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Research article

Applying protection motivation theory to assess collaboration, urban tree risks and storm management in the U.S.

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ABSTRACT

Urban trees are vital components of urban societies and ecosystems, but their management is often contested by diverse and sometimes conflicting goals. As storm frequency and intensity increases, it is important to understand the factors that impact municipal level proactive and reactive storm responses to urban trees including pruning, removal, and emergency procedures. Therefore, we surveyed 920 urban forestry professionals in the Northeastern and Southeastern United States to assess their perceived storm threats, socio-demographic characteristics and whether their affiliated organizations had storm preparedness plans. We used Protection Motivation Theory (PMT) as an analytical lens to assess collaboration as a possible protective response to urban trees and storm events. Specifically, we incorporated PMT variables: threat severity, vulnerability, response efficacy, and self-efficacy perceptions. We also expanded PMT to understand perspectives from a professional audience by including professional experience, knowledge, and perceptions of collective and personal efficacy. Our results suggest that collaboration between urban forestry professionals is often used to enhance storm responses and urban forest management as 56% of respondents used collaboration for tree risk assessment, regular tree maintenance (50%), emergency storm responses (48%), data collection and inventory (43%) and strategic planning (40%). Using a structural equation model, we found that threat appraisal, perceived efficacy beliefs, and the amount of perceived and actual money spent on management were statistically significant predictors of respondents' likelihood to require collaboration as a necessary part of protective action. Our results provide insights into how urban trees are managed in the context of storms, including considerations for collaboration, collective governance, and strategic responses.

1. Introduction

Urban trees are significantly impacted by human decision-making including plant breeding and propagation, nursery care and growing, species selection, site preparation, transplanting, watering, maintenance, and removal (Eisenman and Laskey, 2025). These management decisions play a central role in how cities prepare for and respond to storm events. The effects of climate change, including an increase in storm frequency and intensity, can exacerbate management challenges related to tree health, vulnerability and longevity. These complex issues reflect a need to further understand the underlying factors related to urban trees and socio-ecological resilience, including resilient infrastructure and social capacity to address climate change (Ordóñez and Duinker, 2015).

1.1. Urban trees and perceptions of risk

Urban trees are critical green infrastructure and provide various

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benefits, including shade and cooling, stormwater management, aesthetic beauty, and calming effects (Mullaney et al., 2015). Despite these benefits, people's perceptions of and attitudes towards urban trees, are impacted by various factors including 1) demographic characteristics like age, gender, and education levels (Lo et al., 2017; Ordóñez and Duinker, 2015)) socio-cultural, or 3) geographic factors (Avolio et al., 2015), which inform management practices. Consequently, people's perceptions can impact their behaviors towards urban trees and climate adaptation. For example, a study of climate change risk perceptions found that people may adopt climate change adaptation behaviors depending on their level of exposure to climate effects like urban heat and access to green spaces (Jiang et al., 2025). Overall, urban forest management seeks to enhance the ecosystem services trees provide while minimizing the costs and disservices (Roman et al., 2021; Vogt et al., 2015).

However, urban trees, especially during storms, can also be associated with costs and risks, such as damaging infrastructure, potentially harming people and property through tree failure or fallen debris, and plant litter (Roman et al., 2021). Differing perceptions of tree risks pose challenges to urban tree management (Klein et al., 2019). For instance, the public may view trees as high risk based on their proximity to a property, prompting the removal of trees before or after a storm (Conway and Yip, 2016). Storms can increase infrastructure and property damage, creating additional pressure for urban forestry professionals to minimize conflicts between urban trees and city infrastructure (Roman et al., 2021). Meanwhile, city arborists or urban foresters may distinguish tree risk based on factors such as visual defects (Roman et al., 2015). Although it is difficult to predict tree failures, effective urban tree management practices like proper tree selection, pruning, and assessment can improve tree performance under intense storms (Klein et al., 2019).

In addition, a literature review of tree risk assessment and risk perceptions found that urban forestry professionals were frustrated about the public's fear of trees (Klein et al., 2019). Furthermore, operational urban forestry leaders (personnel oriented toward applied practice) may prioritize residents' concerns more than executive urban forestry leaders (personnel oriented toward conceptual program goals) in tree planting and management decisions (Halasz et al., 2025). However, collaborative partnerships that include residents and other urban forestry professionals may improve tree risk management and an understanding of stakeholder perspectives.

1.2. Collaborations and urban tree management

Understanding urban forestry professionals' perceptions of risk related to tree management and storms is critical to proactive emergency management, especially where both biological and technological infrastructure play a role in building community resilience towards storms. Given the complexity of managing urban trees, it is especially important to understand how perceived storm risk may motivate collaboration among urban forestry professionals. Collaboration includes facilitating access to participants, sharing power to define problems and solutions (McGrath et al., 2021), sharing goals or visions (Elmendorf et al., 2001), interacting and working through differences to find solutions while developing trust (Elmendorf et al., 2001), and achieving consensus (Shapira et al., 2013).

Collaborative actions, like interagency partnerships can: alleviate limited resources, lack of information, funding, equipment, and staff, all relevant to managing trees for storm events (Cadaval et al., 2024a). Engaging in collaboration highlights the interdependence of urban systems where failures or complications in one area such as vegetation management can impact and disrupt other systems like power or other utility infrastructure. In addition, research on power-grid resilience to severe storm impacts demonstrates a need to coordinate solutions across related sectors (Wang et al., 2025). Improving collaboration among urban forestry professionals may reduce barriers that could otherwise lead to more reactive tree maintenance. Proactive measures to manage trees for storm events may reduce the impact on critical city infrastructure vulnerable to weather effects. However, there is still limited understanding of the factors that influence collaboration amongst these actors. Therefore, our study assesses the role of perceived storm threats, professional experience, efficacy beliefs, and perceptions about resource availability on urban forestry professionals' intentions to collaborate in managing trees during storm events.

Stakeholders have different motivations for collective urban forest decision-making and successful partnerships benefit all parties involved (Wang et al., 2025). Stakeholders that shape urban forestry include municipal urban foresters, privately contracted arborists, landscape architects, urban planners, utility managers, emergency management personnel, non-profit organizations, volunteers, residents, and in some cases visitors (Deng et al., 2010). The diversity of stakeholders, reflecting different needs and perspectives, complicates how practitioners seek support for tree programs and stewardship (Roman et al., 2015). Therefore, professionals' actions can intentionally influence a broad suite of services or disservices experienced by communities, including ecological and social outcomes and the reliability of infrastructure systems that can be impacted by storms.

1.3. How do cities manage tree-related risk?

Management choices such as keeping structurally biodiverse and functional urban forests, matching trees to sites and conditions, pruning, inspections and using tree inventories are some options for mitigating tree-related risk (Koeser et al., 2016b, 2020). External factors can also influence engagement in risk mitigation activities as cities with prior legal claims for damage or harm caused by trees (Koeser et al., 2016b), are more likely to implement protective behaviors. Nonetheless, little is known about how urban forestry professionals make decisions about risk and subsequent management choices.

1.4. Protection motivation theory (PMT)

This research incorporates Protection Motivation Theory (PMT) (Rogers, 1975; Maddux and Rogers, 1983) to assess perceived storm-related tree risk held by urban forestry professionals and the resulting management behaviors (operationalized as perceived collaboration needs). Initially developed in 1975 (Rogers, 1975; Maddux and Rogers, 1983), PMT is used to understand people's motivations to engage in certain behaviors to protect themselves from harm (Camerini et al., 2019; Xiao et al., 2014). PMT explains coping behaviors and decision-making in the context of potentially harmful events like emergencies or disasters.

Traditionally, PMT is primarily used to understand motivations and behaviors for health issues such as vaccination decisions (Camerini et al., 2019) or disease exposure (Xiao et al., 2014). Over the past decade, PMT has been adopted and used to explore environmental behaviors like invasive plant management (Clarke et al., 2021), using electric vehicles (Bockarjova and Steg, 2014), climate-friendly behaviors (Grothmann and Patt, 2005), flood protection (Harlan et al., 2019), and wildfire prevention (Martin et al., 2007). To our knowledge, PMT has not been used to examine urban forestry professionals' responses to storm events. However, PMT has been widely used and accepted for analyzing the behavior intentions of individuals and is often used in the context of environmental challenges. Complexity and scale can influence how environmental and natural resources are managed with greater coordination, often being part of the accepted or expected response. Many environmental threats (such as hurricanes, floods, invasive species), however, result in larger scale, broader impacts and collective costs. Thus, a method of capturing perceptions of collective level threats to urban forests and professionals' ability to respond is needed.

PMT includes two key measures to explain protective actions (1) *threat appraisal* (including perceived severity, vulnerability, intrinsic and extrinsic rewards), and (2) *coping appraisal* (response efficacy, self-efficacy and response cost) (Rogers, 1975; Maddux and Rogers, 1983). In other words, *threat appraisal* refers to an individual's assessment of a threat's perceived severity and likelihood of occurring while *coping appraisal* is an individual's assessment about whether they can cope with and reduce the threat. Coping appraisals involve evaluating the efficacy of protective measures (response efficacy), one's capability to execute these measures (self-efficacy), and the associated costs (response cost) (Grothmann and Patt, 2005). Self-efficacy beliefs describe an individual's ability to complete protective actions (Maddux and Rogers, 1983; Bandura, 1977) to reduce a threat's negative consequences (Babcicky and Seebauer, 2020). Higher self-efficacy can motivate individuals to engage in risk mitigation, as seen in hurricane preparedness studies where increased self-efficacy is correlated with viewing non-preparation as riskier (Chevrier et al., 2025). Overall, the theory assumes that individuals will participate in protective behaviors or activities to avoid negative consequences from a perceived threat if they have sufficient understanding and capacity to cope with a given threat (Camerini et al., 2019; Floyd et al., 2000).

Although collective efficacy beliefs are not a key component of the original PMT, in the context of our research, it is important to explore collective efficacy beliefs because urban forest governance and decision-making are shaped by multiple stakeholders (Stewart, 2015), particularly in response to extreme storm events towards shared goals (Babcicky and Seebauer, 2020). Extreme storm events usually require collaboration because professionals rely on each other's expertise to address complex immediate issues related to safety, liability, infrastructure damage, and other emergencies. For groups engaging in collective action, effectiveness is tied to their beliefs in their integrated capabilities to collectively achieve their goals including preparing for and responding to natural disasters (Babcicky and Seebauer, 2020). Therefore, collective efficacy and self-efficacy are interdependent because an individual's belief in group efficacy positively affects both the individual and group's behavior and outcomes (Babcicky and Seebauer, 2020).

Our study explored how perspectives about threat, coping, and costs associated with storms and tree management influenced collaboration needs and actions. Therefore, we expanded the PMT model to measure how participants perceived their ability to achieve a goal together (collective efficacy). New research about collective pro-environmental behavior also expanded the PMT model by adding factors to understand how perceived collective agency motivates group pro-environmental behavior (Stewart, 2015). It is appropriate to use PMT to understand how urban forestry professionals perceive risks and make tree management decisions as part of their professional responsibility in the context of extreme storm events.

While urban forestry research is increasing, there is limited understanding about the socio-psychological factors impacting urban forestry professionals' decision-making (Stewart, 2015). PMT can help explain why some individuals engage in protective behavior while others do not (Floyd et al., 2000; Bockarjova and Steg, 2014). In our study, protective behavior is operationalized as perceived need to collaborate with others to manage trees during storm events. Assessing perceptions and management decisions using PMT can also identify barriers to enhance the likelihood that actors will participate in protective actions such as collaborative tree risk assessments. This study uses a novel approach by integrating PMT to understand drivers of collaboration engagement based on perceived risk, efficacy beliefs and collaboration related to storms.

2. Methods

2.1. Data collection

A survey questionnaire was distributed to urban forestry professionals from June to August 2023 to collect data on risk perceptions, efficacy beliefs, professionals' experiences, communication needs and conceptual variables of the PMT. In addition to the conceptual variables defined by PMT, the survey instrument was informed by the results of the interviews conducted in the research's exploratory phase (Cadaval et al., 2024a; Creswell and Creswell, 2017). This exploratory-sequential approach allowed us to pull contextually relevant experiences about storm preparedness and response and prepare a survey with contextually relevant indicators and survey validation (Creswell and Creswell, 2017). The survey instrument was pilot tested by two experts who are certified arborists with extensive experience working with urban forestry professionals as researchers and colleagues. Both experts independently completed the survey and provided structured feedback on clarity, terminology, relevance and survey flow. Their input informed revisions to the survey which improved the content, validity and usability of the instrument. After testing, the survey was distributed electronically through Qualtrics. The survey was submitted and approved by the University's Internal Review Board (IRB# and detailed TBA after peer-review).

This survey recruited urban forestry professionals in the United States Department of Agriculture Forest Service's Regions 8 and 9: Connecticut, Delaware, Illinois, Indiana, Iowa, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, Washington D.C., West Virginia, Wisconsin, Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, Puerto Rico, South Carolina, Tennessee, Texas, and Virginia. These two regions were selected to encompass a range of storm events including severe thunderstorms, tropical storms, hurricanes, tornadoes, windstorms, derechos, snowstorms, and ice storms.

Urban forestry professionals include a diverse group of participants such as municipal or government employees and arborists, non-profit and community-based leaders and staff, arboricultural consultants, private firm professionals, and others. Participants were recruited through 1) ISA certified arborist directory, and 2) participants had the opportunity to opt-in to the survey after learning about it on professional social media sites (e.g., LinkedIn), announcements on professional listservs and city government's internal departmental listservs (e.g., Parks and Recreation, Public Works, and Sustainability departments). Our recruitment approach may overrepresent professionals who are more engaged in professional networks and underrepresent those with less connectivity. Although our use of multiple recruitment channels and the inclusion of a broad geographic range helped capture diverse organizational contexts and storm experiences. Email invitations sent to urban forestry professionals provided survey details, consent information and a Qualtrics link. All the individuals contacted were asked to share the survey with colleagues to increase the response rate. A total of 920 urban forestry professionals participated in this study.

The survey asked about (1) participant background, (2) storm preparedness and impacts in their cities, (3) perceived self-efficacy, response efficacy, collective efficacy, and motivations, (4) opportunities for collaboration, and (5) demographic information. Several survey questions used a five-point Likert scale (Likert, 1932), asking respondents to rate their levels of agreement (1 = strongly disagree to 5 = strongly agree) with statements about their perceptions of response efficacy, costliness, self-efficacy, and collective efficacy.

2.2. A conceptual model of PMT

Our analysis examines whether threat appraisal and coping appraisal influence protective behavior intentions of urban forestry professionals. Survey questions were framed around four conceptual elements: (1) knowledge, (2) experience, (3) threat appraisal, and (4) coping appraisal (Fig. 1). Threat appraisals determine how one assesses whether to engage in protective behavior (Neuwirth et al., 2000). This study operationalizes "threat appraisal" by defining key measures of the

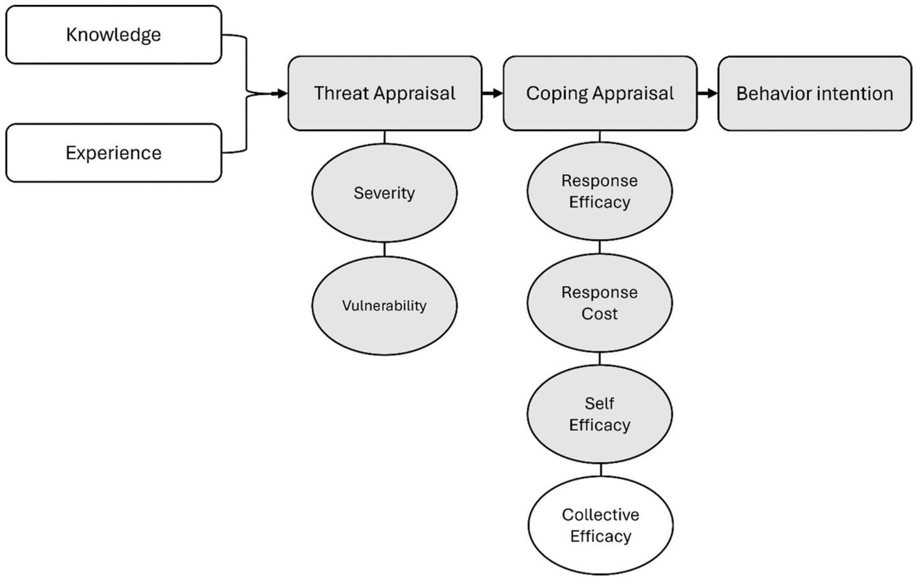

Fig. 1. Our adapted conceptual model includes key protection motivation factors such as "threat appraisal" and "coping appraisal" and variables such as "severity", "vulnerability", "response efficacy", "response cost", "self-efficacy", and "collective efficacy" (in grey) and additional variables from the literature like "knowledge", "experience", and "collective efficacy" (in white because it is a new variable not usually included in PMT).

variables (1) severity of threat and (2) probability of threat. Threat appraisal assumes a positive relationship between the perceived threat and severity of the threat and the likelihood of performing protective behaviors.

While PMT is typically applied to individual decision-making in response to perceived threats, our research extends its application to a professional context where individuals make decisions for a collective. In urban forestry, professionals often implement protective actions that affect entire communities rather than themselves. The shift from personal to collective decision-making is informed by professional experience and perceived collective efficacy.

Our study also incorporates knowledge and experience into the conceptual model. An individual's past experiences and knowledge about a threat (e.g., past floods or storms) may influence risk perceptions (Harlan et al., 2019; Neuwirth et al., 2000). Our model operationalizes experience as the length of time respondents have worked in urban forestry or arboriculture. Level of formal schooling and professional knowledge about risk is used to operationalize "knowledge" in subsequent structural equation modeling. Threat appraisal is operationalized as the severity of the threat by assessing 1) the severity of storm-related impacts in respondents' cities and 2) the storm types experienced. The likelihood of a threat or vulnerability was operationalized based on respondents' perceived 1) susceptibility to storms, 2) storm frequency and 3) likelihood of weather-related impacts.

Based on the PMT model, coping appraisal is operationalized by including 1) response efficacy, 2) response cost, 3) self-efficacy, and 4) collective efficacy. Response efficacy is the belief that specific protective actions will mitigate the threat while response costs involve the resources needed for the protective behavior. The behavior intention, or outcome variable, is defined by how likely the respondent will or intends to engage in recommended protective behaviors, in this case whether tree-risk management collaborations were necessary. We measured response efficacy by asking respondents about aspects of their work that required them to collaborate with others outside of their organizations.

To build additional context, data about participants' work was collected including whether respondent's affiliated organizations used a storm preparedness plan, population sizes of the urban areas they worked in, and socio-demographic characteristics including gender, level of education, and descriptions of professional roles. We hypothesized that urban forestry professionals who expressed stronger needs to collaborate with outside organizations also have higher threat appraisal scores, higher perceived efficacy beliefs, higher perceived costs for managing trees and storms, higher education levels, and more risk assessment qualifications, knowledge, and experience than professionals with lowered perceived threat appraisal scores and efficacy beliefs.

2.3. Data analysis

Descriptive statistics were retrieved for demographic data and professional experiences. Univariate statistics are used to describe responses to questions about the components of PMT. Summary statistics were reported for 1) city population size, 2) whether respondents worked in an organization with a storm preparedness plan, 3) profession types, 4) years of professional experience, and 5) education level. Respondents' years of professional experience and education level were incorporated into the subsequent structural equation analysis.

Structural equation modeling was used to analyze the data on JMP Pro Tools (JMP®, 17 2022) to understand the relationship between independent and dependent variables and the structures of the relationships. Structural equation modeling allows the researchers to combine both path analysis and confirmatory factor analysis to explain variances and correlations among the variables (Agresti and Finlay, 2009). This analysis required two steps, first a measurement model where unobserved factors are pulled from the observed variables or observed variables are used (Agresti and Finlay, 2009). For example, in our model, these are the factors for threat appraisal and coping appraisal (unobserved factors) and experience, and knowledge (observed variables). Second, we incorporated confirmatory factor analysis to estimate the measurement portion of the model (Kline, 2013). All the load-in variables were standardized prior to constructing the structural equation model.

Using the PMT constructs, a model was constructed incorporating the latent variables or factors (efficacy and threat appraisal) and the associated manifest variables (collective efficacy, self-efficacy, response efficacy, and storm type, likelihood of event, and severity) respectively (Table 1). Manifest variables are those directly measurable by the data, while the latent variables address concepts which may not have been directly measured (Ullman, 2006). Additionally, perceptions about cost, storm-related management expenses, experience, risk assessment qualifications, and education levels were included in the model as manifest

Table 1
Variable operationalization from the model involved establishing factors of latent and manifest variables.

Survey items used in structural equation model	SEM Model Load-in (Latent and Manifest Variables)
Knowledge Knowledge defined as level of formal school and knowledge about risk Level of formal education: What is the highest level of education you have completed? Professional knowledge about risk: In what way (s) have you educated yourself about tree risk? Select all that apply.	Level of formal education Risk Assessment Qualifications
Experience Experience defined as years of experience 1. How long have you been working in urban forestry and arboriculture?	Experience
Threat Appraisal Threat appraisal defined as perceived vulnerability and severity **Vulnerability** 1. How often do the following storms [hurricanes, tropical storms, severe thunderstorms, tornadoes, ice storms, blizzards or snowstorms, windstorms, other] impact the urban areas you work in? 2. Please indicate the likelihood of the following weather-related impacts in your city in the next five years. Please select one option per statement. **Severity** 1. Please indicate the severity of the following storm-related impacts in your city in the past five years. Severity is the extent of the damage. (Please select one option per statement)	Threat Appraisal
Coping Appraisal Defined based on self-efficacy beliefs, response efficacy and collective efficacy. **Self-Efficacy** How much do you agree with the following statements. Likert scale questions on a scale from strongly disagree to strongly agree. 1. I have the resources I need to effectively work through a storm response event 2. I am able to effectively communicate with others about storm preparedness and planning 3. I am able to effectively communicate with others during a storm response event **Response Efficacy** How much do you agree with the following statements. Likert scale questions on a scale from strongly agree to strongly disagree) 1. My organization's work contributes to the safety of the community 2. Conducting tree inventories and collecting data about trees in your community contributes positively to storm management 3. Our tree inspection practices are effective at reducing debris and damage from trees during storms 4. Our other maintenance practices are effective at reducing debris and damage from trees during storms **Collective Efficacy** How much do you agree with the following statements (Likert scale questions on a scale from strongly disagree to strongly agree) 1. The organizations or departments that we collaborate with are knowledgeable about storm response 2. Collectively, the diverse urban forestry professionals are capable of managing the consequences of storms effectively	Efficacy
Response Costs 1. How much do you agree with the following statements. (Likert scale ranging from strongly agree to strongly disagree) a) It is very costly for my company, organization, or municipality to prepare for storms b) It is very costly for my company, organization, or municipality to clean-up after storms	Perceived Costs
How much does your organization or company spend annually (USD) on storm management (e.g. storm clean-up, pre-storm pruning)? Your best estimate is sufficient. Select one option from the following list: o Less than $49,000 o $50,000 - $149,999 o $150,000 - $249,999 o $250,000 - $399,999 o $400,000 to $499,999 o $500,000 to $649,999 o $650,000 - $799,999 o $800,000 - $999,999 o >$1,000,000	Amount spent on managing ($) (Actual Monetary Costs)
Behavior intention (proxy used as collaboration needs) What aspects of your work require you to collaborate with others outside of your organization? o Strategic planning o Data collection and inventory o Tree risk assessment o Day to day maintenance of trees o Communication with external organizations/ stakeholders o Communication with the non-expert public o Emergency response for storms o Other	Intention to collaborate

variables (Table 1). A path diagram was created by loading the data to JMP Pro Tools (JMP®, 17 2022) software. The model was estimated using maximum likelihood estimation (Raskind et al., 2019).

The structural equation model was assessed using comparative fit index (CFI) where values > 0.95 represented a good fit (Raskind et al., 2019; Hu and Bentler, 1999). Additionally, Root Mean Square Error of Approximation (RMSEA) values were also used as a secondary assessment of fit. For RMSEA values should preferably be < 0.05 (Hu and Bentler, 1999). The significance level was set at $\alpha = 0.05$. Following, regression models were developed for the factors to identify causal relationships among the latent variables (JMP®, 17 2022).

Our study used an average of the additive measures of professionals' work requiring collaboration as the response variable. This was composed of multiple binary items where respondents indicated if collaboration was required to accomplish a management related activity (Table 1). Because the items are binary, the initial distribution of the index resulted in limited variability, reducing sensitivity in detecting relationships in the structural equation model. To address this limitation, we applied a theoretically informed weighing approach based on literature on storm-related tree management and PMT. “Tree risk assessment” was assigned a higher weight (threefold) because it is central to professionals’ decision-making about storm-related tree management. Risk assessment is also a key process linking threat and coping appraisals within PMT. Accordingly, reweighting “tree risk assessment” ensures that this activity is more appropriately represented within the composite measure of collaboration needs, which we use as a proxy for collaboration intention. By reweighing the variable, we are able to redistribute the variance among the existing components, facilitating the interpretation of results and improving model estimation (McCullagh and Nelder, 1989).

3. Results

3.1. Demographic data and work contexts

The study's results are based on a total sample size of 920 responses; of which 496 responses included complete data. Thirty-three percent of respondents worked in cities with over 1 million residents and 43% worked in cities with 300,000 residents or fewer (Table 2). Most respondents worked as commercial arborists, city foresters, or municipal arborists (Table 2). Few respondents worked as non-profit coordinators or program managers. Fifty-three percent of participants worked in urban forestry related professions for more than 15 years and 93% held more than one tree risk related credentials. Most participants (71%) attended college or had an advanced degree (Table 2), with an average of 49 years old.

Fifty-six percent of respondents indicated that their organizations had a storm preparedness plan, 17% did not, and 9% were unsure. Seventeen percent of respondents indicated that a storm preparedness plan was not applicable to their organization and provided open-ended explanations including uncertainties about the status of plans (n = 15), plans differing by client (n = 2), and not being a part of city planning (n = 5).

3.2. Perceptions about collaboration needs, threat appraisals, efficacy and costs

When asked to specify which aspects of their work required collaboration, most respondents (55%) indicated that collaboration was required for at least three of the listed activities. The top three activities that required collaboration included: 1) communication with the public (65%), tree risk assessments (56%) and external communication with stakeholders or organizations (51%) (Table 2).

On a scale of 1 (not severe) to 10 (very severe), respondents viewed the severity of impacts from trees as "less severe" ($\bar{x}$ = 2.63) when considering cumulative threats from storm related impacts and tree failure, infrastructure damage, tree canopy loss, tree debris increasing localized flooding, loss of wildlife habitats, structural damage, problems with traffic due to debris, loss of human life or injury, and property damage in the last five years. On average, respondents reported the aforementioned weather-related impacts were "not likely" or could happen "less than once every few years" ($\bar{x}$ = 2.64), on a scale where 1 indicates once per year and 5 indicates never. Respondents reported that storm related impacts from hurricanes, tropical storms, severe thunderstorms, tornados, ice storms, blizzards or snowstorms, and windstorms (including derechos) occur once per year ($\bar{x}$ = 2.28).

Perceived collective efficacy averaged a neutral response of "neither agree nor disagree" that the collective capacity to manage trees and storm related events was effective ($\bar{x}$ = 3.07, σ = 1.60). On average ($\bar{x}$ = 2.76, σ = 1.78), respondents "somewhat disagreed" with self-efficacy beliefs about working through a storm response event. Respondents reported that they "somewhat disagreed" or "disagreed" that actions their organizations engaged in to manage trees for storm events were effective ($\bar{x}$ = 1.77, σ = 1.54). Urban forestry professionals reported that preparing or responding to storms was not very costly ($\bar{x}$ = 2.01, σ = 1.84). Additionally, respondents reported spending an estimated \$650,000 - \$799,999 (USD) on managing trees for storms annually ($\bar{x}$ = 7.42, σ = 4.10).

3.3. How perceived cost, efficacy, and threat appraisals drive intentions to collaborate with others managing trees for storm events

The model is an appropriate fit for the data (CFI = 0.9395 and RMSEA = 0.0890). The analysis showed that perceived threat appraisal,

Table 2
Univariate statistics for respondent demographics, work contexts, and model variables.

Univariate statistics describing respondent demographics and work context		
Variable	*Frequency (n=)*	*Percent (%)*
Profession		
Utility forester or arborist	79	11%
Consulting arborist	147	21%
City forester or municipal arborist	174	24%
Nonprofit coordinator or program manager	21	3%
Commercial arborist	178	25%
Other	114	16%
Total	713	100%
Storm plan use		
Yes	392	56%
No	120	17%
I don't know	65	9%
Not applicable to my organization	121	17%
Total	698	100%
Worksite population size		
Less than 50,000 people	116	16%
51,000–100,000 people	84	12%
100,001–300,000 people	106	15%
300,001–500,000 people	60	9%
500,001- 700-000 people	41	6%
700,001–900,000 people	36	5%
900,001 - 1 million people	27	4%
Over 1 million people	234	33%
Total	704	100
Descriptive statistics of PMT variables		
Variable	*Frequency (n=)*	*Percent (%)*
Education level		
Highschool diploma/GED	32	6%
Some college or Associate/Trade degree	117	22%
Bachelor's degree	255	48%
Master's degree or higher	127	24%
Total	531	100%
Years of Experience		
Less than 1 year	8	1%
1 to 5 years	76	11%
6 to 10 years	113	16%
10 to 15 years	136	19%
More than 15 years	376	53%
Total	709	100
Actual Costs (\$ spent annually on storm management)		
Less than \$49,999	98	16%
\$50,000-\$149,999	68	11%
\$150,000-\$249,999	22	4%
\$250,000-\$399,999	11	2%
\$400,000-\$499,999	5	1%
\$500,000-\$649,999	11	2%

(continued on next page)

Table 2 (*continued*)

$650,000-$799,999	2	<1%
$800,000-$999,999	4	1%
>$1,000,000	50	8%
I don't know	137	22%
No budget allocated to storms	203	33%
Total	611	100
Storm Collaboration needs (Yes)		
Strategic planning	204	40%
Data collection and inventory	220	43%
Tree risk assessment	285	56%
Regular tree maintenance	255	50%
External communication with stakeholders/organizations	260	51%
Communication with public	333	65%
Emergency response for storms	243	48%
Another action	21	4%
Total	509	100

	Frequency (n=)	*Median*	*Mean ($\bar{x}$)*	*Std. Deviation (σ)*	*Min*	*Max*
Storm Impact Severity						
Tree failure	594	6	6.28	2.27	0	10
Infrastructure damage	569	5	4.83	2.62	0	10
Loss of tree canopy	587	5	5.48	2.55	0	10
Increased flooding	531	4	4.31	2.74	0	10
Loss of wildlife habitat	552	4	4.37	2.66	0	10
Structural damage	573	5	4.85	2.63	0	10
Debris Traffic	571	4	4.62	2.72	0	10
Injury or loss of life	468	2	2.63	2.68	0	10
Property damage	579	5	5.54	2.69	0	10
Other	22	5	4.82	3.92	0	10
Storm Impact Likelihood						
Tree failure	609	4	4.18	0.75	1	5
Infrastructure damage	607	4	3.55	0.96	1	5
Loss of tree canopy	606	4	3.88	0.91	1	5
Increased flooding	607	3	2.95	1.02	1	5
Loss of wildlife habitat	604	3	3.30	1.08	1	5
Structural damage	606	4	3.51	0.95	1	5
Debris Traffic	607	4	3.50	0.96	1	5
Injury or loss of life	608	2	2.26	0.84	1	5
Property damage	608	4	3.68	0.91	1	5
Other	37	2	2.51	1.64	1	5
Storm Type Frequency						
Hurricanes	691	2	2.02	1.72	0	5
Tropical storms	686	3	2.32	1.87	0	5
Severe thunderstorms	695	5	4.82	0.53	0	5
Tornados	692	3	2.70	1.54	0	5
Ice storms	689	3	2.67	1.51	0	5
Blizzards or snowstorms	690	3	2.70	1.92	0	5
Windstorms/Derechos	695	4	3.63	1.54	0	5
Other	64	3	2.52	2.08	0	5
Collective Efficacy (Likert)						
Collaborators knowledge about storm response …	529	4	3.71	1.04	1	5
Collectively capable of managing storm consequences …	528	4	3.68	0.99	1	5
Self-Efficacy (Likert)						
I have resources I need …	524	4	3.54	1.15	1	5
I can effectively communicate about planning & preparedness …	527	4	3.76	1.02	1	5
I can effectively communicate during a response event …	526	4	3.78	1.04	1	5
Response Efficacy (Likert)						
Organization's work contributes to community safety …	543	5	4.53	0.90	1	5
Our Tree inventories and data contribute to storm management …	543	4	4.37	0.95	1	5
Our tree inspections reduce debris and damage from storms …	540	4	3.98	1.12	1	5
Cost Perception (Likert)						
It is costly for my organization to clean up after storms …	542	4	3.75	1.17	1	5
It is costly for my organization to prepare for storms …	541	3	3.09	1.08	1	5

including the severity of storm-related impacts in the last five years, the likelihood of weather-related impacts, and how often storms occurred, positively influenced the perception that storm-related work required outside collaborations ($p > 0.02$; Table 3). Coping appraisal variables had positive effects on perceptions that storm-related work required outside collaborations ($p > 0.029$; Table 3). With higher perceived storm threats, there was a greater likelihood of indicating a need to collaborate more on tree-related storm management. Perceived efficacy also had positive effects on whether collaboration needs were higher ($p > 0.025$; Table 3).

Perceived costs were statistically significant. Specifically, when more money is spent annually to manage storms, there is a greater perceived need for more collaborations ($p > 0.013$). Additionally, respondents with higher perceived levels of storm related risks (threat appraisal) were related to perceptions that it was costly to prepare for and clean up after storm events ($p < 0.0001$). The more money reportedly spent on storm related tree management, the more positive effect on perceptions of efficacy ($p > 0.042$). Finally, perceived costliness had a positive effect on perceived efficacy ($p < 0.0001$). However, perceived cost did not have significant effects on perceived collaboration needs in managing trees for storms.

Several variables did not show significant effects on perceived collaboration needs (Table 3) including the number of years respondents worked in arboriculture or urban forestry (experience) ($p > 0.527$). Experience did not have a significant effect on perceptions about efficacy ($p > 0.841$). Risk assessment credentials ($p > 0.835$) or whether a college educated ($p > 0.248$) did not significantly influence perceived efficacy beliefs. Threat appraisals did not have a significant effect on the dollar amounts reportedly spent on managing trees for storms

Table 3
Structural Equation Model Regression Results. All variables have been standardized.

Regressions	Estimate	Std. Error	Wald Z	Prob>|Z|
Threat appraisal →Collaboration required	0.372	0.1711	2.172	**0.0298***
Efficacy →Collaboration required	0.316	0.1418	2.232	**0.0256***
Experience →Collaboration required	−0.028	0.0441	−0.633	0.5270
Experience → Efficacy	0.003	0.0173	0.200	0.8418
Amount spent ($) on management. → Collaboration required	0.111	0.0452	2.460	**0.0139****
Cost perception → Collaboration required	−0.152	0.0924	−1.642	0.1006
Threat appraisal → Amount spent ($) on management	0.189	0.1381	1.366	0.1720
Threat appraisal → Cost perception	1.125	0.0532	21.135	**<0.0001*****
Risk assessment qualifications → Efficacy	0.004	0.0175	0.207	0.8358
College → Efficacy	−0.022	0.0194	−1.155	0.2481
Risk assessment qualifications →Collaboration required	0.032	0.0458	0.071	0.4789
College →Collaboration required	−0.027	0.0453	−0.607	0.5438
Amount spent ($) on management→ Efficacy	−0.037	0.0182	−2.031	**0.0422***
Cost perception → Efficacy	0.760	0.0343	22.161	**<0.0001*****

*Indicates significance at p < 0.05. **Indicates significance at p < 0.01 ***Indicates significance at p < 0.0001.

(p > 0.172).

4. Discussion

Using PMT, we assessed the perceptions of urban forestry professionals working in public and private sectors about storm related threats in the Southern and Eastern Regions of the United States, and the subsequent impact on collaborative actions to manage trees for storms. In alignment with PMT, ee found statistically significant relationships between threat appraisals, perceived costs, perceived efficacy beliefs, and perceptions about collaboration. When respondents indicated that their communities and urban forests were more vulnerable to storms (high threat appraisal), and they perceived that their ability to cope with a storm event was more effective (high self-efficacy), they were more likely to express a greater intention to collaborate with others outside of their organizations (protective behavior). When estimating the actual monetary costs of preparing and responding to storm events, higher costs led to greater intention to collaborate.

However, actual monetary costs are marginally negatively correlated to perceived efficacy while perceived costs are highly predictive of efficacy. In other words, perceived costs can be interpreted as having greater influence over efficacy. So, when respondents viewed preparation and response actions as "costly", perceived efficacy is decreased and respondents are more likely to believe that they will struggle in managing trees for storm events. Surprisingly, knowledge and experience are insignificant in our model in relation to any other variables. Among the public, receiving more information about a storm-related event did not result in more protective behavior, however, living an area more prone to storms did (Eusse et al., 2024) Overall, similar to other PMT research surrounding climate and storm-related actions, a geographic approach may lead to more nuanced understanding about the differences between sites where respondents viewed themselves as more vulnerable than others. Perceptions about vulnerability can be shaped by location, levels of public and political support for action, historic maintenance of tree canopy, or the formalization and integration of proactive and collaborative measures into management plans and processes.

4.1. Collaboration needs

Collaboration is often featured in a city's adaptive capacity to address increasing and severe storms and enhance urban forests' resilience to these disturbances. Collaboration in storm-related tree management varies based on season, weather, politics and local environmental contexts at different phases of the preparation, response, and recovery management cycle. Our study found that most respondents reported collaborating on three or more activities with others to address storms and urban trees.

Our research highlights that decision-making about protective actions involving tree risk mitigation, and communicating with the public about storms, necessitates a collective approach to risk management. Our research may inform the development of urban forestry governance by exploring the conditions that could lead to increased collaboration among urban forestry partners and support recovery from storm events. Governance guides how stakeholders interact, consequently shapes the decision-making process through institutions, rules, and structures (Konijnendijk et al., 2021). Governance can include diverse actors, and municipal managers play a large role across different organizations and departments (Konijnendijk et al., 2021). However, professionals can partner with local communities who participate in the governance process as knowledge partners, through advisory committees or boards, or through hands-on stewardship actions.

Of all the tree management activities listed in the survey, respondents needed the most collaborative support to communicate with residents. This finding is noteworthy because residents play a significant role in the structure, maintenance and stewardship of urban trees as homeowners, volunteer tree stewards or through advocacy for, or against certain urban forestry initiatives. Studies found that engaging with the public through a non-profit group or volunteers can support larger urban forestry goals. For example, a study of 1735 communities in the U.S. found that 65% of them worked with partners or volunteers to manage city trees for maintenance, education and training and inventorying (Hauer and Peterson, 2015). This pivotal role of residents is further complicated by the fact that residents often have contrasting perceptions of urban nature than professionals. It may be beneficial to further explore the role of the public as collaborators in managing urban trees for storm events. For instance, volunteer tree stewards may be an untapped resource for urban forestry professionals to educate the public about trees and storms, assist in regular tree maintenance that can improve community tree programs, communication and greater investment in urban forestry (Hauer and Peterson, 2015). Additionally, public engagement increases sense of community, strengthens resilience, and enhances collective capacity, including for natural disasters or emergencies (Speevak-Sladowski et al., 2013).

It may be valuable for stakeholders involved in storm preparation, response, and recovery to proactively expand the network of professionals that can contribute resources, such as public communication, during emergencies and non-emergencies. During emergencies, actors involved in Incident Command Systems (ICS), a standardized management system that enables the command, control, and coordination of emergency response efforts across multiple agencies working towards a common goal, may not have the capacity to incorporate new partners (Moynihan, 2007). Communication is critical for effective collaboration. A study of U.S. arborists found that almost half met with emergency managers about storm related tree concerns while almost one-third reported that emergency managers organized meetings about storm related maintenance of street trees (Koeser et al., 2016a). Proactive actions such as strategic meetings to plan activities and reduce tree-related risk can reduce the impact of storm events (Koeser et al., 2016b). Given that multiple organizations and agencies are involved in risk reduction, viewpoint diversity is expected at the discussion table. Additionally, many respondents required collaboration in tree risk assessments, in alignment with findings from other studies. For example, previous research found that many non-profit and volunteer organizations in Philadelphia and Jacksonville did not require specific credentials to conduct tree risk assessments (Cadaval et al., 2024a). Collaboration allows organizations to borrow expertise from partners where they lack resources like funding or staff to engage in proactive tree-related maintenance.

4.2. Perceived costs, efficacy and vulnerability

Storm-related costs in urban forest management are primarily related to tree services or disservices (Roman et al., 2021) which vary based on past and intended management choices. In alignment with PMT, we found that perceived costs are highly predictive of efficacy beliefs. Tree management costs can be defined as all expenses deducted from urban forestry stakeholders' budgets which can be used to plant, maintain, or remove trees (Roman et al., 2021). Lack of funding is a barrier to accomplishing urban forestry program goals (Cadaval et al., 2024a)as storm-related tree maintenance like pruning and removal carries a financial cost but can reduce storm event costs (Vogt et al., 2015). By anticipating and removing hazardous trees or plant material, professionals can reduce the amount of tree debris and consequent storm damage.

Our study assessed response costs, a component of PMT, by measuring both perceived and actual monetary costs of urban forest management related to storms. Our results suggest a disconnect between perceived costs and actual monetary costs, where perceived costs may be more important in shaping perceptions about efficacy and collaboration needs. Several factors may contribute to this disconnection. For instance, perceived costs can be influenced by uncertainty about storm impacts, past experiences with storms, and how much respondents rely on subjective estimates when they lack exact financial data. The focus on perceptions over actual monetary costs may be reflective of indirect or non-financial costs like limited staff capacity or organizational limitations that are not "counted" in reported monetary costs. Additionally, perceived and actual monetary costs are negatively correlated as higher perceived costs result in greater expressed need for collaboration. This is logical, considering that organizations expecting greater expenses from storms are likely to expect the storm's impacts to be complex and with more resource intensive management. As a protective behavior response, collaboration can mitigate higher costs associated with storms by allowing interested parties to share resources. Interestingly, our study found that reports of actual costs were negatively related to perceived efficacy beliefs, but only marginally. This finding is particularly interesting because a literature review describes privatization of tree care as an option for reducing municipal pruning costs and management efficiency were reported in some local newspapers (Vogt et al., 2015).

Perceived costs may include concerns about financial and social costs as decisions about urban trees have direct impacts on human society. At the city level, for example, costs may include falling trees or limbs, and damage to urban infrastructure like sidewalks, buildings, powerlines, or traffic. However, costs can more broadly reflect safety and access to storm impacted sites for workers and residents alike. At the residential scale, perceived storm threats can impact decision-making about tree removal (Conway and Yip, 2016). Tree removals prompted by fear, especially trees with actual low risk, can undermine urban forestry goals (Koeser et al., 2016a).

In some cities, there may be distrust between historically underserved neighborhoods and urban forestry professionals, prompting additional communication challenges when storms negatively impact trees (Cadaval et al., 2024a; Grant et al., 2024). Consequently, urban tree canopy can be disproportionately distributed with fewer trees on public right-of-way or neighborhoods with more African Americans, renters, and low-income residents (Landry and Chakraborty, 2009). Where urban tree distribution is uneven, storm-affected trees may be unevenly distributed. This is an especially important consideration as large-scale urban tree planting initiatives and budget allocations become commonplace (Eisenman et al., 2025). Previous research suggests that the public may report trees needing attention before or after storms thus shaping how trees are managed around these events (Cadaval et al., 2024a), thereby impacting the actual monetary costs for tree management. In this way, communication between the public and professionals is another form of storm-related collaboration that can be cultivated to guide management strategies (Cadaval et al., 2024b).

In our research, positive perceptions about efficacy were associated with a greater perceived need for collaboration between actors involved in storm-related tree management – in alignment with PMT. Higher efficacy beliefs should promote intentions to take protective action, for example, the adoption of pro-environmental behaviors (Bockarjova and Steg, 2014). In other words, collaboration can be seen as a coping mechanism where professionals are able to visualize and believe that collaborations can be effective for managing trees and storms (Deng et al., 2010). Our research highlights an opportunity to leverage perceived efficacy and collaborative actions like communicating with the public about trees and storms.

4.3. Perceptions of risk and vulnerability

Perceptions about urban tree risk matter because management choices are based on qualitative and quantitative tree risk assessments, which are oftentimes unknown until after the weather event occurred (Vogt et al., 2015). Tree risk is associated with perceived ecosystem disservices from trees including tree limbs, branches, or tree failure (Smiley et al., 2017). Several factors may increase tree risk, including biological factors (i.e., unhealthy, damaged, and decayed wood), biomechanical factors (i.e., strong winds, heavy snow or water on branches), and human factors (e.g., infrastructure interfering with roots; tree species selection; planting design) (Eisenman et al., 2025; Smiley et al., 2017). For example, among Canadian homeowners, trees were removed based on tree health concerns and belief that trees placed near homes increased property damage risk (Conway and Yip, 2016). Importantly, the varied concerns of residents can reduce new tree-planting efforts and tree canopy expansion (Riedman et al., 2022).

In accordance with PMT, we found that if urban forestry professionals perceived high threats, they were more likely to report a greater need for collaboration with other professionals to manage trees for storm events. This suggests that interdependence and coordinated, collective responses are seen as a way of effectively dealing with perceptions of threat. For example, when dealing with widespread threats to urban forests like emerald ash borer (EAB; *Agrilus planipennis*) infestations, collaboration amongst professionals has been central to successful management efforts (Alexander et al., 2020). In Colorado, EAB management was successful because of the advanced identification of the agency roles, responsibilities, and limitations taking place prior to pest detection. Proactive planning and anticipatory collaboration allowed management teams to rapidly mobilize EAB threat response and public education (Alexander et al., 2020).

4.4. Knowledge and experience were less relevant to perceived collaboration needs

This research showed that knowledge and experience are largely unimportant factors in the perceived risks associated with urban trees and how it drives professionals to collaborate to manage trees for storms. Knowledge and experience are often acknowledged as important foundations that influence perceived self-efficacy beliefs in PMT. However, given that respondents identified collaboration as essential for public communication, there may be an opportunity for continuing education and professional development programs to focus on public communication and engagement to enhance knowledge. Public engagement has, for example, occupied a central place in urban planning theory and practice for decades (Eisenman et al., 2025), and municipal planning offices are well situated to facilitate community outreach and intra-departmental collaboration. Non-formal educators like university Extension agents and specialists can expand the capacity and reach of urban forestry professionals seeking to improve public engagement in urban forests. Learning from and collaborating with other types of communicators can facilitate the development of communication toolkits and strategies to support the needs of urban forestry professionals (Bonanno et al., 2021).

Communication with the public can be part of the collaboration process especially if it supports the development of public engagement in current and future urban forestry activities (Konijnendijk et al., 2021). Building platforms for real-time reporting of removal or maintenance needs through public input is one of the ways municipalities can create opportunities for public collaboration on managing trees for storms. Our research shows that impactful events or disturbances like storms can shape how interactions between governance actors take place.

4.5. Limitations and future research

This research explored the aggregated perceptions of urban forestry professionals about storms and collaborations by applying PMT. A limitation of PMT in its application to environmental threats (like storms) is its focus on individual behavior. Disaster response includes individual actions, but responses to disasters also reflect the limitations and collective capacities of public and private institutions (Babcicky and Seebauer, 2020). Additionally, PMT is limited in its ability to predict perceived vulnerability of heterogenous groups. For example, Harlan et al. (2019) applied PMT and social vulnerability theory to study flooding in US cities to understand how risk perceptions are influenced by lived experiences and differing perceptions based on age, gender, racial/ethnic identities and income levels. PMT lacks measures to understand variation within populations and does not include measures for social contexts. Finally, PMT does not consider the possibility that individuals can be biased (Floyd et al., 2000). The influence of subjective decision making is particularly relevant in threat appraisal (perceived severity and vulnerability) and relates to the above-mentioned limitation about diverse experiences. Subjectivity is important to consider because it can be difficult for individuals to estimate the probability of an unknown outcome such as the probability of tree failure resulting from a storm (Floyd et al., 2000).

This research did not incorporate time or geographic variations. Time and contextual factors about urgency may shape how urban forestry professionals perceive collaborative processes. For example, when storm responses are transferred from a localized response team to one requiring control from an ICS, collaborative processes may become less participatory and more procedural with predetermined objectives and resources that guide actions (EMI and ICS Resource Center, 2018). Previous research shows that public requests to prune or remove trees increase before or after storm events (Conway and Yip, 2016), these requests may add urban forest professionals' workload.

Furthermore, there is a need to further assess the communication and collaboration needs between urban forestry professionals. Outside of these emergency timeframes, collaboration varies depending on the phase of preparedness, response, or recovery. Additionally, information about locations of professionals and their collaboration needs could be used to identify and inform the development of communities of practice built around storm preparedness, response, and recovery. Future research is needed to better understand how to strengthen collaborative networks. Urban forestry professionals involved in managing trees for storms described collaboration as building relationships with other professionals and with the public, sharing goals, and sharing resources (Cadaval et al., 2024a). Although some professional associations and organizations offer educational opportunities that build learning around a collaborative exchange of ideas and experiences, research is needed to understand the role these professional societies play in connecting and building partnerships in urban forestry management.

5. Conclusions

Although collaborative processes can contribute to the development and maintenance of social networks among professionals and the public, certain conditions like perceived higher costs of storm related tree management, higher perceptions about efficacy, and views that threats from storms are frequent or severe can lead to views that more collaboration amongst urban forestry professionals is needed. Other aspects like tree knowledge and experience have little impact on professionals' perceived need to collaborate. Urban forestry professionals are important to a city's resilience to storm events and the impacts of future climatic changes and additional research about this population, their attitudes, and experiences would help support the advancement of urban forestry professions and the wellbeing of the communities they serve. Additionally, our research contributes to the development of a greater understanding of how factors like evaluations of risk and efficacy contribute to storm preparedness and response. It would be beneficial to conduct further research on this topic and assess the contexts that make collaboration necessary or appropriate versus not.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the author(s) used Grammarly in order to check and correct grammar. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

CRediT authorship contribution statement

Stephanie Cadaval: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Mysha Clarke:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing. **Lara A. Roman:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Writing – review & editing. **Tenley M. Conway:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Writing – review & editing. **Andrew K. Koeser:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Writing – review & editing. **Theodore S. Eisenman:** Conceptualization, Funding acquisition, Project administration, Resources, Writing – review & editing. **James Colee:** Formal analysis, Writing – review & editing.

Declaration of competing interest

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Data availability

The data that has been used is confidential.

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