Improving Community Hurricane Resilience through a Comprehensive Assessment of Tree Species Wind Resistance

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Executive Summary

Hurricane damage to trees in cities and towns exacerbates hurricane damage in a community and decreases an urban forest's ability to provide beneficial ecosystem services. Knowledge about the capability of different tree species to resist hurricane wind damage informs management activities that can reduce the likelihood of severe hurricane damage to urban forests. In this project, we created a repeatable and broadly applicable updated version of a tree wind resistance rating system developed by Duryea et al. (2007a, b). To create this extended rating system, we conducted a literature review and extracted hurricane tree damage data from 58 studies in 4 languages. We also collected additional data about the focal tree species and study sites from several other sources. We used the species from the original Duryea et al. rating system to train a random forest machine learning model to predict the wind resistance of previously unrated species.

Our evaluation with performance metrics such as accuracy and adjusted Cohen's Kappa indicated that our model can reasonably predict wind resistance ratings for tree species. Of the 11 input variables to the model, wood density, maximum potential tree height, and leaf mass per area were the 3 most important predictors. We used our trained model to assign wind resistance ratings to 281 previously unrated species from hurricane-prone regions in North America, Central America, Australia, Asia, and Oceania. We used these species and the original list from Duryea et al. to create an interactive spreadsheet, the Estimating Tree Community Hurricane Resistance tool (ETCHR, v.01). A community with a tree inventory can use the ETCHR tool to estimate the proportion of their tree population that is composed of Lowest, Medium Low, Medium High, and Highest wind resistant species. Communities can use output from ETCHR to set target goals for the proportion of wind-resistant species in their urban forest. They can also use it to recommend new species for planting and prioritize risk assessment and pruning for species at greater risk of hurricane damage. This expanded wind resistance rating list will enable communities to better prepare and cultivate a resilient urban forest in the face of future hurricanes and climate change.

Project Report

Overview and Purpose

Hurricanes can cause substantial damage to urban forests (e.g., Staudhammer et al. 2009; Duryea et al. 2007a, b). This damage increases recovery costs as communities pay for debris removal as well as damaged property and infrastructure. The loss of urban trees also leads to a loss in the benefits they can provide, such as shading or stormwater mitigation (i.e., ecosystem services). Tree species vary in their ability to resist wind damage; however, a publicly accessible, science-based urban tree wind rating scoring system is only available for a limited number of common trees and palms found in Florida (Duryea et al. 2007a, b). We extended the original wind resistance rating system developed by Duryea et al. (2007a, b) to encompass a broader range of species found in urban forests in the United States and in other regions impacted by hurricanes and tropical cyclones. This extension of the rating system used commonly available tree characteristics and data from other studies of hurricane damage to trees to predict wind resistance ratings for new species.

Importantly, the methodology for this updated rating system is repeatable so that additional trees can be incorporated into the collection of rated species in the future.

A comprehensive tree species wind resistance classification system can contribute to the mitigation of hurricane damage to urban forests and support more informed recovery (replanting) efforts. Its information can be used by communities to select tree species for new planting projects that have greater wind resistance, especially for plantings in high-risk areas such as along streets. Communities can incorporate wind resistance ratings into their recommended urban tree species lists to provide property owners with additional criteria to consider when selecting trees for private property. Communities can also use the interactive spreadsheet containing newly rated species and their tree inventory data to identify species already growing in the urban forest that have low wind resistance. Such trees can be proactively monitored and appropriately pruned to reduce their risk of failure.

Background

One factor that contributes to the costs of hurricanes is the damage to and the damage caused by urban trees. An active hurricane season in Florida (2004–2005) produced an average of 448 cubic yards of urban tree debris per mile of street with an average of $28 per cubic yard (2005 USD) in removal costs (Staudhammer et al. 2009). Tree failure can also contribute to power outages during hurricanes (Yum et al. 2020) and increase tree-related injuries during the recovery period (Marshall et al. 2018). Despite these damage-related costs, urban forests—the collection of trees growing within cities and towns—also provide important benefits to communities such as contributing to improved health (Jennings and Gaither, 2015; Kuo, 2015), decreasing the energy usage of buildings (Ko, 2018), and creating a sense of identity and place (Blicharska and Mikusiński, 2014). Understanding the factors that influence the ability of trees to resist extreme wind damage is necessary to help emergency management professionals, urban forest managers, landscape architects, and planners mitigate potential tree-related hazards prior to hurricanes and tropical storms.

Many characteristics of trees, their surrounding environment, and their history of care influence their ability to resist damage from severe winds. In their literature review of tree wind resistance, Everham and Brokaw (1996) identified a wide variety of factors that can influence wind damage to trees in rural forests, including tree size; proximity to other trees; species traits such as wood density; topography; storm characteristics; and soil type. Duryea et al. (2007a, b) conducted a multi-year study of hurricane damage to urban trees across Florida and Puerto Rico. They observed distinct differences in the frequency of damage among different species and increased resistance to damage when trees were planted in groups rather than as individuals or in rows. Both Everham and Brokaw (1996) and Duryea et al. (2007a, b) produced wind resistance rating systems for species which had been observed in hurricane damage studies. However, both ratings systems are limited in the scope of species that were rated. For example, of the 107 tree and palm species identified as preferred species for replanting the City of Tampa, Florida's, urban forest, 44 of these species lack a wind resistance rating. Additionally, the efforts by Everham and Brokaw (1996) and Duryea et al.

(2007a, b) lack a method for estimating the wind resistance of tree species which are not included in their datasets. A comprehensive wind resistance rating system rooted in post-storm tree failure data could be used to identify species in communities that could pose high risk during a hurricane (e.g., D'Amico et al. 2019). Once developed, this system would allow urban tree managers to select species for new tree plantings that have greater resistance to wind damage. These actions would be important contributions to emergency management mitigation efforts in coastal communities.

In hurricane-prone regions such as Florida, populations and the extent of urbanization are predicted to substantially increase in the coming decades (Carr and Zwick, 2016), exposing more people and property to hurricane risks. Additionally, climate change models also predict with medium-to-high confidence that global tropical cyclones' intensity will increase with 2^{o}C warming in the coming decades (Knutson et al., 2019). These projected increases in the severity of hurricane hazards and exposed populations further emphasize the need for pro-active planning to improve the ability of urban forests to resist damage from hurricanes and contribute to the resilience of communities.

Methods

OVERVIEW

To expand on the original Duryea et al. (2007a, b) rating system, we first conducted a multi-lingual literature review of studies about hurricane damage at the species level. We extracted data from these studies and then found additional characteristic data for each species using several other sources. We used data from the original rated species to train and then test a random forest model designed to predict the wind resistance rating of a species. We then applied the data for new species to the model and obtained their predicted ratings. Our results were consolidated into a spreadsheet that can assess the wind resistance of an urban forest tree inventory.

HURRICANE TREE DAMAGE DATA SOURCES

To find studies which reported hurricane damage to trees at the species level, we searched several search engines, databases, and forestry-related journals published between 1900 and 2002. These sources included Google Scholar, China National Knowledge Infrastructure database, J-STAGE, and SciELO database, among others. We conducted our search in multiple languages since hurricanes and tropical cyclones are a global phenomenon and scientific research is published in languages beyond English. In each source, we searched for "forest AND (hurricane OR cyclone OR typhoon)" in English, Chinese (Mandarin), French, Japanese, Portuguese, and Spanish (Table 1).

Table 1: Search keywords in target languages.

Language	Forest Synonyms	Tropical Cyclone Synonyms
English	Forest	Hurricane, Cyclone, Typhoon

Language	Forest Synonyms	Tropical Cyclone Synonyms
Chinese	城市树木, 园林绿化树木, 行道树, 树	台风
French	Forêt, Jungle, Les bois	Ouragan, Typhon, Cyclone
Japanese	森 or 森林, 林地, 緑地, 街路樹	台風
Portuguese	Floresta, Mata, Selva, Bosque	Furacão, Tufão, Ciclone
Spanish	Bosque, Selva, Rodal, Árbol	Huracán, Ciclón, Tifón, Tormenta

Papers used for our analysis had to meet the following criteria: 1) researchers collected data within 2 years of a hurricane; 2) no other natural disaster co-occurred with the hurricane; 3) data was collected on the ground, not from aerial image analysis; and 4) hurricane damage was reported as a proportion of the population of a given species.

We extracted relevant data from the papers that met the screening criteria. Multi-lingual colleagues assisted with the extraction and translation of data from papers published in languages besides English. Extracted data included study location, the name of the tropical cyclone, methodology, species names, and damage. We classified a study as urban if it occurred in a city or town and all other studies as rural. Urban studies included intensively managed habitats such as roadsides and less managed habitats such as remnant natural areas.

TREE SPECIES DATA SOURCES

We included several species characteristics in our predictive model: whether the tree was an angiosperm or gymnosperm (based on taxonomy); whether the tree had evergreen or deciduous/semi-deciduous leaves (TRY traits database, Kattge et al. 2020); the leaf mass per unit area (LMA; Kattge et al. 2020); maximum plant height at maturity (Moles et al. 2004; Kattge et al. 2020); and wood density (Zanne et al. 2009; Kattge et al. 2020; Table 2). These variables directly relate to the likelihood of hurricane tree damage, or they serve as a proxy to represent a species' successional status and likely position within the structure of a forest (Salisbury et al., 2023). For each dataset, we harmonized the species' names to the Leipzig Catalog of Vascular Plants (Freiberg et al., 2020).

Table 2: The definitions and sources of variables used in the random forest predictive model.

Model Input Variable	Definition	Data Source
Angiosperm or Gymnosperm	The tree type.	Multiple

Model Input Variable	Definition	Data Source
Biome	General habitat type at study location.	Olson et al. 2001
Damage	Proportion of species that died or were damaged during a tropical cyclone.	Original source of data
Latitude	Latitude of study site.	Original source of data
Leaf Type	Leaf phenological type: evergreen or deciduous/semi-deciduous.	Kattge et al. 2020
LMA	Leaf mass per unit area (g/m^2).	Kattge et al. 2020
Longitude	Longitude of study site.	Original source of data
Maximum Plant Height	Mean height at maturity (m).	Moles et al. 2004; Kattge et al. 2020
Previous Tropical Cyclone	Time elapsed between the study's focal storm and the previous tropical cyclone occurring within 50 km of the study site.	Knapp et al. 2010, 2018
Urban or Rural	General landscape setting of study.	Original source of data
Wood Density	Mean wood density (ratio of dry wood weight to fresh volume; g/cm^3).	Zanne et al, 2009; Kattge et al. 2020

STUDY CONTEXT DATA SOURCES

We assigned each study site a biome (a generalized habitat type) using definitions from Olson et al. (2001). Since the collected studies reported different characteristics of the hurricanes they studied, we used an independent database to determine the maximum sustained wind speed for each hurricane (Knapp et al., 2010, 2018). Wind speed served as a variable representing storm intensity, a predictor of hurricane tree damage (Francis and Gillespie, 1993), in our model. We used this same database to determine the amount of time between the study's hurricane and the previous hurricane that impacted the study area (within 50 km of the study location). Some studies have shown damage can vary among frequent storms (Bonilla-Moheno 2010).

RANDOM FOREST MODEL

Random forest classification models are a type of machine learning algorithm that generates predictions by creating an ensemble of hundreds of classification trees. The benefits of this approach are that it does not rely on assumptions about the data and the approach tends to generate predictions with high accuracy (low bias) and consistency (low variance).

We compiled the species damage, characteristics, and study site data into a single dataset for all species that had been given an original wind resistance rating in Duryea et al. (2007a, b). A random sample of 70% of these observations were used as training data for the model, while the remaining 30% served as test data. The model response variable was one of four levels of wind resistance used by Duryea et al. (2007a, b): Lowest, Medium Low, Medium High, and Highest. The model predictors were the percent of damage to a species (mortality, broken stem, broken roots, and/or broken branches), urban/rural, study site latitude, study site longitude, years since previous hurricane, biome, angiosperm/gymnosperm, leaf type, leaf mass per area, maximum plant height, and wood density. The model was set up to create 1,000 random forest trees and 8 variables at each node. We ran the model with the training data using 10-fold cross-validation with 5 repeats to decrease model variance. The model was fitted using the *caret* package (Kuhn 2022) in R.

We used the testing data to evaluate model performance by calculating its overall accuracy, sensitivity, specific, and adjusted Cohen's Kappa. Accuracy is the percentage of correct predictions for the entire dataset. Sensitivity is the percent of correct predictions within the original group of observations in a class (e.g., all species in the Lowest category). Specificity is the percentage of correct predictions within all other classes (e.g., all species in the Medium Low, Medium High, and Highest categories). Adjusted Cohen's Kappa is the probability that classifications are correct, modified to give equal weights to each response category. For each predictor, we determined its importance using a function in *caret* called "varImp," which determines the change in the Gini index (node purity) when data is split on a given variable.

WIND RESISTANCE RATINGS PREDICTIONS

We applied the trained random forest to the 281 other species identified in our literature review that were not originally rated by Duryea et al. (2007a, b). If a species had an incomplete set of wood density, mature height, and leaf mass per area data, we estimated its missing data values using imputation. We gave each species' prediction a confidence rating based on the predictive probability provided by the model: Low Confidence (predicted probability < 0.33), Moderate Confidence (0.33 – 0.66), or High Confidence (> 0.66).

INTERACTIVE SPREADSHEET TOOL

We used the original and new species wind resistance ratings to create the Estimating Tree Community Hurricane Resistance (ETCHR) Tool in Excel. We chose Excel as the platform for our tool because it is widely used, requires no programing knowledge, and can be easily shared and downloaded. We set up ETCHR so that a user can add data from a community's tree inventory and determine the relative proportion of trees that have Lowest, Medium Low, Medium High, and Highest wind resistance ratings.

Results

LITERATURE REVIEW SUMMARY

We found 58 out of 5,449 studies that met our criteria for inclusion in the project (Table 3). Several of the databases we used returned a large number of search results that were not relevant to the study, which is one of the primary reasons the proportion of kept search results was low. From these 58 papers, we extracted 1,094 observations of hurricane damage to individual tree species. Of these observations, we excluded 285 of them from further analysis since they lacked sufficient species trait data to be used in the model. The studies contain data from 15 countries and 42 hurricanes or tropical cyclones.

Table 1: The number of papers found by the literature review search and passed the screening process. Observations of damage to distinct species were extracted from acceptable papers.

Language	Search Returns	Passed Screening	Observations	Species
Japanese	3,709	3	60	53
Spanish	948	3	107	90
English	483	43	728	386
French	140	0	0	0
Chinese	97	9	199	80
Portuguese	72	0	0	0
Total	**5,449**	**58**	**1,094**	**569**

MODEL PERFORMANCE

Classification performance metrics indicated our trained random forest model had good predictive capabilities. Both accuracy and adjusted Cohen's Kappa were 0.91 (maximum potential values of 1). The sensitivity and specificity metrics indicate predictions were better for Medium High and Highest species compared to Medium Low and Lowest species (Table 4).

Table 4: Random forest model performance metrics using the testing dataset. Numbers in parentheses represent the 95% confidence interval.

Wind Resistance Rating	Accuracy	Adjusted Kappa	Sensitivity	Specificity
Overall	0.91 (0.84–0.96)	0.91 (0.9–0.91)	0	0
Lowest	0	0	0.83	0.98
Medium Low	0	0	0.9	0.93
Medium High	0	0	0.95	0.98
Highest	0	0	1	0.99

Notably, the three primary species characteristics—wood density, maximum height, and leaf mass per area (LMA)—were the most important predictors in the model (Figure 1). Percent of damage declined in species with higher wind resistance ratings as expected (Figure 2). LMA showed little variation among wind resistance categories while maximum height was greatest in the two middle ratings. Wood density tended to increase with increasing wind resistance rating, though there was considerable overlap in the distribution of wood density between the ratings. There was a clear lack of distinction in variable distribution among the ratings. This demonstrated the value of using a classification approach with multiple predictors since no single characteristic or damage data appeared to clearly distinguish the rating categories.

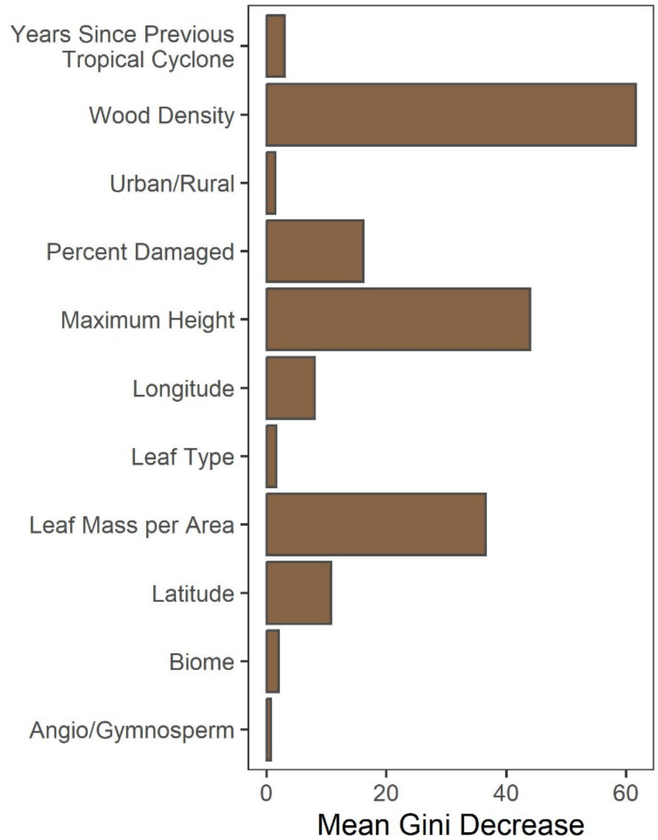

Figure 1: Random forest model predictor importance values.

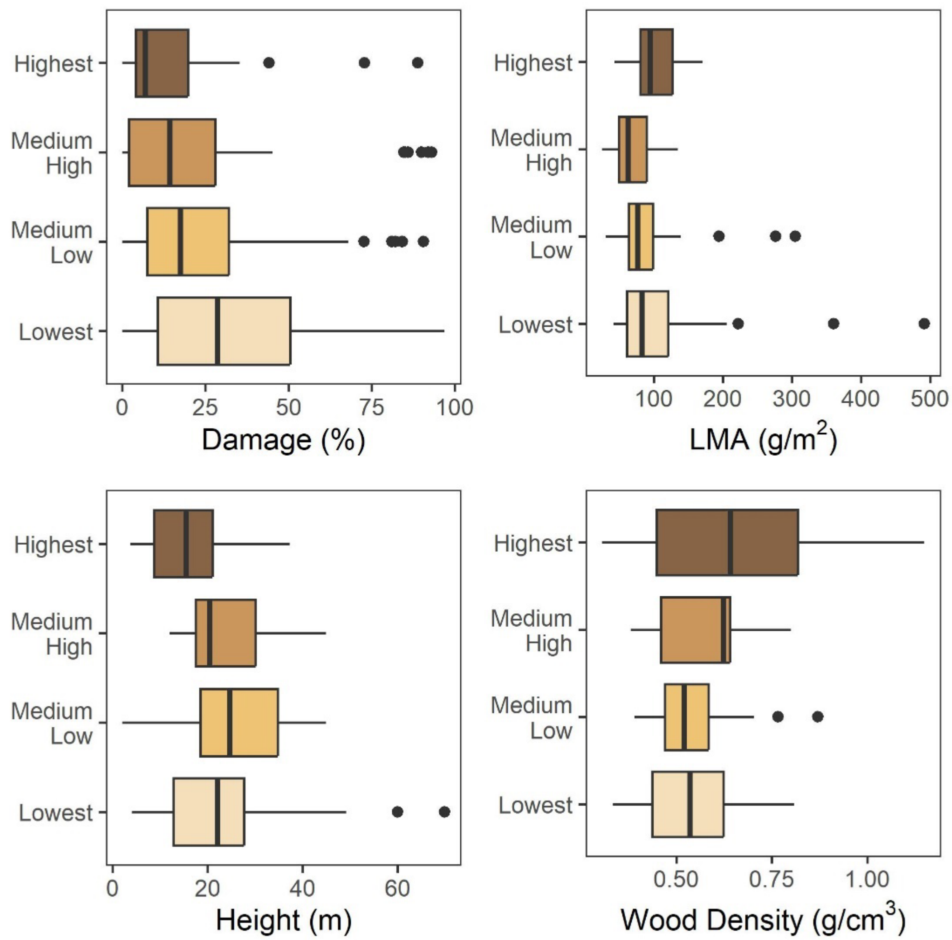

Figure 2: The distribution of damage and species characteristic variables among the four wind resistance ratings.

NEW WIND RESISTANCE RATINGS

Using the trained random forest model, we assigned wind resistance ratings to 281 new species from hurricane prone regions across the world (Appendix Table A1). These were species identified in our literature review which had sufficient damage and characteristic data. Most species were assigned a Lowest rating (42%), followed by Medium Low (30%), then Medium High and Highest (both 14%). Species rated Highest and Medium Low tended to have the predictions with the greatest confidence (Figure 3). Twenty-four percent of species that had Low Confidence in their final rating were judged as such because the model assigned different wind resistance ratings to different observations for those species.

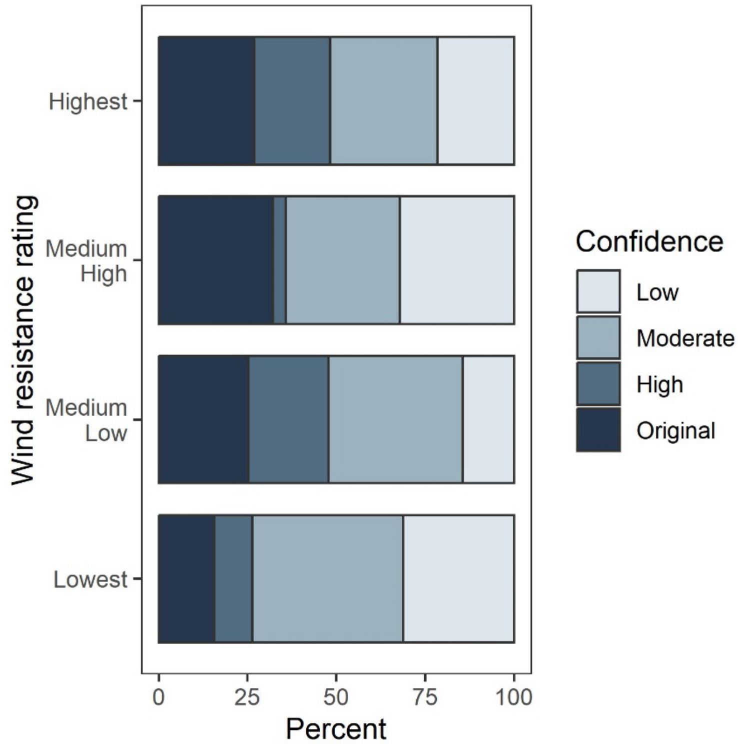

Figure 3: The distribution of prediction confidence among the four wind resistance rating categories. Original indicates that a species was given a wind resistance rating in Duryea et al. (2007a, b).

INTERACTIVE SPREADSHEET TOOL

Our ETCHR v.01 tool contains both the original species from Duryea et al. (2007a, b) and the newly rated species from our random forest model. The spreadsheet contains an Introduction tab that provides an overview of the tool, its purpose, and links to other relevant resources. The Instructions tab explains how a user can input data from a community tree inventory into the DataInput tab (Figure 4). Once an inventory is added into the tool, the Summary tab automatically generates the proportion of trees with Lowest, Medium Low, Medium High, and Highest wind resistance ratings in the inventory. The Species tab contains a list of all the rated species, along with additional information about the original data sources used to generate the ratings.

	A	B	C	D	E	F	G	H
6		*User Input*				*User Input (Optional)*		*User Input*
7								
8		**Scientific Name**	**Common Name**	**Wind Resistance Rating**	**Confidence**	**Alternate Wind Resistance Rating**	**Final Rating**	**Tree Quantity**
9		Acer rubrum	Red maple	Medium Low	Original Rating		Medium Low	600
10		Ligustrum lucidum	Glossy privet	Medium Low	High Confidence		Medium Low	425
11		Robinia pseudoacacia	Black locust	Lowest	Moderate Confidence		Lowest	120
12		Ulmus rubra	Slippery elm	Medium Low	Moderate Confidence		Medium Low	110
13		Ficus elastica	Rubber fig	Lowest	Moderate Confidence		Lowest	80
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23								

Intro | Instructions | **DataInput** | Summary | Species | AltRating

Figure 4: An example of inventory data added to the ETCHR spreadsheet.

COMMUNITY OUTREACH

We shared the preliminary findings from the project at multiple live webinars and in-person presentations. These included 1) the International Society for Arboriculture Virtual Conference held on December 13 and 14, 2022; 2) the United Kingdom Arboricultural Association Wednesday Webinar Series on February 15, 2023; and 3) the FEMA Higher Education Conference held on June 5–7, 2023.

We published a research article based on the preliminary literature review that formed the foundation for this project in *Frontiers in Forests and Global Change*, an open access journal, titled "Predictors of tropical cyclone-induced urban tree failure: an international scoping review" (Salisbury et al., 2023). We have drafted a second research article about the development of the extended wind resistance rating system and ETCHR that we plan to submit to *Arboriculture & Urban Forestry*, also an open access journal with a combined research and practitioner audience.

We have published the ETCHR spreadsheet, the R code used to create and run the random forest model, the original dataset, and a written and video guide for using ETCHR on GitHub (guide included in Appendix 9.2). GitHub allows anyone to access the ETCHR spreadsheet. And if users have the appropriate data available, they can use the R code to predict the wind resistance rating for additional species.

Recommendations

SETTING URBAN FOREST COMPOSITION GOALS

Communities with tree inventories can use output from the ETCHR tool to set target goals for the proportion of Medium High and Highest wind resistance rated tree species in an urban forest. Many communities set goals for the extent of canopy and the type of trees in their urban forest management plans (Hauer and Peterson 2016). These documents provide a roadmap for urban forestry activities and help track progress over time.

Granted, the goal should not be to have an urban forest composed entirely of Medium High and Highest wind resistance species. Maintaining the overall diversity of an urban forest increases the ecosystem services it can provide and increases the urban forest's resilience in the face of climate change and pest and disease outbreaks (Paquette et al., 2021). Communities should focus on planting new trees that have higher wind resistance ratings near infrastructure and saving lower wind resistance species for parks, natural areas, and other places where a fallen or damaged tree will cause less problems. Cultivating a wind resistance urban forest through species is a balancing act that considers the multiple risks and benefits that urban trees can provide.

RECOMMENDED SPECIES LISTS

Both public and private entities manage urban forests. Many municipalities publish recommended tree species planting lists to help guide private landowners through the species selection process (e.g., Northrop et al. 2013). These lists typically feature native and/or non-invasive species that are well adapted to the local landscape. Sometimes the lists include tree characteristics such as size, tolerance for different soil conditions, and appearance. The ETCHR tool can also be used to look up the wind resistance rating of species on local planting lists and add the ratings as a characteristic to consider when planting trees.

RISK ASSESSMENT

Arboriculture risk assessment protocols systematically evaluate the potential risks posed by a tree based on its condition and context. Researchers have demonstrated that trees designated with a high likelihood of failure indeed are more likely to fail during a hurricane (Koeser et al., 2020; Nelson et al., 2022). Urban foresters and arborists can use the wind resistance ratings of local tree species to prioritize trees for risk assessment and pruning to reduce the likelihood of severe hurricane damage to trees (Duryea et al. 2007a; Gilman et al. 2008; Klein et al. 2020).

Conclusions

Predicting the wind resistance ratings of previously unrated species is part of a suite of approaches for mitigating and planning for hurricane damage to urban forests. Our research demonstrated how using a random forest model with a suite of species and location characteristics can effectively extend the original wind resistance rating system by Duryea et al. (2007a, b). We added wind resistance ratings to more than 200 new species from across the world, though more data is needed to add ratings to other species commonly planted in U.S. coastal communities. Many factors influence the likelihood a tree will be damaged during a hurricane. The knowledge of the relative ability of a tree species to resist wind damage can be incorporated into other urban forestry activities such as inventorying, species selection, new tree plantings, risk assessments, and pruning to decrease the likelihood and severity of hurricane damage to the urban forest. While a community can never completely eliminate hurricane risk, these activities can help communities balance the many benefits provided by urban forests with the costs caused by hurricanes and other natural disasters.

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Appendices

Wind Resistance Ratings

Table A1: Wind Resistance Ratings for new and original tree species and the confidence in model predictions.

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Acacia auriculiformis	Black wattle	Lowest	Moderate Confidence
Acacia crassicarpa	Northern wattle	Medium High	Moderate Confidence
Acacia mangium	Silver wattle	Medium Low	Moderate Confidence
Acer negundo	Boxelder	Medium Low	Original Rating
Acer palmatum	Japanese maple	Medium High	Original Rating
Acer pictum	Yellow-paint maple	Medium High	Moderate Confidence
Acer rubrum	Red maple	Medium Low	Original Rating
Acer saccharinum	Sugar maple	Medium Low	Original Rating
Acronychia acidula	Lemon aspen	Medium Low	Low Confidence
Adina cordifolia	Yellow Teak	Lowest	Low Confidence
Aegle marmelos	Bael tree/wood apple	Medium Low	High Confidence
Aglaia pinnata	Leban	Lowest	High Confidence
Albizia julibrissin	Mimosa/persian silk tree	Lowest	High Confidence
Albizia odoratissima	Black Siris	Medium High	Moderate Confidence
Albizia procera	Forest siris	Lowest	High Confidence
Alchornea latifolia	Achiotillo	Lowest	Low Confidence
Aleurites moluccanus	Candle Nut	Lowest	High Confidence
Alstonia rostrata		Highest	High Confidence
Alstonia scholaris	White Cheese wood/devil’s tree	Highest	Low Confidence
Amyris elemifera	Sea torchwood	Highest	High Confidence

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Anacardium occidentale	Cashew tree	Medium Low	Low Confidence
Andira inermis	Cabbage tree	Lowest	Moderate Confidence
Apeiba membranacea	Burillo	Lowest	Low Confidence
Aphananthe aspera	Muku tree	Medium High	Low Confidence
Araucaria cunninghamii	Hoop pine	Lowest	High Confidence
Araucaria heterophylla	Norfolk Island pine	Lowest	Original Rating
Artocarpus altilis	Breadfruit	Medium High	Moderate Confidence
Astronium graveolens	Glassywood	Highest	Moderate Confidence
Azadirachta indica	Neem/Indian lilac	Medium Low	Moderate Confidence
Barringtonia asiatica	Fish poison tree	Lowest	Moderate Confidence
Bauhinia blakeana_x	Hong Kong Orchid Tree	Medium Low	Original Rating
Betula platyphylla	White birch	Medium Low	Moderate Confidence
Bischofia javanica	Bishop wood	Medium High	Low Confidence
Blastus cochinchinensis		Medium High	Moderate Confidence
Bombax ceiba	Cotton tree	Highest	High Confidence
Bridelia retusa	Spinous kino tree	Lowest	Low Confidence
Brosimum alicastrum	Breadnut tree	Medium Low	Low Confidence
Brosimum guianense	Snakewood	Lowest	Moderate Confidence
Brosimum lactescens		Lowest	Low Confidence
Brosimum utile	Cow tree	Medium Low	Moderate Confidence
Bursera simaruba	Gumbo limbo	Highest	Original Rating
Byrsonima crispa		Lowest	Low Confidence
Byrsonima spicata	Locust berry	Lowest	Low Confidence
Callistemon citrinus		Medium Low	Original Rating

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Callistemon viminalis	Crimson bottlebrush	Medium Low	Original Rating
Calophyllum antillanum	Antilles beauty leaf	Medium High	Original Rating
Calophyllum brasiliense	Brazil Beauty-Leaf	Lowest	Moderate Confidence
Calophyllum calaba	Santa-maria	Medium High	Low Confidence
Calophyllum inophyllum	Beauty Leaf	Medium Low	High Confidence
Calophyllum neoebudicum		Medium Low	Low Confidence
Camellia oleifera	Tea oil camellia	Medium High	Moderate Confidence
Cananga odorata	Climbing ylang-ylang tree	Lowest	Moderate Confidence
Carapa guianensis	Crabwood	Medium Low	Moderate Confidence
Carpinus caroliniana	Ironwood	Medium High	Original Rating
Carya alba	Mockernut hickory	Medium High	Original Rating
Carya aquatica	Bitter pecan	Medium High	Low Confidence
Carya floridana	Scrub hickory	Highest	Original Rating
Carya glabra	Pignut hickory	Medium High	Original Rating
Carya illinoinensis	Pecan	Lowest	Original Rating
Carya texana	Black Hickory	Medium Low	High Confidence
Casearia arborea	Gia verde	Lowest	Low Confidence
Casearia commersoniana		Lowest	Moderate Confidence
Casearia nitida	Smooth Casearia	Medium High	Low Confidence
Casearia sylvestris	Wild sage	Medium Low	Moderate Confidence
Casearia thamnia		Medium High	Low Confidence
Cassia fistula	Golden Shower tree	Lowest	Original Rating
Castanopsis fissa		Medium High	Moderate Confidence

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Castanospermum austral	Moreton Bay Chestnut	Medium High	Moderate Confidence
Casuarina equisetifolia	Coastal she-oak	Lowest	Original Rating
Catalpa bignonioides	Common catalpa	Lowest	Moderate Confidence
Cecropia peltate	Trumpet tree	Medium Low	Moderate Confidence
Cedrus deodara	Himalayan cedar	Medium Low	Moderate Confidence
Ceiba aesculifolia	Pochote	Medium High	Low Confidence
Ceiba pentandra	Silk cotton tree	Highest	High Confidence
Ceiba speciosa	Palo borracho	Lowest	Original Rating
Celtis laevigata	Sugarberry	Medium Low	Original Rating
Celtis occidentalis	Hackberry	Medium Low	Original Rating
Celtis sinensis	Chinese Hackberry	Medium High	Low Confidence
Cenostigma gaumeri		Highest	Low Confidence
Cespedesia spathulata		Lowest	Moderate Confidence
Chimarrhis parviflora		Medium Low	Moderate Confidence
Chukrasia tabularis	Chickrassy	Medium Low	High Confidence
Cinnamomum bejolghota	Assamese	Medium Low	Moderate Confidence
Cinnamomum burmanni	Java Cinnamon	Medium Low	High Confidence
Cinnamomum camphora	Camphor tree	Medium Low	Original Rating
Citrus japonica	Kumquat	Medium Low	Moderate Confidence
Cleyera japonica	Japanese cleyera	Medium Low	High Confidence
Coccoloba diversifolia	Pigeon Plum	Medium High	Original Rating
Coccoloba tuerckheimii		Medium Low	Low Confidence
Coccoloba uvifera	Seagrape	Medium Low	Moderate Confidence

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Cochlospermum vitifolium	Brazilian Rose	Medium Low	Low Confidence
Colubrina arborescens	Wild coffee	Medium Low	High Confidence
Cordia bicolor	Muneco	Lowest	Low Confidence
Cordia gerascanthus	Spanish elm	Lowest	Low Confidence
Cordia sulcate	White manjack	Lowest	Low Confidence
Cornus florida	Flowering dogwood	Highest	Original Rating
Crescentia cujete	Calabash tree	Lowest	Moderate Confidence
Croton poecilanthus		Lowest	Low Confidence
Cryptocarya chinensis	Chinese cryptocarya	Medium Low	Moderate Confidence
Cupressus sempervirens	Italian cypress	Lowest	High Confidence
Dacryodes excelsa	Candlewood	Medium Low	High Confidence
Damburneya coriacea	Lancewood	Medium Low	High Confidence
Delonix regia	Royal poinciana	Medium Low	Original Rating
Dendropanax arboreus	Angelica Tree	Highest	Low Confidence
Dimocarpus longan	Longan/Dragon’s eye	Lowest	High Confidence
Diospyros ferrea	Black ebony	Highest	Low Confidence
Diospyros virginiana	Common persimmon	Medium High	Original Rating
Dipteryx oleifera	Eboe/almendro	Lowest	Moderate Confidence
Distylium racemosum	Isu tree	Medium Low	Moderate Confidence
Dodonaea viscosa	Broadleaf hopbush	Highest	Moderate Confidence
Drypetes lateriflora	Guiana plum	Medium Low	Moderate Confidence
Dussia macroprophyllata	Frijolon/sangrillo	Lowest	Low Confidence
Elaeocarpus angustifolius	Blue Marble Tree	Highest	High Confidence

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Enterolobium cyclocarpum	Elephant-ear tree	Medium Low	Original Rating
Erythrina variegate	Variegated Coral tree	Lowest	High Confidence
Erythroxylum rotundifolium	Rat wood/swamp redwood	Medium Low	Low Confidence
Eucalyptus robusta	Swamp-mahogany	Lowest	Moderate Confidence
Eucalyptus tereticornis	Forest red gum	Medium Low	Moderate Confidence
Eucalyptus urophylla	Timor white gum	Medium Low	Low Confidence
Eugenia foetida	Spanish stopper/ Boxleaf stopper	Highest	Original Rating
Eugenia reinwardtiana	Cedar Bay cherry	Highest	Low Confidence
Eurya japonica	East Asian eurya	Lowest	Moderate Confidence
Exostema caribaeum	Caribbean Princewood	Highest	Low Confidence
Fagus crenata	Japanese beech	Lowest	Moderate Confidence
Fagus grandifolia	American beech	Medium Low	High Confidence
Ficus aurea	Florida strangler fig	Medium Low	Original Rating
Ficus benghalensis	Indian Banyan	Medium Low	High Confidence
Ficus benjamina	Weeping fig	Lowest	Original Rating
Ficus concinna	Elegant fig	Lowest	High Confidence
Ficus elastica	Indian Rubber Tree	Lowest	Moderate Confidence
Ficus macrophylla	Moreton Bay Fig	Highest	Moderate Confidence
Ficus microcarpa	Malayan Banyan	Lowest	Low Confidence
Ficus racemosa	Cluster fig	Highest	High Confidence
Ficus religiosa	Bodhi Tree	Lowest	Low Confidence
Ficus virens	White fig	Lowest	High Confidence
Firmiana simplex	Chinese Parasol Tree	Lowest	Moderate Confidence
Flacourtia rukam	Indian Prune	Medium Low	Moderate Confidence

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Fraxinus caroliniana	Carolina ash	Lowest	Moderate Confidence
Fraxinus griffithii	Formosan ash	Highest	High Confidence
Fraxinus mandshurica	Manchurian ash	Medium Low	Moderate Confidence
Fraxinus pennsylvanica	Green ash	Medium Low	Original Rating
Fraxinus profunda	Pumpkin ash/Red ash	Medium Low	High Confidence
Garcinia madruno	Lemon Drop Mangosteen	Medium Low	Moderate Confidence
Geniostoma rupestre	Boiboida	Highest	Low Confidence
Ginkgo biloba	Maidenhair tree	Medium Low	Low Confidence
Gironniera subaequalis	Abmingere	Medium Low	Moderate Confidence
Gliricidia sepium	Mother of cocoa	Lowest	Moderate Confidence
Grevillea robusta	Silky oak	Lowest	Original Rating
Guaiacum officinale	Roughbark lignumvitae	Highest	Low Confidence
Guaiacum sanctum	Lignum vitae	Highest	Original Rating
Guarea bullata		Lowest	Low Confidence
Guarea glabra	Alligatorwood	Medium Low	Moderate Confidence
Guarea grandifolia	Cocora	Lowest	Moderate Confidence
Guarea guidonia	Muskwood	Medium Low	Moderate Confidence
Guarea kunthiana		Lowest	Moderate Confidence
Guarea pterorhachis		Lowest	High Confidence
Guazuma ulmifolia	West Indian elm	Highest	Moderate Confidence
Gymnanthes lucida	Crabwood	Highest	High Confidence
Gyrocarpus jatrophifolius		Lowest	Low Confidence
Handroanthus chrysanthus	Roble amarillo/Yellow trumpet tree	Lowest	Moderate Confidence

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Handroanthus impetiginosus	Pink trumpet tree	Lowest	Moderate Confidence
Heliocarpus donnellsmithii		Highest	Moderate Confidence
Heptapleurum actinophyllum	Australian Umbrella Tree	Lowest	Moderate Confidence
Heptapleurum heptaphyllum		Lowest	Moderate Confidence
Hernandia didymantha		Lowest	Low Confidence
Hirtella triandra	Pigeon berry	Medium High	Moderate Confidence
Holoptelea integrifolia	Indian elm	Lowest	Low Confidence
Homalium racemosum		Lowest	Low Confidence
Hymenaea courbaril	West Indian Locust tree	Lowest	High Confidence
Ilex opaca	American holly	Highest	Original Rating
Ilex verticillata	Common winterberry	Lowest	Moderate Confidence
Ilex vomitoria	Yaupon holly	Highest	Original Rating
Inga coruscans		Medium High	Moderate Confidence
Inga laurina	Guama	Lowest	Moderate Confidence
Inga pezizifera		Lowest	Moderate Confidence
Inga thibaudiana	Guabito	Lowest	Moderate Confidence
Ipomoea wolcottiana		Lowest	Low Confidence
Jacaranda mimosifolia	Jacaranda	Lowest	Original Rating
Juniperus chinensis	Chinese Juniper	Medium Low	Moderate Confidence
Juniperus virginiana	Eastern Red cedar	Lowest	Original Rating
Jupunba macradenia		Highest	Moderate Confidence
Khaya senegalensis	African mahogany	Lowest	Moderate Confidence
Krugiodendron ferreum	Black ironwood	Highest	Original Rating

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Lacistema aggregatum	Tu'l-chow	Lowest	Moderate Confidence
Laetia procera		Lowest	Moderate Confidence
Lagerstroemia indica	Crape myrtle	Highest	Original Rating
Lagerstroemia speciosa	Queen's crape myrtle	Medium Low	High Confidence
Lannea coromandelica	Indian ash tree	Medium High	Moderate Confidence
Larix kaempferi	Japanese larch	Highest	Moderate Confidence
Lepisanthes tetraphylla		Lowest	Low Confidence
Leucaena leucocephala	White leadtree	Medium Low	Moderate Confidence
Licania hypoleuca		Lowest	Moderate Confidence
Ligustrum lucidum	Chinese privet/Glossy privet	Medium Low	High Confidence
Lindackeria laurina	Carbonero	Lowest	Moderate Confidence
Lindera kwangtungensis		Medium Low	Moderate Confidence
Liquidambar formosana	Formosa sweet gum	Lowest	Moderate Confidence
Liquidambar styraciflua	Sweet gum	Medium High	Original Rating
Liriodendron tulipifera	Yellow poplar	Lowest	Original Rating
Lithocarpus glaber	Japanese oak	Medium Low	Moderate Confidence
Lithocarpus longipedicellatus		Medium High	High Confidence
Luehea alternifolia		Lowest	Low Confidence
Luehea candida		Highest	Low Confidence
Lysiloma latisiliqua	False Tamarind	Medium High	Original Rating
Machilus thunbergii	Japanese bay tree	Medium Low	Moderate Confidence

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Maclura tinctoria	Cubanwood	Highest	Moderate Confidence
Magnolia champaca	Champak	Medium Low	Moderate Confidence
Magnolia grandiflora	Southern magnolia	Highest	Original Rating
Magnolia obovate	Japanese bigleaf magnolia	Lowest	Moderate Confidence
Magnolia virginiana	Sweetbay	Medium High	Original Rating
Mangifera indica	Mango	Medium Low	Original Rating
Manilkara bidentata	Balata	Lowest	Low Confidence
Manilkara hexandra	Ceylon Iron Wood	Highest	High Confidence
Manilkara zapota	Sapodilla	Lowest	Low Confidence
Maranthes panamensis		Lowest	Low Confidence
Matayba domingensis	Negra Lora	Medium Low	Low Confidence
Melaleuca quinquenervia	Broad-leaved paperbark	Lowest	Original Rating
Melia azedarach	Chinaberry tree	Medium Low	Low Confidence
Melicoccus bijugatus	Quenepa	Highest	Moderate Confidence
Meliosma angustifolia		Medium Low	High Confidence
Metasequoia glyptostroboides	Dawn Redwood	Highest	Moderate Confidence
Miconia elata		Medium Low	Moderate Confidence
Miconia tetrandra		Lowest	Low Confidence
Micromelum minutum	Limeberry	Lowest	Low Confidence
Mitragyna parvifolia	Kaim	Lowest	Low Confidence
Morella cerifera	Southern bayberry/ southern wax myrtle	Medium Low	Original Rating
Morinda citrifolia	Indian mulberry	Lowest	Low Confidence
Morisonia flexuosa	Limber Caper	Medium Low	Moderate Confidence
Morus rubra	Red Mulberry	Medium Low	Original Rating

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Myrcia deflexa		Medium Low	Low Confidence
Myrcia schiedeana		Medium High	Low Confidence
Myristica globosa	Queensland Nutmeg	Medium Low	Low Confidence
Myrsine seguinii	Myrsine	Highest	Moderate Confidence
Nageia nagi	Broadleaf podocarpus	Medium High	Moderate Confidence
Neea psychotrioides	Saltwood	Lowest	Moderate Confidence
Nyssa aquatica	Swamp tupelo	Medium High	Original Rating
Nyssa sylvatica	Black tupelo	Medium High	Original Rating
Ocotea leucoxylon	Black-cedar	Lowest	Low Confidence
Olea europaea	Common olive	Medium Low	Moderate Confidence
Ormosia krugii	Peronia	Medium Low	Low Confidence
Osmanthus fragrans	Fragrant Olive	Highest	High Confidence
Ostrya virginiana	Hornbeam	Medium High	Original Rating
Otoba novogranatensis	Bogamani	Lowest	Low Confidence
Oxydendrum arboreum	Sourwood	Lowest	Moderate Confidence
Pachira aquatica	Guiana chestnut	Lowest	Moderate Confidence
Paraserianthes falcataria	Peacock's plume	Highest	Moderate Confidence
Peltophorum pterocarpum	Yellow poinciana	Lowest	Original Rating
Persea americana	Avocado	Lowest	Original Rating
Persea borbonia	Red bay	Medium Low	Original Rating
Photinia glabra	Japanese photinia	Highest	High Confidence
Picea abies	Norway spruce	Lowest	High Confidence
Pictetia aculeata	Tachuelo	Medium High	Low Confidence
Pinus caribaea	Caribbean pine	Medium Low	High Confidence

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Pinus clausa	Sand pine	Lowest	Original Rating
Pinus echinata	Shortleaf pine	Medium Low	High Confidence
Pinus elliottii	Slash pine	Medium Low	Original Rating
Pinus glabra	Cedar pine	Lowest	Original Rating
Pinus palustris	Longleaf Pine	Medium Low	Original Rating
Pinus serotina	Pond pine	Medium Low	Moderate Confidence
Pinus taeda	Loblolly pine	Medium Low	Original Rating
Pinus thunbergii	Japanese black pine	Medium Low	High Confidence
Pipturus argenteus	Australian Mulberry	Lowest	Low Confidence
Piscidia piscipula	Florida fishpoison tree	Medium Low	Moderate Confidence
Pistacia chinensis	Pistachio	Medium High	Moderate Confidence
Planera aquatica	Water elm	Lowest	Moderate Confidence
Platanus hispanica_x	London planetree	Medium Low	High Confidence
Platanus occidentalis	Sycamore	Medium Low	Original Rating
Platycladus orientalis	Oriental arborvitae	Medium Low	High Confidence
Plectrocarpa arborea		Medium High	Low Confidence
Pleiogynium timoriense	Sweet plum	Medium High	Low Confidence
Plumeria rubra	Frangipani	Medium Low	Moderate Confidence
Pometia pinnata	Island Lychee	Medium High	Low Confidence
Populus canadensis_x	Canadian poplar	Lowest	Moderate Confidence
Populus deltoides	Eastern cottonwood	Lowest	Moderate Confidence
Populus heterophylla	Swamp cottonwood	Medium Low	Moderate Confidence
Pourouma bicolor		Lowest	Moderate Confidence
Pouteria campechiana	Yellow sapote	Medium Low	Moderate Confidence
Pouteria reticulata		Medium High	Moderate Confidence
Protium pittieri	Alcanfor	Lowest	Low Confidence

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Protium stevensonii		Lowest	Moderate Confidence
Prunus caroliniana	Cherry laurel	Lowest	Original Rating
Prunus jamasakura	Yamazakura	Lowest	Low Confidence
Prunus serotina	Black cherry	Medium Low	Original Rating
Pseudolmedia spuria	Bastard-cherry	Lowest	Low Confidence
Psidium guajava	Common guava	Medium Low	Moderate Confidence
Psychotria asiatica		Lowest	Moderate Confidence
Pterocarpus indicus	Burmese rosewood	Lowest	Moderate Confidence
Pterocarpus officinalis	Dragonsblood tree	Lowest	Moderate Confidence
Pyrus calleryana	Callery pear	Lowest	Original Rating
Quassia amara	Bitter-wood	Lowest	Moderate Confidence
Quercus acutissima	Sawtooth oak	Lowest	Moderate Confidence
Quercus alba	White oak	Medium Low	Original Rating
Quercus aliena	Oriental white oak	Lowest	Moderate Confidence
Quercus falcata	Southern red oak	Lowest	Original Rating
Quercus geminate	Sand live oak	Highest	Original Rating
Quercus gilva	Red bark oak	Lowest	Moderate Confidence
Quercus glauca	Ring-cupped oak	Lowest	Low Confidence
Quercus hemisphaerica	Darlington oak	Medium High	Low Confidence
Quercus incana	Bluejack oak	Highest	Moderate Confidence
Quercus laevis	Turkey oak	Highest	Original Rating
Quercus laurifolia	Laurel oak	Medium Low	Original Rating
Quercus lyrata	Overcup oak	Medium Low	High Confidence
Quercus margarettae	Sand post oak	Highest	High Confidence
Quercus michauxii	Swamp chestnut oak	Medium High	Original Rating
Quercus myrsinifolia	Bamboo-leaf oak	Medium High	Moderate Confidence

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Quercus nigra	Water oak	Lowest	Original Rating
Quercus rubra	Northern red oak	Medium Low	High Confidence
Quercus serrata	Jolcham oak	Lowest	Moderate Confidence
Quercus stellata	Post oak/Iron oak	Medium High	Original Rating
Quercus velutina	Black oak	Medium Low	High Confidence
Quercus virginiana	Live oak	Highest	Original Rating
Robinia pseudoacacia	Black oak	Lowest	Moderate Confidence
Rockinghamia angustifolia	Kamala	Medium Low	Low Confidence
Salix babylonica	Weeping willow	Lowest	Moderate Confidence
Salix nigra	Black willow	Medium Low	Moderate Confidence
Sapindus mukorossi	Chinese soapberry	Lowest	Moderate Confidence
Sapium laurocerasus	Milktree	Lowest	Low Confidence
Sarcosperma laurinum		Medium Low	Moderate Confidence
Sassafras albidum	Sassafras	Medium High	High Confidence
Schefflera morototoni	Mountain trumpet	Lowest	Low Confidence
Schleichera oleosa	Kusum tree	Lowest	Low Confidence
Senna atomaria	Flor de San Jose	Highest	Low Confidence
Senna siamea	Kassod tree	Medium High	Moderate Confidence
Sideroxylon foetidissimum	False Mastic	Medium High	Original Rating
Simarouba amara	Bitter ash	Highest	Moderate Confidence
Simarouba glauca	Paradise-tree	Medium High	Original Rating
Sloanea berteroana	Montillo	Lowest	Low Confidence
Spathodea campanulata	African tulip tree	Lowest	Original Rating
Stereospermum colais	Trumpet flower	Lowest	Moderate Confidence

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Styphnolobium japonicum	Japanese pagoda tree	Lowest	High Confidence
Swietenia macrophylla	Big leaf mahogany	Lowest	Moderate Confidence
Swietenia mahagoni	West Indian mahogany	Medium High	Original Rating
Symphonia globulifera	Boarwood	Lowest	Moderate Confidence
Symplocos lancifolia		Medium High	Low Confidence
Symplocos sumuntia		Medium Low	High Confidence
Syzygium buxifolium	Boxleaf eugenia	Medium High	Low Confidence
Syzygium cumini	Jambolan	Medium High	Moderate Confidence
Syzygium jambos	Rose apple	Medium Low	High Confidence
Tabebuia heterophylla	White cedar	Medium Low	Original Rating
Tabernaemontana arborea		Medium High	Moderate Confidence
Talipariti tiliaceum	Sea Hibiscus	Medium Low	Low Confidence
Tamarindus indicus	Tamarind tree	Lowest	Moderate Confidence
Tapirira guianensis	Wild mahogany	Lowest	Moderate Confidence
Taxodium distichum	Bald cypress	Highest	Original Rating
Tectona grandis	Teak	Lowest	Low Confidence
Terminalia Amazonia	White olive	Lowest	Low Confidence
Terminalia buceras	Black olive	Medium Low	Original Rating
Terminalia catappa	Sea almond	Medium Low	Original Rating
Terminalia tetraphylla		Medium High	Low Confidence
Thouinia paucidentata	Tiger bone	Highest	Low Confidence
Thouinia striata		Highest	Low Confidence
Toona ciliate	Cedrela	Medium Low	Moderate Confidence
Toxicodendron succedaneum	Wax tree	Highest	Moderate Confidence
Triadica sebifera	Chinese tallow	Lowest	Original Rating

Scientific Name	Common Name	Wind Resistance Rating	Confidence
Trichilia trifolia		Medium High	Low Confidence
Ulmus americana	American elm	Medium Low	Original Rating
Ulmus parvifolia	Chinese elm	Lowest	Original Rating
Ulmus rubra	Slippery elm	Medium Low	Moderate Confidence
Vaccinium arboreum	Sparkleberry	Highest	Original Rating
Vachellia farnesiana	Sweet acacia	Medium Low	Moderate Confidence
Vochysia ferruginea	Quaruba	Highest	Moderate Confidence
Vochysia guatemalensis		Highest	Moderate Confidence
Xylopia sericophylla		Lowest	Low Confidence
Xylosma intermedia	Cebuano	Lowest	Moderate Confidence
Zelkova serrata	Japanese Zelkova	Lowest	High Confidence

Interactive Spreadsheet Guide

ESTIMATING TREE COMMUNITY HURRICANE RESISTANCE TOOL V.01 – GUIDE

Updated: July 11, 2023

SUMMARY

We designed the Estimating Tree Community Hurricane Resistance (ETCHR) Tool to help communities evaluate the hurricane wind resistance rating of their tree species. One way to use the ETCHR Tool is to determine the proportion of a tree inventory that is made of Low, Medium Low, Medium High, and High wind resistant species. The Tree Inventory Instructions explain this process below. You can also use the Tool to simply search for the rating of a species. These ratings create a foundation for understanding one aspect of tree resistance to damage from hurricanes and should be used to supplement practitioner experience and knowledge of local conditions.

TREE INVENTORY INSTRUCTIONS

You'll need a tree inventory that lists the quantity of each species in a community.

1. Begin by downloading and saving a copy of the ETCHR spreadsheet.
2. Choose the name of your first inventory species from the "Scientific Name" column.

Scientific Name	Common Name	Wind Resistance Rating

Trichilia trifolia
Ulmus americana
Ulmus parvifolia
Ulmus rubra
Unknown
Vaccinium arboreum
Vachellia farnesiana
Vochysia ferruginea

3. The "Common Name", "Wind Resistance Rating", "Confidence", and "Final Rating" columns should auto-populate.

Scientific Name	Common Name	Wind Resistance Rating	Confidence	Alternate Wind Resistance Rating	Final Rating
Ulmus americana	American elm	Medium Low	Original Rating		Medium Low
Ilex opaca	American holly	Highest	Original Rating		Highest
Platanus occidentalis	American sycamore	Medium Low	Original Rating		Medium Low
Unknown	Areca palm	Unknown	Unknown		Unknown
Taxodium distichum	Bald cypress	Highest	Original Rating		Highest

4. If your local experience suggests a species should have a different Wind Resistance Rating, you can choose a different rating from the "Alternate Wind Resistance Rating" column. This should update the "Final Rating" column.

Scientific Name	Common Name	Wind Resistance Rating	Confidence	Alternate Wind Resistance Rating	Final Rating
Ulmus americana	American elm	Medium Low	Original Rating		Medium Low
Ilex opaca	American holly	Highest	Original Rating		ghest
Platanus occidentalis	American sycamore	Medium Low	Original Rating		Medium Low
Unknown	Areca palm	Unknown	Unknown		Unknown
Taxodium distichum	Bald cypress	Highest	Original Rating		Highest

Lowest
Medium Low
Medium High
Highest

5. Add the number of trees for each species in the inventory in the "Tree Quantity" column.

Common Name	Wind Resistance Rating	Confidence	Alternate Wind Resistance Rating	Final Rating	Tree Quantity
American elm	Medium Low	Original Rating		Medium Low	96,519
American holly	Highest	Original Rating		Highest	15,781
American sycamore	Medium Low	Original Rating		Medium Low	12,115
Areca palm	Unknown	Unknown		Unknown	35,508
Bald cypress	Highest	Original Rating		Highest	1,163,880

6. Repeat this process for all other species in the inventory.

7. If a species does not have a wind resistance rating, choose "Unknown" in the "Scientific Name" column. You can manually type in the species name into the Common Name column for your own reference.*

Scientific Name	Common Name	Wind Resistance Rating	Confidence	Alternate Wind Resistance Rating	Final Rating
Ulmus americana	American elm	Medium Low	Original Rating		Medium Low
Ilex opaca	American holly	Highest	Original Rating		Highest
Platanus occidentalis	American sycamore	Medium Low	Original Rating		Medium Low

Trichilia trifolia
Ulmus americana
Ulmus parvifolia
Ulmus rubra
Unknown
Vaccinium arboreum
Vachellia farnesiana
Vochysia ferruginea

8. You can assign a Wind Resistance Rating to an unrated species in the “Alternate Wind Resistance Rating” column based on your local experience or leave the rating as Unknown.

Scientific Name	Common Name	Wind Resistance Rating	Confidence	Alternate Wind Resistance Rating	Final Rating
Ulmus americana	American elm	Medium Low	Original Rating		Medium Low
Ilex opaca	American holly	Highest	Original Rating		Highest
Platanus occidentalis	American sycamore	Medium Low	Original Rating		Medium Low
Unknown	Areca palm	Unknown	Unknown		Unknown
				Lowest	
				Medium Low	
				Medium High	
				Highest	

9. After entering your inventory data, you can see the proportions of wind resistance species in your tree community on the Summary page.

Wind Resistance Rating Population Summary

Total Quantity of Trees	10,401,415

Wind Resistance Rating	Proportion of Population
Lowest	6%
Medium Low	17%
Medium High	6%
Highest	20%
Unknown	51%

*Note: the scientific name of some species has changed over time. We have tried to use the most up-to-date names wherever possible. If you can’t find a species on the list, you may want to see if its scientific name has any synonyms or alternative names that might be on the list.

BACKGROUND

Many factors influence tree survival during a hurricane. These include intrinsic characteristics of a tree species, the environment it is growing in, and its management history. In 2007, researchers at the University of Florida created a hurricane wind resistance rating system for common urban tree species in Florida. They based their system on observations of damage after hurricanes, expert opinions, and species characteristics (Duryea et al 2007a, b). We extended this original rating system to include more species by using data from other studies and a random forests machine learning model. These newly rated species plus the originals form the basis for the ETCHR Tool.

The Confidence column reflects how good we think the new wind resistance ratings are based on the model we used to predict them. Species which were rated in the original 2007 research are noted as “Original Rating” in the Confidence column. Generally, a species received a “Low” confidence rating if it was missing certain characteristic data (ImputedTrait column = Yes) or if the species was documented in multiple studies and got assigned different ratings by the model (MultRatings = Yes). This information gives you more background on the development of the ratings and emphasizes that these ratings are our best predictions based on available data and may not be applicable in all situations. You can also see what country the original data for a species came from in the Country column in the Species tab.

USING THE RESULTS

There are several ways you can use information from the ETCHR Tool to improve the overall hurricane resilience of your community's urban forest. These include:

- Setting a target proportion of Medium High and Highest wind resistance rating trees in your urban forest management plan.
- Including wind resistance ratings on recommended trees species plantings lists so community members can make more informed tree selection decisions.
- Encouraging planting new trees that have higher wind resistance ratings near infrastructure and saving lower wind resistance species for parks, natural areas, and other places where a fallen or damaged tree will cause less problems. In forests, fallen trees are an important part of the ecosystem. And an urban forest cannot only be composed of High wind resistance species; it needs the benefits Low wind resistance species can provide as well.
- Prioritizing monitoring, conducting risk assessments, and pruning Low and Medium Low rating species that are located near infrastructure. Research shows that risk assessments are an effective way to identify trees with a high likelihood of failure during hurricanes (Koeser et al. 2020; Nelson et al. 2022). And appropriate pruning can also reduce the likelihood of severe hurricane damage to trees (Duryea et al. 2007a; Gilman et al. 2008; Klein et al. 2020).

The goal of these activities is to decrease the likelihood and severity of damage, though we can never completely eliminate these risks. Such activities help communities balance the numerous benefits of the urban forest with the costs caused by hurricanes and other natural disasters.

Sources

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