>
<td>—</td>
</tr>
<tr>
<td>Cinnamomum camphora(^x)</td>
<td>—</td>
</tr>
<tr>
<td>Citrus spp.</td>
<td>—</td>
</tr>
<tr>
<td>Coccoloba uvifera</td>
<td>—</td>
</tr>
<tr>
<td>Delonix regia ((^w) in s. FL)</td>
<td>94</td>
</tr>
<tr>
<td>Eugenia foetida</td>
<td>—</td>
</tr>
<tr>
<td>Ficus aurea</td>
<td>—</td>
</tr>
<tr>
<td>Mangifera indica</td>
<td>76</td>
</tr>
<tr>
<td>Melaleuca quinquenervia(^x)</td>
<td>65</td>
</tr>
<tr>
<td>Persea americana</td>
<td>—</td>
</tr>
<tr>
<td>Quercus gimenata</td>
<td>—</td>
</tr>
<tr>
<td>Quercus laurifolia</td>
<td>—</td>
</tr>
<tr>
<td>Quercus virginiana</td>
<td>—</td>
</tr>
<tr>
<td>Schefflera actinophylla</td>
<td>((^x) in central and south FL)</td>
</tr>
<tr>
<td>Swietenia mahagoni</td>
<td>92</td>
</tr>
<tr>
<td>Tabebuia heterophylla</td>
<td>83</td>
</tr>
<tr>
<td>Monocots—Palms</td>
<td></td>
</tr>
<tr>
<td>Chrysalidocarpus lutescens</td>
<td>94</td>
</tr>
<tr>
<td>Cocos nucifera</td>
<td>77</td>
</tr>
<tr>
<td>Phoenix reclinata ((^w) in s. FL)</td>
<td>—</td>
</tr>
<tr>
<td>Phoenix roebelenii</td>
<td>—</td>
</tr>
<tr>
<td>Roystonea elata ((^w) in PR)</td>
<td>93</td>
</tr>
<tr>
<td>Sabal palmetto</td>
<td>—</td>
</tr>
<tr>
<td>Syagrus romanzoffiana</td>
<td>—</td>
</tr>
<tr>
<td>Veitchia merrillii</td>
<td>89</td>
</tr>
<tr>
<td>Washingtonia robusta</td>
<td>—</td>
</tr>
<tr>
<td>Conifers</td>
<td></td>
</tr>
<tr>
<td>Pinus clausa</td>
<td>—</td>
</tr>
<tr>
<td>Pinus elliottii var. Densa</td>
<td>89</td>
</tr>
<tr>
<td>(P. caribaea in PR)</td>
<td></td>
</tr>
<tr>
<td>Pinus palustris</td>
<td>—</td>
</tr>
<tr>
<td>Taxodium distichum</td>
<td>—</td>
</tr>
</tbody>
</table>

*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.

\(^x\)Prohibited from use in Florida.

\(^w\)Invasive and not recommended for use in Florida.

\(^\ast\)Caution: may be used but manage to prevent escape in Florida (Fox et al. 2005).

The table of species resistance to catastrophic wind (1996) ranked 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-resistant 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. 2007). However, in the two south Florida hurricanes, both survival and branch loss for these oaks were similar (Figures 1 and 2). 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. 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).

Conifers

Of the conifer species, baldcypress survived Hurricane Charley the best with 95% survival (Figure 1A). Baldcypress also experienced little damage after Hurricane Hugo (Gresham et al. 1991; Putz and Sharitz 1991). After Hurricane Andrew, cypress in the Everglades National Park was still standing on the edges of the hammocks, whereas 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. 2007). South Florida slash pine is next best in wind resistance for the conifers across the south Florida hurricanes but longleaf pine (Pinus palustris), which is usually similar to slash pine in wind resistance in the coastal plain hurricanes (Duryea et al. 2007), 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 1 year with 17% to 25% dying (Platt et al. 2000). We returned 3 months after Hurricane Charley and found that 27% of the standing south Florida slash pines and 48% of the standing longleaf pines had died.

Puerto Rico Species

Of the species measured in Puerto Rico, the species with the highest survival and least branch damage were Santa Maria (Calophyllum calaba), Caribbean pine, schefflera, West Indian mahogany, and Oriental arborvitae (Thuja orientalis) (Table 2). Many trees had extensive branch loss that reduced...
Table 2. Survival and branch loss of tree species (excluding palms, see Table 1) in Puerto Rico after Hurricane Georges (110 mph)*.

<table>
<thead>
<tr>
<th>Tree species</th>
<th>Sample size</th>
<th>Survival (%)</th>
<th>Branch loss (%)</th>
<th>Recalculated survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Araucaria heterophylla</td>
<td>25</td>
<td>88</td>
<td>41</td>
<td>52</td>
</tr>
<tr>
<td>Bauhinia monandra</td>
<td>31</td>
<td>71</td>
<td>41</td>
<td>39</td>
</tr>
<tr>
<td>Bucida buceras</td>
<td>286</td>
<td>84</td>
<td>33</td>
<td>59</td>
</tr>
<tr>
<td>Calistemon citrinus</td>
<td>42</td>
<td>81</td>
<td>12</td>
<td>69</td>
</tr>
<tr>
<td>Calophyllum calaba (* in south FL)</td>
<td>295</td>
<td>93</td>
<td>20</td>
<td>81</td>
</tr>
<tr>
<td>Cassia javanica</td>
<td>28</td>
<td>86</td>
<td>42</td>
<td>57</td>
</tr>
<tr>
<td>Cassia siamea</td>
<td>94</td>
<td>85</td>
<td>53</td>
<td>30</td>
</tr>
<tr>
<td>Crescentia cajete</td>
<td>21</td>
<td>67</td>
<td>12</td>
<td>62</td>
</tr>
<tr>
<td>Cupressus sempervirens</td>
<td>31</td>
<td>29</td>
<td>7</td>
<td>29</td>
</tr>
<tr>
<td>Delonix regia (* in s. FL)</td>
<td>194</td>
<td>94</td>
<td>33</td>
<td>68</td>
</tr>
<tr>
<td>Enterolobium cyclocarpum</td>
<td>20</td>
<td>100</td>
<td>23</td>
<td>85</td>
</tr>
<tr>
<td>Eucalyptus robusta</td>
<td>69</td>
<td>86</td>
<td>59</td>
<td>28</td>
</tr>
<tr>
<td>Ficus benjamina</td>
<td>65</td>
<td>83</td>
<td>25</td>
<td>63</td>
</tr>
<tr>
<td>Ficus macrocarpa</td>
<td>33</td>
<td>76</td>
<td>18</td>
<td>67</td>
</tr>
<tr>
<td>Ficus microcarpa (* in central and south FL)</td>
<td>22</td>
<td>100</td>
<td>25</td>
<td>73</td>
</tr>
<tr>
<td>Hibiscus elatus</td>
<td>25</td>
<td>100</td>
<td>63</td>
<td>20</td>
</tr>
<tr>
<td>Lagerstroemia speciosa</td>
<td>138</td>
<td>88</td>
<td>28</td>
<td>70</td>
</tr>
<tr>
<td>Mangifera indica</td>
<td>76</td>
<td>76</td>
<td>36</td>
<td>51</td>
</tr>
<tr>
<td>Melaleuca quinquenervia²</td>
<td>37</td>
<td>65</td>
<td>21</td>
<td>57</td>
</tr>
<tr>
<td>Melicoccus bijugatus</td>
<td>22</td>
<td>82</td>
<td>25</td>
<td>64</td>
</tr>
<tr>
<td>Pinus caribaea</td>
<td>53</td>
<td>89</td>
<td>16</td>
<td>85</td>
</tr>
<tr>
<td>Pterocarpus indicus</td>
<td>32</td>
<td>97</td>
<td>29</td>
<td>75</td>
</tr>
<tr>
<td>Pterocarpus macrocarpus</td>
<td>43</td>
<td>95</td>
<td>33</td>
<td>77</td>
</tr>
<tr>
<td>Schefflera actinophylla (* in central and south FL)</td>
<td>24</td>
<td>88</td>
<td>17</td>
<td>79</td>
</tr>
<tr>
<td>Spathodea campanulata</td>
<td>24</td>
<td>67</td>
<td>52</td>
<td>37</td>
</tr>
<tr>
<td>Swietenia mahagoni</td>
<td>146</td>
<td>92</td>
<td>21</td>
<td>80</td>
</tr>
<tr>
<td>Swietenia macrophylla</td>
<td>69</td>
<td>74</td>
<td>28</td>
<td>64</td>
</tr>
<tr>
<td>Swietenia macrophylla × mahagoni</td>
<td>36</td>
<td>89</td>
<td>43</td>
<td>58</td>
</tr>
<tr>
<td>Tabebuia heterophylla</td>
<td>334</td>
<td>83</td>
<td>26</td>
<td>65</td>
</tr>
<tr>
<td>Terminalia catappa (* in south FL)</td>
<td>44</td>
<td>89</td>
<td>35</td>
<td>52</td>
</tr>
<tr>
<td>Thuya orientals</td>
<td>36</td>
<td>92</td>
<td>16</td>
<td>86</td>
</tr>
</tbody>
</table>

*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.

²Prohibited from use in Florida.

³Invasive and not recommended for use in Florida.

⁴Caution: may be used but manage to prevent escape in Florida (Fox et al. 2005).

Some species have a tendency to break at the main stem compared with uprooting. South Florida slash pine mostly broke at the main stem in Jeanne (64% broke) and Charley (76%). In Hurricane Andrew, 90% of the south Florida slash pine that fell broke (Duryea et al. 1996). Van Hooser and Hedlund (1969) also found that pines tended to snap compared with uprooting for broadleaf species. Seventy-one percent of the sand pine broke in Jeanne yet in Ivan sand pine uprooted (Duryea et al. 2007). Live oak with its dense wood tended to uproot (63% uprooted) compared with laurel oak in where 80% of the trees broke. Walker (1991) also noted less breakage with higher-density wood species. Palms mostly uprooted in our study (in Hurricane Charley, coconut had

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59% uprooted; royal, 100%; sabal, 67%; and queen [Syagrus romanzoffiana], 81% uprooted).

Property Damage
In Hurricanes Jeanne and Charley, only 3% and 4% of the trees that fell damaged property. In Jeanne, all of this damage was to major property (houses, power lines, or docks), and the only two species with more than 3% of their fallen trees causing damage were sand and south Florida slash pines. In Charley, half of the damage (2% out of a total of 4% of the fallen trees) was to major property (houses or power lines) and there were no dominant species causing damage.

Eleven percent of the trees that fell damaged property in Hurricane Georges. Of these, 27% damaged major property (houses, power lines, screened enclosures, automobiles, and so on) and 73% damaged minor property (fences, sheds, side-walks). The only tree species that caused more than 3% damage was swamp mahogany. With 20%, 21%, and 8% of the trees that fell causing property damage in Hurricanes Ivan, Erin, and Opal, respectively, it appears that falling trees cause more damage in these north Florida hurricanes than in south Florida (Duryea 1997; Duryea et al. 2007); this could be attributable to the increased urban forest canopy in north Florida and the poor health and aged condition of trees such as laurel oaks, water oaks, and pecans.

Direction of Fall
To investigate the direction that trees fell in Hurricane Andrew, we conducted a χ² analysis using species with sample sizes larger than 20 trees (n = 318 trees). We found that most trees fell to the west (48%) followed by south (21%) and the southwest (15%). These three directions totaled 83% of the fallen trees and were significantly different than the total of all the other directions, which encompassed 17% of the trees (P = 0.0001).

What Makes a Tree More Wind-Resistant?
The goal of this research project is to attempt to determine what biological and cultural factors make trees more or less wind-resistant. By evaluating these factors, we can better understand the differences between species (i.e., whether they have dense wood or defoliate quickly in wind) and between certain practices (such as rooting space or planting trees in groups compared with individual tree plantings), which could result in a healthier and more wind-resistant urban forest.

Defoliation
In a logistic regression with survival as the response variable and leaves (percent lost) as the explanatory variable, leaf loss had no relationship with survival in Hurricanes Jeanne, Charley, or Georges. This is in contrast to Hurricane Ivan in which southeastern coastal plain tree species that lost more leaves also survived better (Duryea et al. 2007). Losing leaves and reducing the wind drag or resistance from the crown may be a strategy for some species and not for others.

Native and Exotic Species
Native tree species survived better in Hurricanes Jeanne, Charley, and Andrew but not in Hurricane Georges (Figure 3). 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 with 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 toward more damage in exotic forest plantations, although they also point out that these exotic forests are often monocultures. 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%, 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 significant). With few exotic species in the urban forest population, natives also did not survive better in the southeastern United States Coastal Plain during Hurricane Ivan (Duryea et al. 2007).

Trees Growing in Groups
We asked the question whether trees growing in groups or clusters, as compared with singly, might survive hurricane
force winds better. A group was defined as five or more trees each growing within 3 m (9.9 ft) of another tree (but not in a row), and we measured this site characteristic for Hurricane Jeanne. Trees growing in groups had 88% survival during Hurricane Jeanne compared with 78% for those growing as individual trees \((P = 0.0001)\). In addition, trees growing in groups had less branch loss than individual trees (19% versus 27%, \(P = 0.09\)). Trees in groups also survived Hurricane Ivan better than individual trees (Duryea et al. 2007).

**Wood Characteristics**

Wood density was not related to survival or branch loss for tree species in Hurricanes Jeanne, Charley, Georges, or Andrew. Species with low wood densities (0.31 and 0.42 \(g/cm^3\)) and high survival rates in these hurricanes are gumbo limbo and baldcypress. Australian pine and melaleuca with low survival in all the hurricanes have high wood densities of 0.83 and 0.65 \(g/cm^3\). In Jeanne, for example, melaleuca with its relatively high wood density had the lowest survival (22%) and the highest branch loss (60%) of all the species. This lack of relationship between tree survival and wood density is in contrast to many studies in which species with denser wood are less likely to fail in hurricanes (Putz et al. 1983; Webb 1989; Zimmerman et al. 1994; Francis 2000; Duryea et al. 2007). Francis and Gillespie (1993) spoke about exceptions of these positive effects of wood density by citing examples of tree species (balsa, *Ochroma pyramidale* and *yagrumo, Cecropia schreberiana*) that have light weak wood but survived better in Hurricane Hugo compared with pitch apple (*Clusia rosea*) and Australian pine that have strong wood but experienced trunk snap and major branch breakage. However, King (1986) noted that the flexibility and strength conferred by high wood density give trees the ability to resist winds.

Here it is important to point out that different strategies are most likely at work for different species. Everham and Brokaw (1996) emphasize that species differences do exist and they are probably explained by difference in canopy architecture, wood density, bole shape, rooting patterns, and susceptibility to disease. Also they point out that these differences may be obscured by difference in exposure, soil, or silvicultural (cultural) treatments.

Two other measurements of wood strength are the modulus of elasticity (Young’s elastic modulus) and the modulus of rupture. The modulus of elasticity measures the wood’s stiffness; after applying a certain weight (in MPa), it measures whether the wood recovers to its original position (Reyes et al. 1992; Forest Products Laboratory 1999; Niklas 1999). Tree species with the highest modulus of elasticity (oaks and south Florida slash pine, all above 9,600 MPa) survived Hurricane Jeanne better and lost fewer branches than the one species with the lowest values (sand pine with 7,000 MPa) \((P = 0.05)\). However, the modulus of elasticity had no relationship to tree species survival or branch loss in the stronger 233 km/h (145 mph) winds of Hurricane Charley; two species with the lowest modulus of elasticity are gumbo limbo and baldcypress, and these species experienced the highest survival and nearly the lowest branch loss.

Modulus of rupture is a measure of the bending stress that wood can experience without mechanically failing (Forest Products Laboratory 1999; Niklas 1999). Again, sand pine with the lowest modulus of rupture experienced significantly \((P = 0.05)\) lower survival and higher branch loss than the other species (oaks and south Florida slash pine). In Hurricane Ivan, survival was also higher for those species with the highest modulus of rupture, and branch loss showed no relationship (Duryea et al. 2007). In Hurricane Charley, there appeared to be no relationship with the lowest modulus of rupture for balsa (46,000 kPa) and the highest for live oak (82,000 kPa), whereas baldcypress had the highest survival (95%) and lowest branch loss (18%) compared with live oak’s 78% survival and 43% branch loss.

**Crown Characteristics**

Crown density is an estimate of the openness of the crown or the ratio of positive and negative space within the crown (Hightshoe 1988; Gilman 2005). We determined from the literature and observation the density class of each species and then compared open with moderate with dense crowns for branch loss and survival (Hightshoe 1988; Gilman 2005). In Hurricane Charley, dense crowns had significantly greater survival than moderate crowns (78% versus 64%; \(P = 0.02\)) but were not different than open crown survival (75%). Branch loss was also greatest for moderate crown density trees (45% versus 36% and 34% for dense and open, \(P = 0.08\) and \(P = 0.02\)), and the recalculated survival (subtracting the trees with greater than 50% branch loss) was the poorest for trees with moderate crown densities (37%). In Hurricane Jeanne, again dense-crowned trees survived better (88%) than (79%) moderate, which survived better than open trees (47%, \(P\) ranged from 0.05 to 0.0001). Branch loss was the greatest for moderate (43%), then open (33%), and the least with dense-crowned species (19%) \((P\) ranged from 0.05 to 0.0001). Dense-crowned trees include citrus, black olive, laurel oak, sand live oak, and live oak. Moderate density trees included sea grape, Florida scrub hickory, and melaleuca. Open-crowned trees include gumbo limbo, Australian pine, Norfolk Island pine, baldcypress, and the pines. In contrast to our results, Everham and Brokaw (1996) in their review of hurricanes and trees discuss the tendency for dense-crowned trees to be more damaged in hurricanes compared with trees with more open-foliated crowns. In agreement with this study’s results, in our study of southeastern coastal plain species, dense crowns also survived better but lost more branches (Duryea et al. 2007).

The growth form of a tree can be categorized as excurrent or recurrent. Excurrent trees have strong apical dominance.
with the main trunk present throughout the life of the tree (giving rise to cone-shaped crowns with a central trunk). Decurrent trees have lateral branches, which grow as rapidly as the central trunk; they have no dominant main leader (Harris et al. 2004). Excurrent and decurrent trees had equal survival and branch loss in Hurricane Charley. When survival was recalculated (subtracting the trees that had 50% or greater branch loss), decurrent trees survived slightly better than excurrent trees (52% versus 45%, \( P = 0.06 \)). In Hurricane Jeanne, decurrent trees survived better (87% versus 56%, \( P < 0.0001 \)) and lost fewer branches (21% versus 42%, \( P < 0.0001 \)) than excurrent trees. Typical excurrent trees are Annona glabra—Chrysobalanus icaco greater than 20 trees (including a total of 371 trees) were ranked with low wind resistance (Table 4). 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 et al. 1996; Duryea 1997; Duryea et al. 2007). 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 crapemyrtle (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, in another study of 24 species experiencing Hurricane Georges, West Indian mahogany had the best survival and the least branch loss (Francis 2000).

**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 4). 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 et al. 1996; Duryea 1997; Duryea et al. 2007). 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 crapemyrtle (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, in another study of 24 species experiencing Hurricane Georges, West Indian mahogany had the best survival and the least branch loss (Francis 2000).

**Rooting Space**

Giving trees enough rooting space is important for both tree health and anchorage. In Hurricane Georges, we measured rooting space and compared it with survival and branch loss. Trees with the most rooting space (>7 m²) had the lowest branch loss and the greatest recalculated survival (Table 3). When discussing soil conditions, Everham and Brokaw (1996) summarize many papers on soil and wind by saying that soil conditions that restrict root development and anchorage lead to more tree and forest damage in wind.

**Pruning**

After Hurricane Andrew, we reported that gumbo limbo, live oak, and black olive had better survival if they had previously been correctly pruned (Duryea et al. 1996). We reanalyzed these data using the dicot tree species that had a sample space greater than 20 trees (including a total of 371 trees)—black olive, gumbo limbo, bottlebrush (Callistemon viminalis), royal Poinciana, live oak, West Indian mahogany, and white cedar. Survival for pruned trees was 73% compared with 47% for unpruned trees (\( P = 0.0001 \)).

**Table 3. Survival and branch loss in Hurricane Georges for trees growing in different amounts of rooting space**

<table>
<thead>
<tr>
<th>Rooting space (m²)</th>
<th>Sample size for survival and branch loss</th>
<th>Survival (%)</th>
<th>Recalculated survival (%)</th>
<th>Branch loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 3.5</td>
<td>270 (224)</td>
<td>90 a</td>
<td>64 a</td>
<td>36 a</td>
</tr>
<tr>
<td>3.6 to 7</td>
<td>133 (99)</td>
<td>90 a</td>
<td>73 a</td>
<td>29 a</td>
</tr>
<tr>
<td>&gt;7</td>
<td>98 (70)</td>
<td>98 a</td>
<td>91 b</td>
<td>20 b</td>
</tr>
</tbody>
</table>

*Numbers in columns with different letters are significantly different at \( P = 0.05 \).*

**Implications for Arboriculture and Urban Forestry**

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 (Figure 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 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. Some of the other practices and conditions of the urban forest and their associated recommendations are:

- One of the most important findings and therefore recommendations from this study are the rooting space results. It is clear that the more rooting space that a tree
Table 4. Results of the survey of arborists, scientists, and urban foresters in Florida with their rankings for wind resistance of tropical and subtropical tree species.

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Common name</th>
<th>Wind resistance</th>
<th>Wind resistance</th>
<th>Wind resistance</th>
<th>P Value</th>
<th>Total n</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>High n</td>
<td>Percent</td>
<td>Medium n</td>
<td>Percent</td>
<td>Low n</td>
</tr>
<tr>
<td><strong>Dicots</strong></td>
<td></td>
<td></td>
<td></td>
<td>n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acer rubrum</td>
<td>Red maple</td>
<td>12</td>
<td>20</td>
<td>32</td>
<td>52</td>
<td>17</td>
</tr>
<tr>
<td>Annona glabra</td>
<td>Pond apple</td>
<td>10</td>
<td>71</td>
<td>4</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>Araucaria heterophylla</td>
<td>Norfolk Island pine</td>
<td>8</td>
<td>18</td>
<td>14</td>
<td>31</td>
<td>23</td>
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<tr>
<td>Averrhoa carambola</td>
<td>Star-fruit or carambola</td>
<td>3</td>
<td>18</td>
<td>6</td>
<td>35</td>
<td>8</td>
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<tr>
<td>Bauhinia blakeana</td>
<td>Hong Kong orchid</td>
<td>1</td>
<td>5</td>
<td>9</td>
<td>41</td>
<td>12</td>
</tr>
<tr>
<td>Bacida buceras</td>
<td>Black olive</td>
<td>8</td>
<td>30</td>
<td>14</td>
<td>52</td>
<td>5</td>
</tr>
<tr>
<td>Bursera simarouba</td>
<td>Gumbo limbo</td>
<td>21</td>
<td>64</td>
<td>10</td>
<td>30</td>
<td>2</td>
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<tr>
<td>Callistemon spp.</td>
<td>Bottlebrush</td>
<td>8</td>
<td>21</td>
<td>23</td>
<td>61</td>
<td>7</td>
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<tr>
<td>Callophyllum calaba</td>
<td>Brazilian beautyleaf</td>
<td>6</td>
<td>38</td>
<td>8</td>
<td>50</td>
<td>2</td>
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<tr>
<td>Cassia fistula</td>
<td>Golden shower</td>
<td>4</td>
<td>18</td>
<td>7</td>
<td>32</td>
<td>11</td>
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<tr>
<td>Ceiba (or Chorisia) speciosa</td>
<td>Floss-silk</td>
<td>4</td>
<td>18</td>
<td>12</td>
<td>55</td>
<td>6</td>
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<tr>
<td>Chrysobalanus icaco</td>
<td>Cocoplum</td>
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<td>5</td>
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<td>0</td>
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<td>Chrysophyllum oliviforme</td>
<td>Satinleaf</td>
<td>11</td>
<td>61</td>
<td>7</td>
<td>39</td>
<td>0</td>
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<tr>
<td>Citrus spp.</td>
<td>Citrus (e.g., lime, orange)</td>
<td>18</td>
<td>44</td>
<td>18</td>
<td>44</td>
<td>5</td>
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<td>Coccoloba diversifolia</td>
<td>Pigeon plum</td>
<td>11</td>
<td>58</td>
<td>8</td>
<td>42</td>
<td>0</td>
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<tr>
<td>Coccoloba uvifera</td>
<td>Sea grape</td>
<td>18</td>
<td>50</td>
<td>12</td>
<td>33</td>
<td>6</td>
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<tr>
<td>Conocarpus erectus</td>
<td>Buttonwood</td>
<td>11</td>
<td>35</td>
<td>17</td>
<td>55</td>
<td>3</td>
</tr>
<tr>
<td>Cordia sebestena</td>
<td>Geiger tree</td>
<td>8</td>
<td>33</td>
<td>13</td>
<td>54</td>
<td>3</td>
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<tr>
<td>× Cupressocyparis leylandii</td>
<td>Leyland cypress</td>
<td>7</td>
<td>22</td>
<td>13</td>
<td>41</td>
<td>12</td>
</tr>
<tr>
<td>Delonix regia (* in S. FL)</td>
<td>Royal poinciana</td>
<td>2</td>
<td>6</td>
<td>20</td>
<td>63</td>
<td>10</td>
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<td>Enterolobium cyclocarpum</td>
<td>Ear tree</td>
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<td>5</td>
<td>7</td>
<td>33</td>
<td>13</td>
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<tr>
<td>Eriobotrya japonica</td>
<td>(* in central and s. FL)</td>
<td>9</td>
<td>24</td>
<td>24</td>
<td>63</td>
<td>5</td>
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<tr>
<td>Eucalyptus cinerea</td>
<td>Silver dollar eucalyptus</td>
<td>2</td>
<td>13</td>
<td>9</td>
<td>56</td>
<td>5</td>
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<tr>
<td>Eugenia axillaris</td>
<td>White stopper</td>
<td>7</td>
<td>64</td>
<td>3</td>
<td>27</td>
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<td>Eugenia foetida</td>
<td>Boxleaf, Spanish stopper</td>
<td>7</td>
<td>64</td>
<td>2</td>
<td>18</td>
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<td>Strangler fig</td>
<td>4</td>
<td>36</td>
<td>5</td>
<td>46</td>
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<td>Ficus benjamina</td>
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<td>0</td>
<td>0</td>
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<td>4</td>
<td>8</td>
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<td>16</td>
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<td>Lignumvitae</td>
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<td>83</td>
<td>2</td>
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<td>Dahoon holly</td>
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<td>76</td>
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<td>Jacaranda, black poui</td>
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<td>7</td>
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<td>75</td>
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<td>Liquidambar styraciflua</td>
<td>Sweetgum</td>
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<td>43</td>
<td>22</td>
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<td>Litchi chinensis</td>
<td>Lichee</td>
<td>8</td>
<td>57</td>
<td>5</td>
<td>36</td>
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<td>Lysiloma latissilqua</td>
<td>Wild tamarind</td>
<td>9</td>
<td>50</td>
<td>6</td>
<td>33</td>
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<td>Magnolia grandiflora</td>
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<td>82</td>
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<td>Mango tree</td>
<td>6</td>
<td>20</td>
<td>16</td>
<td>53</td>
<td>8</td>
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<td>Peltophorum pterocarpa</td>
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<td>Persea americana</td>
<td>Avocado tree</td>
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<td>3</td>
<td>20</td>
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<td>Pinus clausia</td>
<td>Sand pine</td>
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<td>7</td>
<td>7</td>
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<td>Pinus elliottii var. densa</td>
<td>FL slash pine</td>
<td>18</td>
<td>38</td>
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<td>52</td>
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<td>Pinus palustris</td>
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<td>Podocarpus</td>
<td>24</td>
<td>75</td>
<td>7</td>
<td>22</td>
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</table>

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Table 4. Results of the survey of arborists, scientists, and urban foresters in Florida with their rankings for wind resistance of tropical and subtropical tree species. (continued)

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Common name</th>
<th>Wind resistance</th>
<th>n</th>
<th>Percent</th>
<th>n</th>
<th>Percent</th>
<th>n</th>
<th>Percent</th>
<th>P Value</th>
<th>Total n</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>High</td>
<td></td>
<td></td>
<td>Medium</td>
<td></td>
<td>Low</td>
<td></td>
<td></td>
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<tr>
<td>Prunus caroliniana</td>
<td>Carolina laurel cherry</td>
<td>5</td>
<td>16</td>
<td></td>
<td>15</td>
<td>48</td>
<td>11</td>
<td>36</td>
<td>NS</td>
<td>31</td>
</tr>
<tr>
<td>Quercus geminata</td>
<td>Sand live oak</td>
<td>36</td>
<td>92</td>
<td></td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>0.0001</td>
<td>39</td>
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<tr>
<td>Quercus laurifolia</td>
<td>Laurel oak</td>
<td>3</td>
<td>4</td>
<td></td>
<td>27</td>
<td>39</td>
<td>39</td>
<td>57</td>
<td>0.0001</td>
<td>69</td>
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<td>Quercus nigra</td>
<td>Water oak</td>
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<td>8</td>
<td></td>
<td>14</td>
<td>36</td>
<td>22</td>
<td>56</td>
<td>0.0009</td>
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<td>Quercus stellata</td>
<td>Post oak</td>
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<td>33</td>
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<td>67</td>
<td>0</td>
<td>0</td>
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<td>15</td>
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<tr>
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**Palms**

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*a* is the number of respondents for each species out of a total of 85 experts. *P* values from the $\chi^2$ test for equal proportions indicate the significance level for one or more of the categories being different from the others; NS means that there is no significant difference between the categories of high, medium, and low (*P* > 0.05).

*x* Invasive and not recommended for use in Florida.

*y* Caution: may be used but manage to prevent escape in Florida (Fox et al. 2005).
has, the healthier it is and this means better anchorage and resistance to wind.

- Another important cultural practice for broad-leaved 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 with 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, it is especially important to know the exotic species that 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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Résumé. En 1998 lorsque l’ouragan Georges (177 km/h) a traversé complètement l’île de Porto Rico, et en 2004 lorsque les ouragans Jeanne (193 km/h) et Charley (233 km/h) ont frappé le Sud de la Floride, nous avons alors mesuré les impacts de ces ouragans sur la forêt urbaine composée d’espèces tropicales et subtropicales. De plus, nous avons aussi utilisé des données provenant de l’ouragan Andrew pour certaines analyses. Le pourcentage de perte dans la forêt urbaine a varié de 13% pour Georges à 16% pour Jeanne et jusqu’à 18% pour Charley. Dans les ouragans Jeanne et Charley, les palmiers ont significativement mieux survécu que tous les autres arbres. Certaines des espèces qui ont le mieux survécu lors des ouragans en Floride sont le Bursera simarouba, le Coccoloba uvifera, le Ficus aurea, le Quercus virginiana, le Quercus laurifolia et le Taxodium distichum. Des mesures espérées à Porto Rico, celles qui ont eu le meilleur taux de survie et le plus faible taux de dommages aux branches ont été le Calophyllum calaba, le Pinus caribea, le Schefflera actinophylla et le Swietenia mahogani. La perte de feuilles durant ces ouragans n’a eu aucune relation avec le « comment bien » les arbres ont survécu. Lors des ouragans Jeanne, Charley et Georges, 3%, 4% et 11% des arbres qui sont tombés ont causé des dommages aux propriétés. Les espèces indigènes ont mieux survécu que celles introduites lors des ouragans Jeanne et Charley, mais pas lors de l’ouragan Georges. Les arbres poussant en groupes ont connu un plus haut taux de survie et moins de dommages aux branches lors de l’ouragan Jeanne que ceux poussant individuellement. La densité du bois n’a eu aucun lien avec le taux de survie ou la perte en branches chez les différentes espèces d’arbres lors des ouragans Jeanne, Charley, Georges ou Andrew. Deux autres mesures de la résistance du bois, soit les modules d’élasticité et de rupture, ont été reliés au taux de survie et à la perte de branches dans le cas de l’ouragan Jeanne, mais pas pour Charley. Les espèces d’arbres avec des cimes denses ont eu un taux de survie plus élevé et des pertes en branches plus faibles que celles aux cimes moins denses ou ouvertes. Les espèces d’arbres avec une croissance de forme plus « pyramidale » ont mieux survécu que celles avec une forme plus expansive en hauteur, et ce lors de l’ouragan Jeanne, mais pas dans le cas de Charley où cela n’a eu aucune influence. Les arbres avec la plus grande surface racinaire (>7 m²) ont eu le plus faible taux de perte en branches et le plus haut taux de survie lors de l’ouragan Georges. Une re-analyse de sept espèces et de leur survie lors de l’ouragan Andrew a permis de montrer que le taux de survie des arbres élagués était de 73% par rapport à 47% pour les arbres non élagués. Une enquête auprès de 85 arboriculteurs, scientifiques et forestiers urbains a permis de classifier les arbres selon leur degré de résistance au vent. En utilisant les résultats provenant de nos mesures des ouragans et en les incorporant avec ceux provenant de l’inventaire et les données de la littérature scientifique, nous avons développé une liste de résistance relative au vent pour les espèces tropicales et subtropicales. Ces listes sont présentées avec l’avertissement qu’aucun arbre n’est totalement à l’abri du vent et que d’autres facteurs tels le sol, les pratiques culturales, l’âge et la santé de l’arbre contribuent aussi au renforcement face au vent.


Resumen. En 1998 cuando el Huracán Georges (177 km/h) pasó sobre la isla de Puerto Rico, y en el 2004 cuando los Huracanes Jeanne (193 km/h) y Charley (233 km/h) golpearon el sur de la Florida, se midió el impacto de estos huracanes en el bosque urbano compuesto de especies tropicales y subtropicales. Además, para este análisis, se usaron también datos previos publicados del Huracán Andrew. El por ciento de pérdida de bosque urbano estuvo desde 13% para Georges, 16% para Jeanne a 18% para Charley. En los Huracanes Jeanne y Charley, las palmas supervivieron significativamente mejor que todos los otros árboles. Algunas de las especies que mejor supervivieron en los huracanes de Florida fueron bursera (Bursera simarouba), uva marina (Coccoloba uvifera), higo (Ficus aurea), encino (Quercus virginiana), encino laurel (Quercus laurifolia) y ahuehuete (Taxodium distichum). De las otras especies medidas en Puerto Rico, las de más alta supervivencia y menor pérdida de ramas fueron Santa María (Calophyllum calaba), pino del caribe (Pinus caribaea), schefflera (Schefflera actinophylica) y caoba (Swietenia mahogani). La pérdida de ramas durante estos huracanes no tuvo relación con la supervivencia de los árboles. En los Huracanes Jeanne, Charley y Georges, 3%, 4%, y 11% de los árboles que cayeron dañaron propiedades. Las especies nativas supervivieron mejor que las especies exóticas en los Huracanes Jeanne y Charley pero no en el Huracán Georges. Los árboles que crecieron en grupos tuvieron más alta supervivencia y menor pérdida de ramas en el Huracán Jeanne que los que crecieron individualmente. La densidad de la madera no estuvo relacionada a la supervivencia o pérdida de ramas para las especies de árboles en los Huracanes Jeanne, Charley, Georges o Andrew. Otras dos mediciones de resistencia de la madera, módulos de elasticidad y de ruptura, estuvieron relacionadas con la supervivencia y pérdida de ramas en Jeanne pero no en Charley. Las especies de árboles con copas densas tuvieron mayor supervivencia y menor pérdida de ramas que las especies de copas menos densas o abiertas. Las especies con crecimiento de forma decurrente supervivieron mejor que los árboles excurrentes en el Huracán Jeanne, sin diferencia en Charley. Los árboles con mayor espacio de raíces (>7 m²) tuvieron la más baja pérdida de ramas y la mayor supervivencia en el Huracán Georges. Un re-análisis de siete especies dicotiledóneas y su supervivencia en el Huracán Andrew mostró que la supervivencia para árboles podados fue 73% comparada con 47% para árboles no podados. Una encuesta de 85 arboristas, científicos y dasónimos urbanos clasificó las especies por su resistencia al viento. Utilizando estos resultados de los huracanes e incorporándolos a las de la encuesta y la literatura científica, se desarrollaron listas de especies tropicales y subtropicales relativamente resistentes a los vientos. Estas listas están publicadas con la advertencia de que los árboles no son completamente a prueba de vientos y otros factores como condiciones del suelo, intensidad del viento, prácticas culturales, salud y edad del árbol, también contribuyen a la resistencia al viento.