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Standardizing Pre- and Post-Storm Data Collection for Urban Forestry Research

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Abstract

Background: To better understand the impacts of storms on urban forests and to develop effective management strategies, it is essential to collect accurate and consistent data on urban forests before and after a storm. However, there is often limited time for researchers to establish sampling protocols and gather data before cleanup efforts erase key visual information, such as failure modes and damage severity. Moreover, storms differ in how frequently and predictably they impact regions, potentially limiting some researchers' opportunities to gain experience with storm assessment methods. *Methods:* This paper presents a standardized protocol for collecting pre- and post-storm data on urban forests based on previous studies and the authors' experiences collecting urban tree data following severe storms. *Results:* The protocol covers a wide range of data, including tree species, size, and condition; risk factors; and damage type. The protocol also includes instructions for post-storm data collection using a variety of methods, including field surveys, remote sensing, and citizen science efforts. *Conclusions:* A standardized protocol will help researchers collect consistent data on urban forests before and after storms, while also making the findings more relevant to urban forest managers, as the data will align with what they already collect.

Keywords: data standardization; urban resilience; data management; hurricane; tornadoes; ice storms

1. Introduction

Urban forests are essential components of urban infrastructure. Like other infrastructure, the services provided by urban trees can be compromised by severe and extreme weather events such as ice or wind storms (Cadaval et al., 2024). While infrastructure elements like electrical utilities can be intentionally engineered to enhance their resilience to climate challenges (Stewart, 2015), urban foresters must work with the biomechanical limits of the trees they manage when preparing for severe and extreme weather. However, research indicates that proper species selection (Duryea et al., 2007a; Duryea et al., 2007b; Salisbury et al., 2024), pruning (Duryea et al., 2007b; Klein et al., 2020), and preventing construction damage (Johnson et al., 2019) are effective strategies for reducing storm-related losses.

Many of these findings are based on research conducted through observations of actual storm events. In this work, researchers typically assess urban forests in the aftermath of severe and extreme weather to determine if trees or tree parts failed under the storm conditions, considering a range of intrinsic and extrinsic risk factors. When available, pre-storm inventory data (collected by urban tree managers or the researchers themselves) can enhance sampling designs and help assess pre-storm conditions that may no longer be evident due to tree removal or site cleanup (Bloniarz et al., 2001; Bond, 2005).

Modern urban forestry is a data-driven management process that involves tracking, analyzing, and reporting tree assets, site characteristics, and work orders (Nitoslawski et al., 2019). Recognizing the potential scientific importance of this data and the disparate nature in which it currently exists, urban forestry researchers have worked to develop data standards for general inventories (Nowak et al., 2013) as well as those specifically related to the assessment of tree growth and longevity over time (Roman et al., 2020).

The earlier effort by Nowak et al. (2013) aimed to create a comprehensive standard for all inventory data, encompassing general tree metrics such as tree taxa, trunk diameter and tree height, methods for recording tree location and site variables, as well as tree maintenance activities and defects related to risk. The more recent effort by Roman et al. (2020), while focusing on data most relevant to tracking tree condition and survival over time, addressed many of the same data inputs. Nowak et al.'s (2013) work is reflected in the International Society of Arboriculture's B*est* M*anagement* P*ractices Tree Inventories* (Bond, 2013).

Data standards ensure consistent terminology, structure, and organization of datasets, as well as guidelines for how data should be stored and used (Gal and Rubinfeld, 2019). Standardization allows data to be easily interpreted and used by others (Gal and Rubinfeld, 2019), facilitates the aggregation of datasets into large-scale models, supports both longitudinal (Roman et al., 2020) and meta-analyses, ensures that key data omissions are avoided, and helps create greater research transparency (AgMIP, 2023). Standardization also facilitates meta-analyses that will support comparisons of urban tree databases across multiple regions.

Data standards can also serve as a roadmap for scientists exploring new research areas or for practitioners seeking guidance on data collection options for storm preparation and response. For many researchers and industry professionals, severe and extreme weather such as windstorms and ice storms are relatively infrequent events (Hauer et al., 1993; Hauer et al., 2011; Hauer and Schulz, 2023). As a result, when a storm strikes a nearby community, they may lack the experience needed to make quick decisions about data collection. For researchers, this can result in post-storm assessments being conducted after cleanup efforts have already removed critical observable failures, or in rushed data collection that leads to omissions, preventing important questions from being properly articulated and addressed.

Additionally, data collection efforts that lack randomized or stratified sampling may, at best, limit the ability to generalize findings to a larger urban tree population, and at worst, result in a biased understanding of tree storm damage. Such missteps can undermine the value of data and findings derived from extensive fieldwork.Beyond research, hastily-constructed data sets can hinder the recovery efforts of local governments and lead to issues when applying for disaster relief funds.

The authors have conducted numerous pre- and post-storm assessments, which has allowed them to refine their approaches and increase efficiency in data collection. Additionally, several of us recently conducted an international, systematic literature review based on post-storm assessments (Salisbury et al., 2023). Through this effort, we observed the wide range of data researchers have collected in an attempt to predict tree failure during tropical windstorms. This combination of experience and knowledge is presented here to outline best practices and data standards for pre- and post-storm assessment research in urban forestry. These standards can be used by urban forest managers in storm preparation and response efforts, as well as by researchers when planning fieldwork. Moreover, they can help facilitate mutually beneficial partnerships between managers and researchers—creating scenarios where insights can be gleaned by those working directly on recovery from adverse weather events while also benefiting the broader industry as a whole.

2. Methods

For this paper, we examine existing efforts to standardize data collection in urban forestry and past predictors from storm assessments to develop a master list of potential variables for assessing the impacts of storms on trees. The range of data options for pre- and post-storm data collection comes from three key sources. The first is a comprehensive literature review conducted by Salisbury et al. (2023). In this work, the authors performed a systematic review of tropical cyclone pre- and post-storm assessments to determine which intrinsic (tree-related) and extrinsic (environment-related) factors predicted tree failure. The review, conducted internationally, involved searching peer-reviewed literature in English, French, Japanese, Mandarin, Portuguese, and Spanish. It followed the PRISMA-ScR guidelines (Tricco et al., 2018) and utilized the search string "forest AND (hurricane OR cyclone OR typhoon)," along with translations and synonyms in six languages. The search covered peer-reviewed research and dissertations published between 1900 and 2022 across multiple databases, with additional studies identified through backward and forward chaining (Salisbury et al. 2023).

The second source, Nowak (2010), provides guidelines for the general assessments of species composition and ecosystem services, as well as standards for assessing tree defects and maintenance issues. The final source, Roman et al. (2020) outlines procedures for collecting core field data necessary for longitudinal monitoring of urban trees.

Data collection options are arranged into three categories: metadata, pre-storm data, and post-storm data. Within each category, we outline the minimum data set requirements necessary for meaningful analysis and data sharing. Additionally, we include optional metadata, response, and predictor variables that can be considered when developing predictive models for tree failure. Each variable is accompanied by a description, the type of data it represents (e.g., binomial, continuous, nominal, ordinal), the applicable values or units, and the source (Nowak, 2010; Roman et al., 2020; Salisbury et al., 2023) from which the data is derived.

3. Results and Discussion

3.1. Sampling Design

To avoid bias, sampling activities related to the selection of trees, plots, or both should be completed before any observations are made. If a community has an existing inventory, selecting trees or plots can be a relatively straightforward remeasurement of all trees or a random sample. If the inventoried population is manageable and resources allow, a complete reassessment of all trees is ideal. When this is not practical, sampling is appropriate. Completely random sampling may not be as effective as stratified sampling because the latter can result in more representative data (Jaenson et al. 1992). Stratification can be across neighborhoods or street sections, or proportional to land uses (e.g., residential, commercial, parks). Crews should avoid ad hoc data collection data, nor should they adjust sampling to focus only on areas most impacted by the storm. Doing so reduces bias and the potential over-reporting of storm-related failures (Edberg and Berry, 1999).

Most importantly, damaged and undamaged trees should be measured. There is a tendency to focus data collection efforts solely on failed trees (Chen 2024), but this severely limits the utility of the data. Failures may be rare or represent a large portion of the tree population, but without knowing the total number of trees (damaged and undamaged), there is no context to assess the likelihood of failure. Without understanding the likelihood of failure, it is impossible to determine which factors—such as species, specific environmental conditions (e.g., wind exposure, soil conditions, associated precipitation), or other variables—increase or decrease the potential for failure. A condition may appear to be associated with a higher likelihood of failure simply because it is more commonly observed in the sample, not because it compromises the tree's structural integrity (e.g., Koeser et al., 2023). Lastly, there is tremendous value in understanding what factors are present in trees that are strong enough to resist severe weather, as these trees may represent optimal tree selection, planting, and management practices.

3.2. Metadata

Metadata plays an essential role in science and data sharing, as it provides context about the data, such as how it was collected, processed, formatted, and organized. This information ensures that datasets are easily understandable, reproducible, and usable by other researchers, facilitating collaboration and enhancing the transparency of scientific work. Well-documented metadata helps prevent misinterpretation, enables effective data integration across studies, and improves the long-term usability of data, making it a valuable resource for future research. Metadata standards such as ISO 19115 (https://www.fgdc.gov/metadata/iso-standards) could be used to ensure documentation that meets federal requirements in the US, but we recommend several metadata elements as a minimum metadata set when working with pre-and post storm inventory data (Table 1).

Table 1. Recommended metadata to accompany publicly available datasets collected after a storm has damaged trees in the urban forest. These data may be recorded as variables within the dataset itself. Data should be reported in the methods section of a research paper documenting storm-related tree failures.

Metadata	Description	Values or Units	Source
Field crew identification	Information about the individual(s) who collected field data on the tree or plot	Examples: job titles, relevant credentials, education/experience, etc.	Roman et al. 2020
Field crew experience level	Categorized experience level of the most experienced individual on the field crew	Novice, intermediate, expert	Roman et al. 2020
Location	Information about the study site's geographic position	Latitude, longitude Street address	n/a
Date of storm	Year, month, and day of storm event	Calendar date	n/a
Type of storm	Categorized storm type based on conditions experienced	Blizzard, Ice Storm, High Wind, Severe Thunderstorm,	NWS undated

		Tornado, Extreme Wind, Tropical Storm, Hurricane/Tropical Cyclone/Typhoon	
Storm severity	Information about the storm's intensity	Maximum gust or sustained wind speed, precipitation Beaufort Scale, EF Scale	n/a
Storm Severity Source	Source of the information regarding the storm's intensity	Examples: national weather agencies, local weather stations, direct measurement, etc.	n/a
Other notes	Site soil conditions, management history, past storm events, etc.		Nowak, 2010

The first two metadata elements suggested for the minimum data set in Table 1 provide information about the inventory crews who conduct field work. First, field crew identification should include details on whether volunteers, students, or professionals gathered the data. Information such as education, training, or industry credentials (especially those related to tree risk assessment) should also be included. In addition to these descriptions, an ordinal rating of experience level (novice, intermediate, expert) allows others to gauge data quality.

Most other metadata elements suggested for the minimum data set are intended to provide details about the storm (Table 1). They include its date, type (e.g. hurricane, tornado, ice) and severity (e.g. hurricane category level, tornado EF or F level, measured wind speed, measured ice accumulation), and the source of the storm information. Weather associated with a storm, even in the same region, is often characterized differently (Landry et al., 2021) depending on the geographic focus. Furthermore, details on storm events can be difficult to obtain, and researchers may draw from a variety of sources, including local weather stations, news outlets, weather services, and national agencies—each of which may provide slightly different estimates of storm intensity. Storm data should be reported from reputable sources close to the tree population being assessed. Depending on the size of the storm, conditions may differ dramatically, even a few kilometers apart. When available, report relevant storm variables like precipitation received, average and maximum sustained wind speeds, average and maximum gust speeds, storm duration, storm surge, flooding, and average, maximum, and minimum temperatures. To provide context for researchers in other regions, average climate across the area should be reported, both annually and for the month that the storm occurred. This presents the baseline or normative conditions experienced by the tree population. In some cases it may be appropriate to include information about precipitation immediately prior to the storm event. Areas that had received high levels of precipitation which saturated the soils may experience high levels of tree blowdown even in less severe wind events (Kamimura et al., 2012).

3.3. Response Variables

The response variables collected determine the research questions that can be asked. In some cases, researchers have the opportunity to form their hypotheses first, and then gather the most appropriate data to address those questions. Other times, researchers will be working with data previously collected during routine inventories or post-storm urban or utility forestry operations (Urban Forest Strike Teams, 2024). In this latter scenario, the available data will limit the range of possible research directions. Additionally, data quality can vary. However, using existing data sources, when available, can help conserve resources and offer a snapshot of the immediate aftermath of a storm and the associated cleanup efforts.

Dead trees present a particular challenge because it is sometimes difficult or impossible to determine the cause of mortality. Large scale damage, data gaps, and delayed mortality after a storm can increase this uncertainty (Armentano et al. 1995). Depending on the timing of the post-storm assessment, crews may encounter a standing or fallen dead tree, or find only a stump or vacant planting site. While all these scenarios can be categorized as "dead," it is often impossible to attribute urban tree mortality to a specific storm with certainty, especially if there is a time gap between the pre- and post-storm assessments and the actual storm. When trees are missing, crews might consider contacting the property owner or manager to confirm whether the tree died or failed during the storm (by knocking on the door or leaving a door hanger). For example, post-storm assessment crews followed this approach to disregard missing trees that had been removed for site development prior to Hurricane Irma (Landry et al., 2021).

While a simple assessment of whether a tree survives or not is useful, data on partial branch failure can be highly valuable from a risk assessment or utility management perspective. In these cases, damage could be evaluated using a simple ordinal rating system. For example, Roman et al. (2020) include a "Crown vigor" variable, described as "a holistic assessment of overall crown health, reflecting the proportion of the crown with foliage problems and major branch loss," with five classes ranging from healthy to dead. Additionally, other existing crown assessment techniques, typically used for evaluating condition, health, or estimating ecosystem services, could be applied to document tree damage that is not an immediate source of mortality (Bond, 2012; i-Tree, 2021).

Post-storm work orders from local urban forestry programs can serve as a proxy for graduated damage assessment, particularly if they are generated as part of a systematic evaluation. Trees that suffer little to no damage will be skipped when determining the need for care after the storm, while those with more significant damage may require pruning to remove broken branches and restore crown structure. Trees with severe crown damage, trunk failure, or root failure will be scheduled for removal. This dual-purpose approach benefits both practical management and research. With this in mind, data collection crews should seek opportunities to collaborate with local urban foresters and other urban vegetation managers to generate work orders or damage reports from post-storm assessments conducted for research.

Most post-storm research focuses on tree damage and death, and the models generated from this research can help managers predict losses in urban forest value and benefits after a storm event. From an urban tree risk perspective, post-storm tree damage is a critical response that helps inform likelihood of failure, but it does not provide a complete picture. Risk also includes the likelihood of impact and consequences of failure. To gain a better understanding of the risks posed by trees in a population, researchers must conduct surveys of property owners and managers to assess the consequences of failure to targets such as structures, utilities, vehicles, and people.

3.4. Pre-Storm Inventory Data - Minimum Data Set

In addition to the metadata listed in Table 1, the minimum pre-storm data set includes five other variables (Table 2). The first is the date the tree was inventoried or last updated. The second is a unique identifier of each tree that allows users to combine pre- and post-storm data sets. Additionally, location information sufficient for re-assessment should be recorded—whether this is (in order of greatest to least useful) coordinates stored in a GIS, an address or unique identifier of the planting space. Species identification, according to internationally-accepted taxonomic databases like the Royal Botanical Garden, KEW's International Plant Names Index and Plants of the World Online (POWO, 2024), should also be recorded to both aid in relocation and to identify species-specific likelihood of failure. Taxon is consistently one of the most significant predictors of failure (Salisbury et al., 2024). Lastly, trunk diameter should be recorded to aid in relocation efforts, especially when groups of a single species exist in a small area. Because the height at which trunk diameter is measured varies regionally (Magarik 2021), it should be included, as should the protocol for measuring diameter when a tree consists of multiple trunks (Table 2).

Table 2. Pre-storm Inventory Data - Minimum Data Set.

Variable Type	**Variable**	**Description**	**Values or Units**	**Source**
Meta	Date of observation	Year, month, and day of field data collection	Calendar date	Roman et al., 2020
Meta	Tree record identifier	Unique identifier that remains connected to the tree during future monitoring	n/a	Roman et al., 2020 Nowak, 2010
Meta/Predictor	Location	Information about the tree's geographic position in the landscape	Latitude, longitude Street address	Roman et al. 2020 Nowak, 2010
Predictor	Species	Tree species	Genus, species, common name	Roman et al. 2020 Nowak 2010
Predictor	Trunk diameter	Diameter of main stem measured above ground	cm (in.)	Roman et al. 2020 Nowak 2010
Meta	Height to measurement of trunk diameter	Point at which trunk diameter was measured given tree form and local conventions.	cm (in.) or m (ft.)	Roman et al., 2020

3.5. Pre-Storm Inventory Data - Optional Data

While the minimum data set described in Section 3.4 is sufficient for creating random or stratified samples, additional pre-storm data collection can be valuable when addressing specific questions related to risk assessment and tree biomechanics (Table 3). Some of these variables are best collected prior to a storm if they are to be included in the analysis. These include components of visual risk assessments (i.e., qualitative safety assessments of a tree and its surroundings using industry best practices), which could be biased by the hindsight that occurs during post-storm evaluations. Additionally, aspects of tree conditions, such as opacity and quality (Bond, 2012), may be affected by the storm. While many measurements are easier to take before a storm, most can still be measured or estimated afterward, as explained in Section 3.8.

Table 3. Pre-Storm Inventory Data - Optional Data.

Variable Type	Variable	Description	Values or Units	Source
Predictor	Risk - likelihood of failure rating	Assessed failure potential of the tree or tree part	Varies by method	QTRA, 2024 VALID, 2024 Salisbury et al., 2023 Dunster et al., 2017 Pokorny, 2003
Predictor	Risk - overall risk rating	Assessed risk rating for the tree NOTE: Includes likelihood of failure, likelihood of impact, severity of consequences	Varies by method	QTRA, 2024 VALID, 2024 Salisbury et al., 2023 Dunster et al., 2017 Pokorny, 2003
Predictor	Risk - observed defects	Defects associated with greater likelihood of failure	Examples: decay, cut root(s), split	QTRA, 2024 VALID, 2024 Dunster et al., 2017 Nowak, 2010 Pokorny, 2003
Predictor	Risk - most significant defect	Defect that is most likely to be associated with failure	Examples: decay, cut root(s), split	QTRA, 2024 VALID, 2024 Dunster et al., 2017 Nowak, 2010 Pokorny, 2003
Predictor	Tree condition/health	A measure of how well the tree functions physiologically	Varies by method	Roman et al., 2020 Bond, 2012 Nowak, 2010
Meta	Notes for supervisory review	Issues that cannot be resolved in the field; entering a note flags the tree for review by the project supervisor.	n/a	Roman et al., 2020

Understandably, urban forest managers may be hesitant to make tree risk and condition assessments publicly available, as residents might be alarmed to learn that a tree near them poses an elevated risk. Moreover, public risk records could lead to future litigation if a tree identified as high-risk fails before mitigation can occur. If data will be published in a paper or posted in a repository, one strategy is to remove these risk assessment ratings; alternatively, the data can be anonymized by eliminating identifying location information (e.g., addresses, coordinates, storm names). Researchers affiliated with a university should consult with their research offices or libraries to discuss specific requirements for sharing sensitive data. These offices can also assist in creating data management and sharing plans, which may be required by funding sources to demonstrate to reviewers that these issues have been thoroughly considered.

3.6. Post Storm Assessment - Minimum Data Set

Several parameters collected during the pre-storm assessment (Tables 2 and 3) are also collected during the post-storm assessment (Table 4). First, if a pre-storm assessment was conducted, use the unique identifiers of each tree to pair pre- and post-storm data collection. If a pre-storm assessment was not conducted, the post-storm data set will require unique tree identifier numbers. Similarly, location, species, and trunk diameter are necessary for both data sets in order to ensure pre- and post-storm data are appropriately matched. Lastly, the minimum post-storm data set should include a measured response related to tree damage. This could be as simple as a binary variable (1 = damage, 0 = no damage), or more detailed information could be collected, such as the location of damage (e.g., roots, trunk, crown) and the severity of failure within the tree as described in Section 3.3.

Table 4. Post Storm Assessment - Minimum Data Set.

Variable Type	**Variable**	**Description**	**Values or Units**	**Source**
Meta	Date of observation	Year, month, and day of field data collection	Calendar date	Roman et al., 2020
Meta	Tree record identifier	Unique identifier that remains connected to the tree during future monitoring	n/a	Roman et al., 2020
Meta/Predictor	Location	Information about the tree’s geographic position in the landscape	Latitude, longitude Street address	Roman et al., 2020
Predictor	Species	Tree species	Genus, species, common name	Roman et al., 2020
Predictor	Trunk diameter	Diameter measured 1.4 m (4.5 ft.) above ground	cm (in.)	Roman et al., 2020
Response	Damage	A description of the type and extent of damage to the tree	Expressed as a % of how much the tree is impacted Yes (1), no (0) Categories such as none, low, moderate, extensive	Salisbury et al., 2023

3.7. Post Storm Assessment - Optional Data Set

Optional post-storm data collection could include a wide range of response data beyond simply the presence or absence of tree damage (Table 5). Alternatives include damage expressed as a percentage of the whole tree or the crown, ordinal rankings of damage, damage in specific tree locations (e.g., roots, trunk, crown), and tree mortality. Post-storm assessments could also evaluate property damage or injuries/deaths. Work orders from post-storm cleanup efforts can also be analyzed to gauge damage severity.

Table 5. Post Storm Assessment - Optional Data.

Variable Type	Variable	Description	Values or Units	Source
Response	Mortality	Trees that died as a result of the storm (within one year of the event)	%, numerical values between 0 and 1 Yes (1), No (0)	Salisbury et al., 2023
Response	Failure - branch	Branch or crown failure. May simply be the presence or absence of failure or some assessment of severity (e.g. proportion of crown damaged)	Expressed as a % of all branches Yes (1), No (0) Categories such as none, low, moderate, extensive	Salisbury et al., 2023
Response	Failure - stem	Trunk or main stem failure. Typically the presence or absence of failure given the severity of this damage.	Expressed as a % of all stems (if multi-stemmed) Yes (1), no (0)	Salisbury et al., 2023
Response	Failure - root	Visible uprooting, leans, or whole tree failure. Typically the presence or absence of failure given the severity of this damage.	Categories such as partial, leaning heavily, broken roots exposed, fully uprooted Yes (1), no (0)	Salisbury et al., 2023
Response	Crown loss - defoliation	Visible leaf/crown loss. May simply be the presence or absence of defoliation or some assessment of severity (e.g. proportion of crown damaged)	Expressed as a % of all foliage Yes (1), no (0)	Salisbury et al., 2023

			Categories such as none, low, moderate, extensive	
Response	Crown loss - branches	Visible branch/crown. May simply be the presence or absence of failure or some assessment of severity (e.g. proportion of crown damaged)	Expressed as a % of all branches	Salisbury et al., 2023
			Yes (1), no (0)	
			Categories such as none, low, moderate, extensive	
Response	Consequences of failure	Damage or injury/death caused by tree failure Obtained through observation and/or surveying property owners.	Property damage, injury, death	n/a
Response	Work orders	Tree maintenance/removal records tied to the storm recovery efforts.	Pruning type, removal, support systems	Nowak, 2010.

3.8. Optional Data That Can Be Collected Before or After a Storm

To study the impact of storms on trees, many optional data can be collected before or after the storm to better understand tree vulnerability and resilience (Table 6). Tree characteristics such as age, species growth form, and species growth rate can provide insights into the developmental stage and overall health of trees (Salisbury et al., 2023). Defects such as leans or decay may indicate predispositions to failure during extreme weather events (Hickman et al., 1995; Kane, 2008; Nelson et al., 2022). Variables such as native status, wood density, and the wood's modulus of elasticity and rupture can affect a tree's inherent strength (Francis, 2000; Duryea et al., 2007b; Uriarte et al., 2019; Nakamura, 2020). Additional structural factors like height, stem taper, and the presence of vines can influence a tree's risk of wind damage (Allen et al., 1997; Tabata et al., 2020; Torres-Martínez, 2021). Pruning history and root conditions (including root loss and available rooting space) can further impact a tree's load-bearing capacity (Kane, 2008; Johnson et al., 2019; Klein et al., 2020).

Table 6. Additional Optional Data - can be collected pre-storm, post-storm, or both.

Variable Type	**Variable**	**Description**	**Values or Units**	**Source**
Predictor	Age	Tree age or stand age	Years	Salisbury et al., 2023
Predictor	Buttress presence	Presence or absence of buttress or stilt roots	Yes (1), no (0)	Salisbury et al., 2023
Predictor	Crown class	From silviculture: Classification based on crown position relative to the crowns of adjacent trees	Categories such as emergent, dominant, codominant, intermediate, suppressed	Salisbury et al., 2023
Predictor	Defects (see reference for specific	Tree contains structural defects that reduce load-bearing capacity	Yes (1), no (0)	QTRA, 2024 VALID, 2024 Salisbury et al., 2023 Dunster et al., 2017 Pokorny, 2003
Predictor	Growth form	Excurrent or decurrent growth form		Salisbury et al., 2023
Predictor	Growth rate	Tree growth rate	Annual twig extension or radial increment (cm (in.)) Categories such as low, moderate, high	Salisbury et al., 2023
Predictor	Structural - Height^z	Tree height	Height measurement (m (ft.)) Height class	Salisbury et al., 2023 Ma et al., 2021, Nowak, 2010
Predictor	Leaf/Crown Properties	Factors that affect wind movement through the canopy	Leaf area index, porosity, drag coefficient, crown volume/diameter	Salisbury et al., 2023 Nowak, 2010

Predictor	Native status	Species is native to the study area	Yes (1), no (0)	Salisbury et al., 2023
Predictor	Pruning	Branches have been removed to reduce size/density of crown, reduce structural defects, maintain clearance for traffic/utilities, or remove dead/decayed wood.	Categorized by pruning type (raised, reduced, removed) Yes (1), no (0)	Salisbury et al., 2023 ANSI, 2023
Predictor	Root loss	Tree experienced root loss given decay or construction activities	Expressed as % of root system Yes (1), no (0)	n/a
Predictor	Rooting space	Area of exposed (unpaved) soil surrounding a tree	Expressed as % of root system Categorized by area, such as small, medium, large	Salisbury et al., 2023. Nowak, 2010
Predictor	Slenderness	Ratio of total height to trunk diameter	m/cm (ft./in.)	Salisbury et al., 2023.
Predictor	Vines	Presence or absence of vines	Yes (1), no (0) Categorized by proportion of tree/trunk covered	Adapted from Salisbury et al., 2023.
Predictor	Wood - density	Average wood density for a species based on field measurement or literature values	kg/m^3 (lbs./ft.^{3})	Salisbury et al., 2023.

Predictor	Wood - modulus of elasticity	Resistance of wood to deformation, the ratio of stress to strain (higher value indicates stiffer material)	N/m^2 (psi)	Salisbury et al., 2023
Predictor	Wood - modulus of rupture	Strength of wood in bending (higher value indicates stronger material)	N/m^2 (psi)	Salisbury et al., 2023
Predictor	Aspect of slope or exposure	Direction of slope relative to the prevailing storm winds	Compass degree (0 - 359) Cardinal (ordinal) direction	Salisbury et al., 2023 Nowak, 2010
Predictor	Distance from Storm Center	Distance from the eye of a tropical storm or the path of a cyclone.	km (mi.)	Adapted from Salisbury et al., 2023.
Predictor	Elevation	Tree elevation	m (ft.) above sea level	Salisbury et al., 2023
Predictor	Grouped Trees[y]/Site Exposure	Level of protection offered by neighboring trees or structures	Yes (1), no (0) Expressed as % of 360 degrees that are protected Categorized by amount of shelter, such as protected, partially protected, exposed	Salisbury et al., 2023 Nowak, 2010
Predictor	Land Use	A description of the way the property around or adjacent to the tree is used by humans	Single-family residential – detached, single-family residential – attached, multi-family residential, mixed use, industrial, institutional, maintained park, natural area, cemetery, golf course, agricultural, utility, water / wetland, transportation, vacant lot, other	Roman et al., 2020 Nowak, 2010
Predictor	Site Type	A description of the trees immediate location	Sidewalk cutout, sidewalk planting strip, median, planter box, other hardscape, front	Roman et al., 2020

			yard, side yard, back yard, maintained park, other landscapes area, natural area	
Predictor	Topography	A description of the landforms and features of the site		Salisbury et al., 2023
Meta	Tree photo	A photograph taken to include the entire tree in the context of its immediate location and showing built infrastructure objects	n/a	Roman et al., 2020 Bond, 2013

[z] Height may be more difficult to assess post storm in trees where partial crown failure has occurred. [y] Grouped trees are trees in close proximity where full or partial canopy closure has occurred.

Environmental conditions and tree site factors are also important considerations. Aspect of slope or exposure, along with site elevation and proximity to the storm center, have all been investigated to determine how environmental forces interact with individual trees or groups of trees (Salisbury et al., 2023). Grouped trees or those in protected sites might experience differing levels of damage compared to isolated trees or those in exposed sites (Duryea et al., 2007a; Duryea et al., 2007b). When considering group trees, consider the stem taper, soil drainage characteristics, height above or below the dominant canopy height, and species diversity (Mitchell, 1995). Collecting such data helps researchers assess not only the structural properties of trees but also the influence of their surroundings, ultimately informing storm preparedness and mitigation strategies.

3.9. The Future of Pre- and Post-Storm Assessment

We have presented what we consider current best practices for data collection in pre- and post-storm assessments. But we acknowledge that novel attributes and methods will likely arise as researchers and practitioners learn more and novel circumstances arise. As technologies like ground-based light detection and ranging (LiDAR; Nguyen et al. 2020) and photogrammetry (Roberts et al. 2018) become more widespread, new metrics—beyond what can be measured with traditional forestry tools—may emerge as valuable predictors of storm damage.

In an effort to create a living standard that evolves as methods advance, we have established the Urban Tree Storm Data Network (UTSDN, 2024). This network will include the published data standard, a bibliography of pre- and post-storm assessment research, a data repository for uploading storm data, and a wiki of metadata, response variables, and predictor variables (including descriptions, units, sources, etc.) used in past studies. We encourage both researchers and industry professionals to contribute their data using the standards documented here and draw from this resource as we work toward creating more resilient forests in a changing global climate.

4. Conclusion

Our work highlights the importance of developing standardized data collection methods for pre- and post-storm assessments in urban forestry. By adopting standard practices and data in community inventories and field research, scientists and practitioners can generate more reliable, comparable, and actionable information to predict tree failure and assess the health and resilience of urban forests in the face of severe and extreme weather. Consistency in data collection will improve the ability to draw meaningful conclusions from post-storm data, inform species selection and tree management practices, and ultimately contribute to more storm-resilient urban landscapes. Standardized approaches not only enhance the scientific rigor of post-storm studies but also facilitate collaboration across regions, helping cities and municipalities better prepare for and mitigate the impacts of future storms on their urban forests.

However, tree risk and condition ratings may not be publicly available to researchers. Moreover, biometric data such as stem diameter, height, and species identification may be collected in an unusable format (i.e., without units), contain errors, or utilize outdated or regionally specific taxonomic conventions. Consequently, reassessing the existing inventoried population is preferred.

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