

Wind and Trees: Lessons Learned from Hurricanes¹

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Introduction

Hurricane-force winds can be extremely damaging to communities and urban forests. Without question, trees can become damaged and pose risks to personal safety and property. As destructive as these storms are, it is important not to forget that trees provide many environmental benefits, such as providing shade and energy conservation, reducing the “heat island” effect in cities caused by concrete and pavement, increasing property values, and enhancing human health. Also, there are opportunities to better prepare for the next hurricane season by rebuilding a healthy urban forest. Valuable lessons can be learned from knowing more about how, when, and why trees fail in storms. A key issue facing communities is how to manage the urban forest from an ecological standpoint, so urban forests are healthier and more wind resistant.

A healthy urban forest is composed of trees that maximize ecosystem benefits while being able to withstand natural and anthropogenic stresses and disturbances, such as wind from hurricanes and tropical storms, flooding, pollution, etc.

This fact sheet reports on the lessons learned from research conducted after 10 hurricanes by scientists at the University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS). It also includes valuable field observations from professionals, such as urban foresters, scientists, and arborists.

Our goal is to promote a healthy and more wind-resistant urban forest. This publication is aimed at citizens and communities who seek to rebuild and promote better urban forest management practices so that future storms are less devastating.

The Study

Since 1992, when Hurricane Andrew struck south Florida, researchers at UF/IFAS have been studying the impacts of hurricanes on the urban forest (Duryea et al. 1996). Hurricane wind damage to urban neighborhoods was measured again in 1995 when two hurricanes struck the Pensacola, FL, area (Duryea 1997) and once more in 1998

when Hurricane Georges crossed over the entire island of Puerto Rico. In 2004, four hurricanes (Charley, Jeanne, Francis, and Ivan) struck Florida with maximum sustained winds ranging from 105 to 145 mph. In 2005, Hurricanes Dennis, Katrina, and Rita struck the Gulf Coast of the US (Figure 1).



Figure 1. In the UF/IFAS study, urban trees were measured in neighborhoods following the 9 hurricanes striking Florida and the Gulf Coast and 1 hurricane in Puerto Rico. For each hurricane, the year and maximum sustained wind speed (mph) are included.

Credit: UF/IFAS, Mary Duryea and Eliana Kampf

The impacts of these hurricanes gave us the opportunity to study over 150 urban tree species and their comparable responses to hurricanes (Duryea et al. 2007).

Our goal was to answer the question; *what makes a tree more wind resistant?* Our main objective was to determine what biological, site, and cultural factors make trees more or less wind resistant. By evaluating these factors, we can understand the difference between species (e.g., whether they defoliate quickly in wind) and between certain practices (such as planting trees in groups compared to individual tree planting). This fact sheet describes the lessons and recommendations about the urban forest, trees (i.e., species and structure), and soil and rooting conditions.

I. Lessons about the Urban Forest

Lesson 1: THE HIGHER THE WIND SPEED OF THE HURRICANE, THE MORE LIKELY TREES WILL FAIL

In the 10 hurricanes we studied, we measured standing, leaning, or fallen trees in yards. Standing trees were considered survivors of the wind. Trees were considered not surviving if they had fallen or were leaning at less than a 45-degree angle.

From these numbers we calculated the percent of urban forest lost in each hurricane, which ranged from 11% in Hurricane Erin to 21% in Hurricane Rita to 23% in Hurricane Katrina to 38% in Hurricane Andrew (Figure 2). As wind speed increases, trees are more likely to suffer damage (i.e. uproot, break, or lean), resulting in greater urban forest loss.

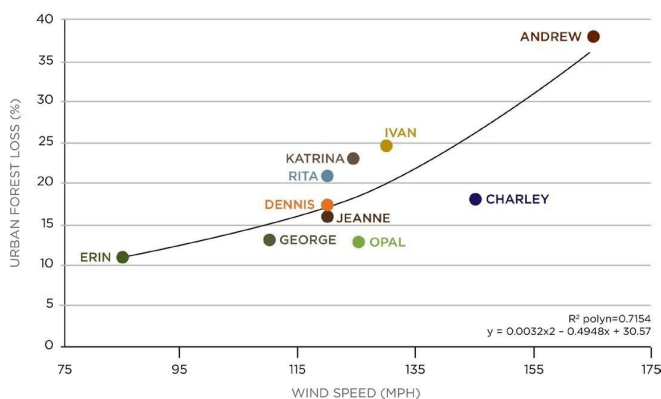


Figure 2. Urban forest loss (%) at different wind speeds (mph) in 10 hurricanes.

Credit: Mary Duryea and Eliana Kampf

However, it is important to point out that in addition to wind intensity and speed, other factors influence urban forest damage during hurricanes:

- Conditions accompanying the hurricane, such as precipitation and the time it takes to move through an area
- Tree species, age, health, and structure
- Site characteristics, such as soil conditions (e.g., soil depth, water table, soil compaction) and soil composition
- Urban forest conditions, such as overall tree canopy density and composition

These factors together will determine whether a tree will fail during winds. Biological factors such as tree species, age, health, and condition are related to urban forest composition and structure. For example, Pensacola, FL, has a denser tree canopy composed of older trees, and these trees suffered considerably more damage during hurricanes when compared to Miami, FL, with less canopy cover and younger trees.

Conditions accompanying the hurricane also influence tree fall. For instance, a slower-moving storm with a lot of precipitation will mean more water accumulating in the soil and less friction between roots and soil to hold trees up.

Trees growing in shallow soils, such as in Miami-Dade County with soils no more than one foot deep, will also behave differently from those planted in deeper soils. Trees in shallow soils are more prone to blow over than trees rooted more deeply.

RECOMMENDATION

Establish and manage a healthy urban forest to improve wind resistance by

- Developing and updating as needed a comprehensive tree management plan for your community
- Selecting appropriate species and design spaces based on tree size requirements
- Diversifying and incorporating wind-resistant species
- Planting high-quality trees with central leaders and good structure
- Beginning a structural pruning program for young and developing trees
- Pruning damaged and dead branches in mature trees

Lesson 2: TREES IN GROUPS SURVIVE WINDS BETTER THAN TREES GROWING INDIVIDUALLY

Trees in groups had a 10% advantage. In Hurricanes Ivan and Jeanne, trees growing in groups survived the winds better than individual trees (80% versus 70% in Hurricane Ivan, and 88% versus 78% in Hurricane Jeanne). A group was defined as 5 or more trees, each growing within 10 feet of another tree, but not in a row.

Trees with more rooting space were less likely to fail due to wind (see section Lessons Learned about Soil and Rooting Conditions for more details). Adequate soil space further helps trees develop a strong supporting root system and resist toppling.

RECOMMENDATIONS

- Plant trees in groups of at least 5 trees as opposed to individually.
- Give trees adequate space to grow (Figure 3).
- Plant a variety of species, ages, and layers of trees and shrubs to maintain tree diversity in your community.



Figure 3. Give trees a space to grow and consider mature tree size within confined planting locations.

Credit: Adobe Stock, Iklales

Lessons about Trees

Lesson 1: SOME SPECIES RESIST WIND BETTER THAN OTHERS

Based on tree responses to 10 hurricanes, tree species vary in resistance to wind. Tree wind resistance is defined as the ability or capacity of a tree to survive (remain standing and living) hurricane-force winds, which means that they do not easily uproot or break in the winds.

One of the main objectives of this study was to develop lists of wind-resistant tree species. To complement our findings, we conducted a survey of arborists, scientists, and urban foresters who ranked wind resistance of urban tree species they observed after hurricanes. We used these ratings along with our research results and the available scientific literature to classify broad-leaved, conifer, palm, and fruit tree species into highest, medium-high, medium-low, and lowest wind resistance. The recommended tree species are divided into the Southeastern Coastal Plain region (including USDA hardiness zones 8 and 9) and Tropical and Subtropical regions (USDA hardiness zones 10 and 11).

RECOMMENDATION 1

Select and plant tree species that have been shown to be more wind resistant. Planting a diverse urban forest provides resiliency to other biotic (e.g., pest) and abiotic (e.g., drought) stressors. Thus, planting for diversity, and especially incorporating wind resistance, helps build longer lasting urban tree populations.

RECOMMENDATION 2

Inspect over-mature trees and tree species that have demonstrated poor survival in hurricanes. Remove those at high risk of failure. This is especially true if trees are over-mature, endangering lives and property, and belong to the lowest wind resistance list. Some of these species can be seen below and include sand pine, pecan, laurel oak,

and water oak in north Florida and queen palm, Australian pine, melaleuca, weeping banyan, and Washington palm in south Florida. For borderline species, consult a professional urban forester or a certified arborist.

RECOMMENDATION 3

When a tree fails, plant a new tree in its place. In the streets of Bagdad, Florida, laurel oaks are being replaced with more wind-resistant, longer-living street tree species, such as live oaks (Figure 4). The renewed urban forest, with its mixture of young and mature trees, will provide benefits from future tree canopy cover, greater tree diversity, and mitigation of high winds. When possible, plant groups of trees. Doing so can improve wind resistance.



Figure 4. Replace trees that were lost in storms with appropriate, long-lived, and wind-resistant species.

Credit: Adobe Stock, Gift culture Media/KOTO

ANOTHER FINDING: OAKS

When comparing survival of sand live oak, live oak, and laurel oak in four Panhandle Florida hurricanes (Erin, Dennis, Opal, and Ivan), laurel oak had poorer overall survival than both live oak and sand live oak (Duryea et al. 2007) (Figure 5). However, in two south Florida hurricanes (Jeanne and Charley), both survival and branch loss for these oaks were similar. Speculations about the reasons for this lack of difference 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).

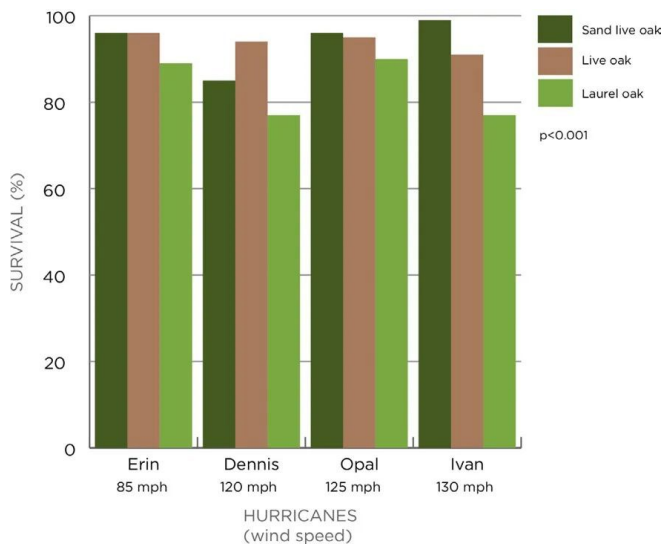


Figure 5. Graph of percent survival of sand live oak, live oak, and laurel oak for four different hurricanes. Tree species differ in survival following hurricanes. Credit: Mary Duryea and Eliana Kampf

RECOMMENDATION

Become familiar with the recommended tree species and how they perform in natural and urban ecosystems in your community. The same species in different locations may behave differently due to soils, climate, local disease problems, and other factors.

Lesson 2: AS A GROUP, PALM SPECIES SURVIVE HURRICANES BETTER THAN BROAD-LEAVED AND CONIFER TREES

When compared to broad-leaved and other conifer trees (such as pines), palms have often been observed to be more resistant to winds. Palms grow differently than other trees because they have one terminal bud. If that bud is not damaged, palms may lose all their fronds (leaves) and still survive. Our research shows that palms in the coastal plain, tropical, and subtropical regions are often more resistant to winds (Figure 6). However, individual palm species do vary in response to wind. Examples would be Queen and Washington palms, which have exhibited poor survival in south Florida during hurricanes (Figure 7).



Figure 6. Palms native to hurricane prone areas such as Sabal Palmetto have natural resistance. Credit: UF/IFAS Communications



Figure 7. Some palms perform poorly due to their species or unsuitable site conditions. Credit: Adobe Stock, bilanol

RECOMMENDATION 1

Consider planting wind-resistant palm species. Examples include sabal palm, Canary Island date palm, and manila palm.

RECOMMENDATION 2

Monitor palms carefully after storms. Bud damage may not show up immediately after the storm. Allow at least 6 months for palms to put out new fronds. Palms should also be checked for hidden root, stem, or bud damage.

Lesson 3: PINES MAY SHOW NO IMMEDIATE VISIBLE DAMAGE AFTER HURRICANES, BUT MAY DECLINE OVER TIME

In our study, we measured pines right after hurricanes, when they looked green and healthy (Figure 8). However, we went back 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. Pines have been observed to be very sensitive to wind damage. They

may show no immediate visible damage after high winds but may die sometime later. They can die slowly over a period of 6 months to 2 years after windstorms. Some may remain green for a year or more, and then suddenly turn yellow (Figure 9) and quickly progress to brown needles in a very short period. The causes of yellowing of the needles and pine death are not completely understood. It is likely due to hidden damage produced by bending and twisting during hurricane-force winds. Prolonged winds may also rupture smaller roots without breaking the larger support roots. The injured stems and roots are unable then to supply the water and nutrients needed in the crown, resulting in pine decline and death.



Figure 8. Assessing the health of pine trees after a hurricane can be a long-term process. While they may look green and healthy now, damage can appear many months later.

Credit: UF/IFAS Communications



Figure 9. Pine tree decline may seem sudden, but internal damage may not be visible until needles yellow and then turn brown.

Credit: Adobe Stock, g0d4ather

RECOMMENDATION

Monitor pines carefully. Sometimes there is hidden damage, and the tree declines over time. Look for signs of stress or poor health. Check closely for insects. Weakened pines may be more susceptible to beetles and diseases.

Lesson 4: TREES THAT LOSE ALL OR SOME OF THEIR LEAVES IN HURRICANES ARE NOT NECESSARILY DEAD

The greater the wind speed, the more leaves trees lose during hurricanes, and leaf loss may help trees to survive mechanical breakage. Trees can lose all or some of their leaves in most hurricanes. However, leaf loss does not mean the tree is dead; rather it means the tree is temporarily unable to photosynthesize (produce food) and store energy due to lost foliage. With time, the tree will produce new leaves which are a sign of recovery since they restore the tree's ability to photosynthesize and bring the tree back to health. Some species defoliate (lose leaves) easily during winds. Losing leaves may be a good strategy, helping the tree to better resist wind damage. Our research on Hurricane Ivan found that trees that lost their leaves survived the winds better. Live oak (in north Florida) and gumbo limbo (in south Florida) are examples of trees that readily lose leaves and small branches and stand up well to high winds.

RECOMMENDATION

Wait, watch for leaves, and monitor the tree's health. Most trees will leaf out again in a few months or in the spring of the following year. If the tree does not grow new leaves by the spring or early summer following the hurricane, it is not likely to recover. Note that some species, such as pines, may not recover if defoliated.

Lesson 5: NATIVE TREE SPECIES SURVIVED BETTER IN SOUTH FLORIDA HURRICANES (JEANNE, ANDREW, AND CHARLEY)

In our research, native trees survived better in south Florida hurricanes but not in north Florida (Hurricane Ivan) (Figure 10). Native species also lost fewer branches than exotic species in Jeanne (36% versus 21%) and Charley (39% versus 36%) in south Florida. Some of the exotic species with low survival in south Florida were melaleuca, Australian pine, and queen palm as compared to native species with high survival, such as live oak, gumbo limbo, and sabal palm. In tropical and subtropical areas, exotics represent a large proportion of the urban forest (for Hurricane Jeanne, exotics made up 38% of the trees in the urban forest, for Hurricane Charley, 42%, and for Hurricane Andrew, 64% were exotics). In the southeast coastal plains (Hurricane Ivan), exotic tree species make up 9% of the trees in the urban forest. The major exotic species were crape myrtle, Chinese tallow (a prohibited invasive species), camphor tree (an invasive species), Bradford pear, and palms such as pindo and Washington. These differences in the composition of the urban forest may explain why, with fewer exotics in their population, natives did not survive better in the coastal plain during Hurricane Ivan. Native trees also survived winds better in south Florida hurricanes when compared to Puerto Rico (Hurricane Georges) (Figure 11). Out of the 35 tree species

measured in Puerto Rico, only 4 were native to the island. The lighter winds and conditions of Hurricane Georges showed no differences between native and exotic species.

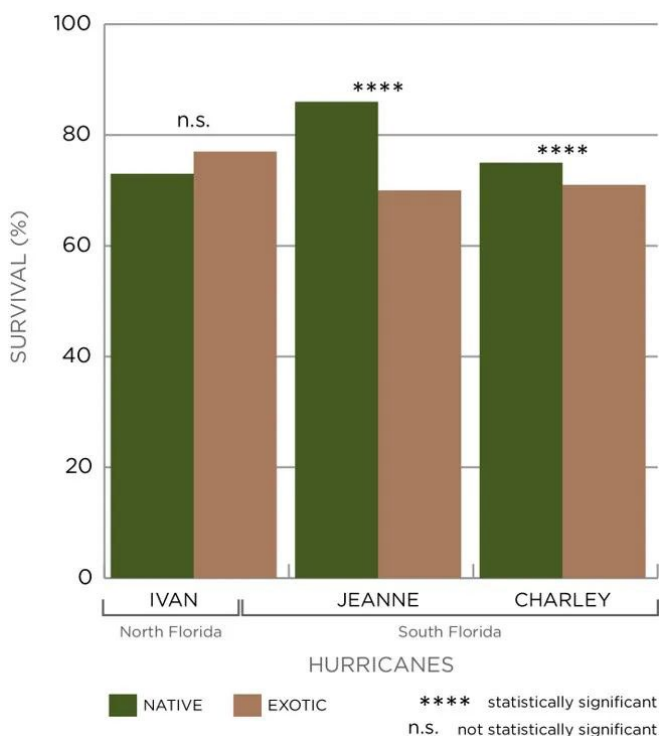


Figure 10. The response of native tree species tended to better survive hurricanes in north Florida compared to south Florida.

Credit: Mary Duryea and Eliana Kampf

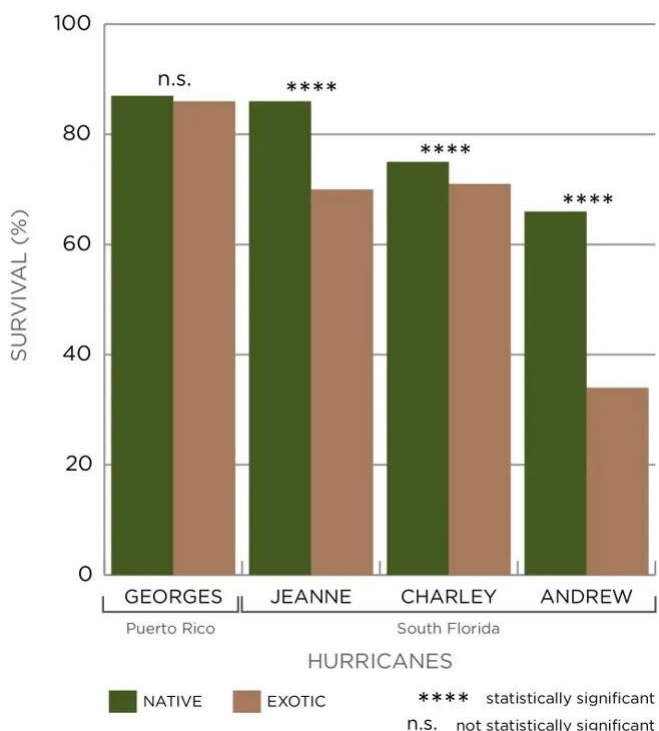


Figure 11. Native tree species tended to better survive hurricanes in Puerto Rico compared to those in south Florida.

Credit: Mary Duryea and Eliana Kampf

RECOMMENDATION

Consider native tree species when selecting trees for planting. Native trees should receive strong consideration when selecting trees for the urban forest. Additional benefits of using native species include their values for wildlife and native ecosystem conservation.

Lesson 6: OLDER TREES ARE MORE LIKELY TO FAIL IN HURRICANES

As trees grow and age, they become more susceptible to insects and diseases; branches and parts of the tree begin to die, they become less flexible, and they may be more vulnerable to winds. Our research shows that larger and older trees lose more branches in hurricanes. Larger trees (40 to 79 inches in diameter) lost a greater percentage of their branches compared to small trees (less than 8 inches in diameter) (Figure 12). Every tree species has an inherent life span. Some tree species live longer than others (Table 1). It is important to keep in mind that the risk of failure from wind increases with age. For example, the life span of laurel oak is typically 50 years; it begins to decay and shows signs of diseases as it reaches 40 years. The older a tree gets, the greater the likelihood of diseases and pathogens, breakage during winds, and the greater the risk of it causing damage when it fails.

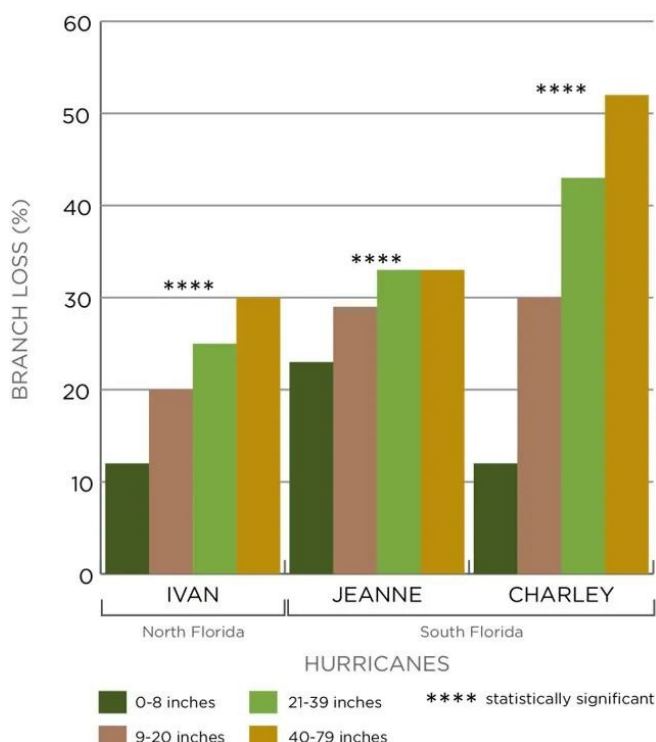


Figure 12. Larger trees tend to experience greater branch loss from hurricane winds.

Credit: Mary Duryea and Eliana Kampf

RECOMMENDATION 1

Consider life span when selecting and managing urban forests for wind resistance (Table 1).

RECOMMENDATION 2

Over-mature trees present a high risk to people and property and should be removed and replaced by new trees. These trees should be monitored regularly for structural defects. Consult with a certified arborist or urban forester.

Lesson 7: UNHEALTHY TREES ARE PREDISPOSED TO DAMAGE

Old trees with decayed root systems, stem decay, or large dead branches are vulnerable to hurricanes. Decay, a major cause of tree failure, is caused by fungi that weaken wood (Figure 13). Cracks, seams, butt swell, dead branch stubs, and large older wounds suggest internal decay. They can be weak points on a trunk and increase the likelihood of tree failure. Mushrooms at the base of the tree trunk might also indicate root problems. They can be the sign of Armillaria or other fungi than can decay roots, creating unstable trees (Figure 14). Root rot can be diagnosed with careful, regular inspections by qualified arborists.



Figure 13. Internal decay and codominant stems contributed to trunk failure.

Credit: UF/IFAS, Dr. Ed Gilman



Figure 14. Mushrooms perform an essential ecological role in breaking down plant material; however, growing at the base of a living tree might be a sign of a fungal disease.

Credit: UF/IFAS Communications

RECOMMENDATION

Remove high-risk trees before the wind does. Have a certified arborist inspect your trees for signs of disease and decay. They are trained to advise you on tree health.

Lesson 8: TREES WITH POOR STRUCTURE OR INCLUDED BARK ARE MORE VULNERABLE IN THE WIND

A tree with two or more trunks or stems of equal size originating from the same point on the tree is said to have codominant stems. Codominant stems may develop bark inclusions, which are weak unions between branches, and are very susceptible to breakage. To develop a strong structure, trees may need to be managed with structural pruning.

RECOMMENDATION 1

For a more wind-resistant, sustainable landscape, plant high-quality trees with central leaders and good form.

RECOMMENDATION 2

Follow with a preventive structural pruning program of young and mature trees.

Lesson 9: WELL-PRUNED TREES SURVIVE HURRICANES BETTER THAN POORLY PRUNED OR UNPRUNED TREES

Poor pruning practices, such as topping or removing large branches, make trees more susceptible to wind failure. Old, large pruning cuts can become an entry point for fungi that begins the decay process (Figure 15). In our study of Master Gardeners after Hurricane Andrew in 1992 (Duryea et al. 1996), we found that trees that had been pruned properly (not topped and with more open and well-distributed crowns) survived high winds better than unpruned trees. An analysis with broad-leaved tree

species—black olive, gumbo limbo, bottlebrush, royal Poinciana, live oak, West Indian mahogany, and white cedar—showed survival for pruned trees was 73% compared to 47% for unpruned trees. Thus, active management through proper pruning paid survival dividends with pruned trees that are less likely to fail in hurricanes.



Figure 15. Large pruning wounds can lead to greater decay and make a tree more prone to fail from wind a few decades later.

Credit: Dr. Ed Gilman, UF/IFAS

RECOMMENDATION 1

Begin a preventive pruning program for both young and mature trees. The main goal of preventive pruning is to form an appropriate, species dependent tree structure and as needed to reduce the length and size of branches competing with the main trunk.

RECOMMENDATION 2

Select trees appropriate for the growing space to avoid improper pruning practices. To allow healthy crown development, consider the aerial space needed for a mature-sized tree (Figure 16). Under power lines, the preferred option is to plant smaller trees that will better fit the space.

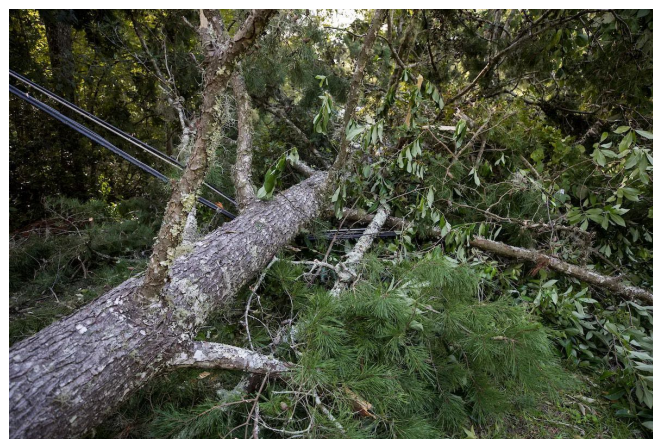


Figure 16. Use mature tree size as a guide for selecting trees appropriate to the site. Large trees that grow into an electrical line are a bad choice.

Credit: UF/IFAS Communications

II. Lessons about Soil and Rooting Conditions

Lesson 1: TREES WITH MORE ROOTING SPACE SURVIVE BETTER

The most important factor in designing a healthy urban landscape is also probably the one most often overlooked—that is, providing enough soil space for tree roots to grow. In Hurricane Georges (Puerto Rico), more rooting space led to greater tree survival during winds (Table 2).

Soil growing space and volume allow for growth of the trunk and development of the structural roots that are directly connected to the tree stem. To provide anchorage for the tree, roots need to spread beyond the edge of the canopy and grow into the soil. Sidewalks, curbs, buildings, parking lots, driveways, and other urban structures restrict root development. A strong supporting root system with adequate rooting space is one of the most critical factors to the ability of trees to withstand hurricane-force winds in urban landscapes.

RECOMMENDATION

Give trees enough rooting space based on their mature size:

- Small trees need at least 10 feet by 10 feet
- Medium trees need 20 feet by 20 feet
- Large trees need at least 30 feet by 30 feet

Lesson 2: GOOD SOIL PROPERTIES, SUCH AS ADEQUATE SOIL DEPTH, A DEEP WATER TABLE, AND NO COMPACTION, HELP WIND RESISTANCE

Trees without proper root development can become unstable and fall over in strong winds. Trees in shallow

soils are more likely to blow over than trees rooted more deeply (Figure 17). Trees planted in compacted soil grow poorly and often less healthy. This is especially true when the soil is poorly drained, or the water table is high.



Figure 17. Confined growing space can impact tree root development and increase the likelihood of tree failure from wind.

Credit: Alyssa Vinson, UF/IFAS

RECOMMENDATION 1

Make sure that planting sites have 3 feet of soil depth with a deep water table to allow healthy root system development.

RECOMMENDATION 2

Keep soil compaction to a minimum. In some cases, it may be necessary to incorporate organic matter into the soil to improve water holding capacity, pH, and bulk density.

Lesson 3: DAMAGED ROOT SYSTEMS MAKE TREES VULNERABLE IN THE WIND

Roots anchor the tree. It is important that roots under the canopy are not cut because many roots are located just below the surface of the soil. Tree roots need to extend out from a tree in all directions to stabilize it against wind throw. When roots under the canopy are cut, trees are more predisposed to falling over (Figure 18).



Figure 18. These tree roots were severed during sidewalk and curb repair, making them prone to toppling during a hurricane.

Credit: Dr. Ed Gilman, UF/IFAS

RECOMMENDATION

Do not damage or cut main support roots during construction. Never cut roots closer than the distance of 5 times the trunk diameter. Be aware that when tree roots are cut, the anchoring system of the tree may be harmed and compromised.

Final Considerations

A healthy and more wind-resistant urban forest depends on managing existing trees well, and, at the same time, establishing new trees properly. Follow these recommendations when managing older trees or planting new trees.

Older Tree Management

- Consider life span when managing urban forests for wind resistance. Over-mature trees should be evaluated, removed if high-risk, and replaced by new trees.
- Remove high-risk trees before the wind does. Have a certified arborist inspect your trees for signs of disease and decay.
- Consider removing tree species that have demonstrated poor survival in hurricanes, especially if they are over-mature and endangering lives and property.
- Be careful not to damage or cut main support roots during construction. Be aware that when the tree roots are cut, the anchoring system of the tree may be harmed and compromised.
- Establish a preventive structural pruning program for both young and mature trees.

Planting

- When a tree fails, plant a new tree in its place.
- Plant tree species that have been shown to be more wind resistant.
- To reduce your risk, maintain diversity in your yard and community by planting a mixture of species, ages, and layers of trees and shrubs.
- Plant trees in groups as opposed to individually.
- Give trees enough rooting space based on their mature size: small trees need at least 10 feet by 10 feet, medium trees 20 feet by 20 feet, and large trees 30 feet by 30 feet.
- To allow healthy root system development, make sure that planting sites have 3 feet of soil depth with a deep water table. Keep soil compaction to a minimum.
- To allow healthy crown development (instead of misshapen pruning) under power lines, plant small trees such as buttonwood, dogwood, crape myrtle, and wax myrtle.
- For a more wind-resistant, sustainable landscape, plant high-quality trees with central leaders and good form. Begin a structural pruning program for young trees.

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<https://doi.org/10.48044/jauf.2007.011>

Table 1. Lifespan of Tree Species in the Forest.*

Short Lived (<50 Years)	Medium Lived (50–100 Years)	Long Lived (>100 Years)
laurel oak	African tuliptree	live oak
red bud	paradise tree	sweetgum
bottle brush	red maple	southern magnolia
Hong-Kong orchid tree	gumbo limbo	baldcypress
jacaranda	sea grape	mahogany

*Note: Trees in urban areas have shorter life spans than those in a forest.

Table 2. Rooting Space and Survival Rate.

Tree Location	Rooting Space	Survival Rate
Streets Parking Lots Yards	0 to 3m ² (0 to 39 ft ²)	64%
Yards Parks	4 to 7 m ² (40 to 75 ft ²)	73%
Campuses Parks Yards	> 7m ² (>75 ft ²)	91%

Table 3. Southeastern Coastal Plain Tree Species and Wind Resistance

Highest Wind Resistance	Medium-High Wind Resistance	Medium-Low Wind Resistance	Lowest Wind Resistance
Dicots			
<i>Carya floridana</i> , Florida scrub hickory <i>Cornus florida</i> , dogwood <i>Ilex cassine</i> , dahoon holly <i>Ilex glabra</i> , inkberry <i>Ilex opaca</i> , American holly <i>Ilex vomitoria</i> , yaupon holly <i>Lagerstroemia indica</i> , crape myrtle <i>Magnolia grandiflora</i> , southern magnolia <i>Quercus geminata</i> , sand live oak <i>Quercus laevis</i> , turkey oak <i>Quercus myrtiflora</i> , myrtle oak <i>Quercus virginiana</i> , live oak <i>Podocarpus</i> spp, podocarpus <i>Vaccinium arboreum</i> , sparkleberry	<i>Acer saccharum</i> , Florida sugar maple <i>Acer palmatum</i> , Japanese maple <i>Betula nigra</i> , river birch <i>Carpinus caroliniana</i> , ironwood <i>Carya glabra</i> , pignut hickory <i>Carya tomentosa</i> , mockemut hickory <i>Cercis canadensis</i> , red bud <i>Chionanthus virginicus</i> , fringe tree <i>Diospyros virginiana</i> , common persimmon <i>Fraxinus americana</i> , white ash <i>Liquidambar styraciflua</i> , sweetgum <i>Magnolia virginiana</i> , sweetbay magnolia <i>Magnolia x soulangiana</i> , saucer magnolia <i>Nyssa aquatica</i> , water tupelo <i>Nyssa sylvatica</i> , black tupelo <i>Ostrya virginiana</i> , American hophornbeam <i>Prunus angustifolia</i> , chickasaw plum <i>Quercus michauxii</i> , swamp chestnut <i>Quercus shumardii</i> , Shumard oak <i>Quercus stellata</i> , post oak <i>Ulmus alata</i> , winged elm	<i>Acer negundo</i> , boxelder <i>Acer rubrum</i> , red maple <i>Acer saccharinum</i> , silver maple <i>Celtis laevigata</i> , sugarberry <i>Celtis occidentalis</i> , hackberry <i>Cinnamomum camphora</i> , camphor ^b <i>Eriobotrya japonica</i> , loquat ^c <i>Eucalyptus cinerea</i> , silverdollar eucalyptus <i>Fraxinus pennsylvanica</i> , green ash <i>Morus rubra</i> , red mulberry <i>Myrica cerifera</i> , wax myrtle <i>Persea borbonia</i> , redbay <i>Platanus occidentalis</i> , sycamore <i>Prunus serotina</i> , black cherry <i>Quercus alba</i> , white oak <i>Quercus phellos</i> , willow oak <i>Salix x sepulcralis</i> , weeping willow <i>Ulmus americana</i> , American elm	<i>Carya illinoensis</i> , pecan <i>Liriodendron tulipifera</i> , tulip poplar <i>Prunus caroliniana</i> , Carolina laurelcherry <i>Pyrus calleryana</i> , Bradford pear <i>Quercus falcata</i> , southern red oak <i>Quercus laurifolia</i> , laurel oak <i>Quercus nigra</i> , water oak <i>Sapium sebiferum</i> , Chinese tallow ^a <i>Ulmus parvifolia</i> , Chinese elm
Conifers			

Highest Wind Resistance	Medium-High Wind Resistance	Medium-Low Wind Resistance	Lowest Wind Resistance
<i>Taxodium distichum</i> , baldcypress <i>Taxodium ascendens</i> , pondcypress		<i>Pinus elliottii</i> , slash pine <i>Pinus palustris</i> , longleaf pine <i>Pinus taeda</i> , loblolly pine	<i>Juniperus silicicola</i> , southern red cedar <i>x Cupressocyparis leylandii</i> , Leyland cypress <i>Pinus clausa</i> , sand pine <i>Pinus glabra</i> , spruce pine
Palms			
<i>Butia capitata</i> , pindo or jelly <i>Phoenix canariensis</i> , Canary Island date <i>Phoenix dactylifera</i> , date <i>Sabal palmetto</i> , cabbage, sabal			<i>Washingtonia robusta</i> , Washington fan
<p>^aProhibited in Florida</p> <p>^bInvasive, not recommended in Florida</p> <p>^cCaution: manage to prevent escape in Florida (IFAS Assessment 2026)</p> <p>We present these lists with the caveat that no tree is perfectly wind-proof and that many other factors contribute to wind resistance including soil conditions, wind intensity, previous cultural practices, tree health, and age. 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.</p>			

Table 4. Tropical/SubTropical Tree Species and Wind Resistance

Highest Wind Resistance	Medium-High Resistance	Medium-Low Resistance	Lowest Wind Resistance
Dicots			
<i>Bursera simaruba</i> , gumbo limbo <i>Carya floridana</i> , Florida scrub hickory <i>Conocarpus erectus</i> , buttonwood <i>Chrysobalanus icaco</i> , cocoplum <i>Cordia sebestena</i> , geiger tree <i>Eugenia axillaris</i> , white stopper <i>Eugenia confusa</i> , redberry <i>Eugenia foetida</i> , boxleaf stopper <i>Guaiacum sanctum</i> , lignum vitae <i>Ilex cassine</i> , dahoon holly <i>Krugiodendrum ferreum</i> , ironwood <i>Lagerstroemia indica</i> , crape myrtle <i>Magnolia grandiflora</i> , southern magnolia <i>Podocarpus</i> spp, podocarpus <i>Quercus virginiana</i> , live oak <i>Quercus geminata</i> , sand live oak	<i>Annona glabra</i> , pond apple <i>Calophyllum calaba</i> , Brazilian beautyleaf ^c <i>Chrysophyllum oliviforme</i> , satinleaf <i>Coccoloba uvifera</i> , sea grape <i>Coccoloba diversifolia</i> , pigeon plum <i>Liquidambar styraciflua</i> , sweetgum <i>Lysiloma latsiliqua</i> , wild tamarind <i>Magnolia virginiana</i> , sweetbay magnolia <i>Nyssa sylvatica</i> , black tupelo <i>Sideroxylon foetidissimum</i> , mastic <i>Simarouba glauca</i> , paradise tree <i>Swietenia mahagoni</i> , mahogany	<i>Acer rubrum</i> , red maple <i>Bauhinia blakeana</i> , Hong-Kong orchid <i>Bucidas buceras</i> , black olive <i>Callistemon</i> spp, bottlebrush <i>Cinnamomum camphora</i> , Camphor ^b <i>Delonix regia</i> , royal poinciana ^c <i>Enterolobium cyclocarpum</i> , ear tree <i>Eriobotrya japonica</i> , loquat ^c <i>Eucalyptus cinerea</i> , silverdollar eucalyptus <i>Ficus aurea</i> , strangler fig <i>Kigelia pinnata</i> , sausage tree <i>Myrica cerifera</i> , wax myrtle <i>Persea borbonia</i> , redbay <i>Platanus occidentalis</i> , sycamore <i>Quercus laurifolia</i> , laurel oak <i>Tabebuia heterophylla</i> , pink trumpet tree <i>Terminalia catappa</i> , tropical almond ^c	<i>Casuarina equisetifolia</i> , Australian pine ^a <i>Cassia fistula</i> , golden shower <i>Chorisia speciosa</i> , floss-silk tree <i>Ficus benjamina</i> , weeping banyan <i>Grevillea robusta</i> , silk oak <i>Jacaranda mimosifolia</i> , jacaranda <i>Melaleuca quinquenervia</i> , melaleuca ^a <i>Quercus nigra</i> , water oak <i>Peltophorum pterocarpa</i> , yellow poinciana <i>Prunus caroliniana</i> , Carolina laurelcherry <i>Sapium sebiferum</i> , Chinese tallow ^a <i>Spathodea campanulata</i> , African tuliptree <i>Tabebuia caraiba</i> , silver trumpet tree <i>Ulmus parvifolia</i> , Chinese elm
Conifers			
<i>Taxodium ascendens</i> , pondcypress <i>Taxodium distichum</i> , baldcypress		<i>Pinus elliottii</i> , slash pine <i>Pinus palustris</i> , longleaf pine	<i>Araucaria heterophylla</i> , Norfolk Island pine <i>x Cupressocyparis leylandii</i> , Leyland cypress <i>Juniperus silicicola</i> , southern red cedar <i>Pinus clausa</i> , sand pine
Palms			

Highest Wind Resistance	Medium-High Resistance	Medium-Low Resistance	Lowest Wind Resistance
<i>Butia capitata</i> , pindo or jelly <i>Dypsis lutescens</i> , areca <i>Coccothrinax argentata</i> , Florida silver <i>Hyophorbe lagenicaulis</i> , bottle <i>Hyophorbe verschaffeltii</i> , spindle <i>Latania loddigesii</i> , blue latan <i>Livistona chinensis</i> , Chinese fan ^b <i>Phoenix canariensis</i> , Canary Island date <i>Phoenix dactylifera</i> , date <i>Phoenix reclinata</i> , Senegal date ^b <i>Phoenix roebelenii</i> , pygmy date <i>Ptychoesperma elegans</i> , Alexander <i>Sabal palmetto</i> , cabbage, sabal <i>Thrinax morrisii</i> , key thatch <i>Thrinax radiata</i> , Florida thatch <i>Veitchia merrillii</i> , Manila	<i>Caryota mitis</i> , fishtail <i>Cocos nucifera</i> , coconut <i>Dypsis decaryi</i> , triangle <i>Roystonea elata</i> , royal		<i>Syagnus romanzoffiana</i> , queen ^c <i>Washingtonia robusta</i> , Washington fan
Fruit Trees			
	<i>Litchi chinensis</i> , lychee	<i>Averrhoa carambola</i> , star-fruit, carambola <i>Citrus</i> spp, oranges, limes, grapefruits <i>Mangifera indica</i> , mango	<i>Persea americana</i> , avocado
^a Prohibited in Florida ^b Invasive, not recommended in Florida ^c Caution: manage to prevent escape in Florida (IFAS Assessment, 2023) We present these lists with the caveat that no tree is perfectly wind-proof and that many other factors contribute to wind resistance including soil conditions, wind intensity, previous cultural practices, tree health, and age. 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.			

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