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Risk Assessment and Risk Perception of Trees: A Review of Literature Relating to Arboriculture and Urban Forestry

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Abstract. In the presence of a target, tree failures have the potential to damage property, disrupt services, or threaten public safety. Worldwide, several qualitative methods have been developed to provide a systematic approach for tree risk assessment and management. The consistency and accuracy of these methods, the values placed on the tree in question and its potential targets, and the risk perceptions and levels of acceptance of the evaluator and tree owner all influence how risk is managed. This review explores the concept of risk, examines and contrasts the most commonly referenced tree risk assessment methods, and summarizes research on public perceptions of trees and the risk of trees and greenspaces in built environments. The review identifies general summarized themes and gaps in the available literature to guide future research.

Key Words. Decision Making; Hazard Tree; Mitigation; Public Safety; Qualitative and Quantitative Risk Assessment Methods; Risk; Tree Risk Assessment; Tree Risk Perception; Urban Forest.

Trees provide a wide variety of benefits, as well as potential risks (Miller et al. 2015). While a significant body of research exists for the former consideration (Dwyer et al. 1992; Clark et al. 1997; Lohr et al. 2004; McPherson et al. 2005; Tyrväinen et al. 2005; Nowak and Dwyer 2007; Roy et al. 2012), less is known about the costs and risks posed by trees (Hauer et al. 2015; Vogt et al. 2015). What is now known is that it is not uncommon for a city to face litigation for tree-related injuries or property damage. In a survey of urban forestry programs in the United States, Koeser et al. (2016) found that 52% of responding communities acknowledged that past claims had been filed against them. This litigation appears to be a significant motivator for risk management. Communities involved in a past tree-related claim were twice as likely to have active risk assessment and management programs (Koeser et al. 2016).

The history of tree risk assessment as documented in the literature is relatively recent. Most sources cite the publication by Wagener (1963) for recreational sites in California, U.S. as being the first to explore the idea of trees being hazards to both people and property (Kane et al. 2001; Pokorny 2003; Norris 2007). Paine (1971) provided further guidance to assess hazardous trees in recreational areas (Pokorny 2003; Ellison 2005a; Norris 2007). Hazard tree assessment guides remained focused on recreation areas during the 1970s and for much of the 1980s (Johnson and James 1978; Johnson 1981; Mills and Russell 1981). While the terms "hazard" and "hazardous tree" were common vernacular during that period, the term "tree risk assessment" is used more commonly today (Pokorny 2003).

Interest surrounding tree risk has continued to grow in recent years. Several international research summits have focused on tree risk assessment as a whole, as well as the costs associated with not maintaining trees, and the biomechanics of trees as these relate to tree failure potential (Koeser 2009; NTSG 2011; Dahle et al. 2014; Koeser et al. 2016). The latter area of research has arguably been the most active, with knowledge gained from biomechanics research often being used to develop guidelines, techniques, and technologies for gauging tree failure potential. Biomechanics researchers have developed or assessed devices and procedures for testing the presence of decay (Rinn et al. 1996; Costello and Quarles 1999; Gilbert and Smiley 2004; Johnstone et al. 2007; Wang and Allison 2008; Johnstone et al. 2010a; Johnstone et al. 2010b; Arciniegas et al. 2014), designed protocols for measuring the strength of different branch attachments or tree leans (Lilly and Sydnor 1995; Kane and Clouston 2008), modeled wind load dynamics (James et al. 2006; James and Kane 2008), and conducted comparative assessments of the mechanical stability of root systems (Smiley 2008; Bartens et al. 2010; Gilman and Masters 2010; Ow et al. 2010; Gilman and Grabosky 2011; Gilman and Wiese 2012; Gilman et al. 2013). Given this level of research activity, several researchers have conducted literature reviews specifically about tree biomechanics (Dahle et al. 2017; James et al. 2014). In contrast, the aim of this literature review is to move beyond factors that influence likelihood of failure. While tree-related factors are important, research indicates that the arborist assessing a tree can have more influence over the final risk determination than the actual tree assessed (Norris 2007; Koeser and Smiley 2017).

Until recently, little attention has been given to the role that professional and public perception plays in influencing tree risk assessment and management in landscape settings (Norris 2007; Koeser et al. 2015; Klein et al. 2016; Koeser and Smiley 2017). Attempts to independently assess the effectiveness of tree risk assessment methods are also limited (Matheny and Clark 1994; Mattheck and Breloer 1994; Hickman et al. 1995; Pokorny 2003; Matheny and Clark 2009; Smiley et al. 2011; Dunster et al. 2013). Research has shown that there is significant variability in the final determinations made by risk assessors (Ball and Watt 2013a) and by arborists using common tree risk assessment methods (Norris 2007; Stewart et al. 2013; Koeser and Smiley 2017). This indicates that there are inconsistencies in risk assessment that have yet to be addressed through existing best management practices and training programs. Personal biases likely account for some of the variability seen (Norris 2007), but more research is needed to determine if there are interactions between the method of assessment and the risk perceived by those conducting the assessment. This review covers the current state of research and knowledge on tree risk assessment methods and risk perception as it relates to arboriculture and urban forestry. The summarization and synthesis that follows depicts what is currently known, given the limited research at hand, and offers suggestions for future research intended to improve the effectiveness of tree risk assessment methods.

LITERATURE REVIEW METHODS

Several review strategies were used in combination to identify and assess relevant publications in this literature review. First, the authors reviewed the scholarly journals *Arboricultural Journal*, *Arboriculture & Urban Forestry* (formerly *Journal of Arboriculture*), and *Urban Forestry & Urban Greening* in their entirety (from the initial volumes until the drafting of this manuscript in 2017) for articles related to tree risk and the perceived risk associated with trees and greenspaces. A past citation list compiled by Matheny and Clark (2009) was cross-referenced to identify omitted, yet relevant publications.

Additionally, researchers performed keyword searches in several electronic databases, including Google Scholar, JSTOR, Web of Science, Science Direct, and the University of Florida George A. Smathers Library collections database. The following English language terms were used to conduct the search: urban forest risk assessment; tree risk assessment; tree failure; risk perception; perception of trees; perception of natural spaces; and environmental psychology. Articles in the search were not limited to any particular time frame. Articles were first assessed by their title, filtering nonrelevant papers. After this initial screening of approximately 1,000 articles, researchers read the abstract of each article, and again eliminated those articles outside the scope of the review, leaving 150 relevant articles. The remaining articles were read and qualitatively analyzed for inclusion in the literature review.

RESULTS & DISCUSSION

Definitions of Risk, Risk Assessment, and Risk Perception

Ball (2007) defined risk as the probability of some specified adverse event occurring *within a specified time interval*. In their tree risk assessment guidebook, Dunster et al. (2013) defined risk as the likelihood of an event occurring and the severity of its potential consequences. Thus, risk has three elements: 1) an adverse event or consequence, 2) some probability or likelihood that the adverse event could occur, and 3) a specified period.

Risk assessment is a formalized method of identifying, analyzing, and evaluating risk (Dunster et al. 2013). In assessing trees, all commonly used risk assessment methods consider: 1) the likelihood that all or part of the tree will fail (i.e., failure potential); 2) the likelihood of the target being present/struck (i.e., target occupancy/likelihood of impact); and 3) the consequences of failure (i.e., personal injury, damage to property, or disruption of services/activities) (Matheny and Clark 1994; Mattheck and Breloer 1994; Pokorny 2003; Ellison 2005a; Smiley et al. 2011; Dunster et al. 2013). Going back to the definition offered by Dunster et al. (2013) above, the first two considerations (i.e., likelihood of impact and likelihood of failure) directly relate to the likelihood that an adverse event will occur.

While it is possible to quantitatively measure some factors that directly influence tree risk during a risk assessment (i.e., target occupancy of the site or the size of the tree/tree part of concern), in practice the inputs of a tree risk assessment are typically left to the judgment of the assessor (Pokorny 2003; Ellison 2005a). As such, management decisions are influenced by the actual, assessed, and perceived risk surrounding trees. Recommendations based on the findings of the assessment are then passed on to the person or people who ultimately make the final decisions—typically a homeowner, property manager, or urban forester (Dunster et al. 2013). As such, both the assessor's and the decision maker's perceptions and tolerances of risk affect what, if any, mitigation efforts are taken to reduce potential harm to people and damage to property (Pokorny 2003).

An arborist's assessment of risk is influenced by both the reality of the situation and his or her perception of the threat posed. Risk perception is influenced by personal experiences (Spangler 1984; Gavin 2001; Botterill and Mazur 2004) and one's personal fears (Slovic 1999; Botterill and Mazur 2004). Additionally, individuals sharing social networks within a community tend to have similar perceptions of risk (Scherer and Cho 2003). For example, the authors have noticed arborists from different nations, whom are trained to use different risk assessment methods, appear to have differing underlying perceptions of tree risk.

Depending on an individual's background, their perception of risk may or may not correspond with the reality of the situation (Renn 2004). Predicting the failure of a living structure with heterogeneous material properties is in itself an imprecise undertaking. The addition of personal biases can contribute additional variability to risk ratings (or artificial precision among assessors, if a strong bias is shared by a group).

Risk reality, the arborist's assessment of that risk, and the property manager's or homeowner's perception of risk are interconnected and each influence which risk management strategy is adopted. In a study on tree risk management and arboriculture in Australia, Davison and Kirkpatrick (2014) interviewed several arborists who expressed their frustration in dealing with clients that seemed to possess an illogical fear of trees. The authors noted that disconnects in real and perceived risk could negatively affect management efforts to maximize the benefits trees provide, or to limit the effectiveness of efforts to minimize the related risks. In the most extreme cases, disconnects between risk reality and risk perception can lead to unnecessary tree removal or ill-advised tree retention (Smiley et al. 2011).

Identifying and documenting the underlying beliefs or biases that influence perceived risk may ultimately make risk assessments and management strategies less variable—potentially limiting cases where practitioners suggest mitigation options that appear at odds with one another (Stewart et al. 2013). While all commonly used risk assessment methods consider the same three standard inputs (i.e., likelihood of failure, likelihood of impact, and consequences of failure), imprecise definitions and vague decision criteria give users the flexibility to draw on their knowledge and expertise. Research is needed to identify whether this (often intentional) imprecision reflects the current uncertainty surrounding tree risk assessment or if it simply adds an unnecessary layer of variability to assessments (Koeser and Smiley 2017). For example, the ISA BMP method does not clearly define how many hours a day constitute a given level of occupancy, or what large, medium, or small mean when describing a tree part. This lack of a common starting point may explain why, when assessments for nearly 300 arborists using the ISA BMP were analyzed, likelihood of impact and consequences of failure were the two most significant sources of variation (Koeser and Smiley 2017).

SCIENTIFIC BASIS FOR THE COMPONENTS OF TREE FAILURE

Likelihood of Impact and Target Occupancy

The presence or absence of one or more targets is considered by some to be the most important factor in a risk assessment (Ellison 2005a). When no target is present, there is no risk (Ellison 2005a; Smiley et al. 2011; Dunster et al. 2013). When evaluating tree risk, it is important to assess each potential target's level of occupancy, as well as the factors that might affect occupancy (Hayes 2002; Ellison 2005a; Sreetheran et al. 2011). For instance, the presence of pedestrian targets in a park varies greatly depending on the time of day. Similarly, a park bench may attract people to a site and prolong their occupation of an area. When assessing occupancy, it is also important to consider that many outdoor recreational sites may have reduced occupancy levels during storms—the very kinds of conditions that increase a tree's likelihood of failure (Ellison 2015).

The occupancy of a site can be qualified using a standard rating system. Alternatively, it can be quantified directly using traffic counters or indirectly by accessing existing traffic count data. In laying out the framework for his tree risk assessment method, Ellison (2005a) evaluated the occupancy of vehicular targets on different road classes using Great Britain's 1996 transportation statistics. This method multiplies each traffic count by the time needed for a vehicle to pass by, or come to a complete stop in front of, a given point within the target zone of an assessed tree. For pedestrian count data, Ellison (2005a) suggested multiplying each count by five seconds to gauge occupancy at a given point in a tree's target zone.

In addition to the use of existing traffic data, Ellison (2005a) noted that target occupancy can be easily quantified with the use of pedestrian and vehicle traffic counters. Traffic counters allow the assessor to quantify occupancy rates over time, potentially allowing for greater accuracy than visual occupancy assessments that are based solely on a short visit to the site (i.e., the time it takes to perform a visual assessment) and professional judgment. In assessing two trees in the United Kingdom, Papastavrou et al. (2010) found estimates of traffic occupancy derived from five-minute surveys were up to three orders of magnitude different than those derived from the professional judgment of a trained tree assessor. Despite the potential benefits of traffic counters and the availability of pre-existing count data in many municipalities, arborists in North America rely on a quick visual assessment of site occupancy when assessing tree risk. These subjective assessments can lead to less accurate, biased (given the time of day), and more variable estimates of target occupation (Klein et al. 2016). As an example, Klein et al. (2016), found that about 6 in 10 arborists increased their ratings of target occupancy one level when viewing videos of sites filmed during rush hour (as compared to their ratings of the same site filmed during non-peak travel times).

Failure Potential

Tree failure is defined as the breaking of any root, branch, or stem, or the loss of mechanical support in the roots (Dunster et al. 2013). All trees have some level of failure potential (Brakken 1995; Hayes 2002; Pokorny 2003; James et al. 2006); however, this varies by species and the presence or absence of various growth and structural characteristics (Hauer et al. 1993; Meilleur 2006; Kane 2008; Jim and Zhang 2013). Factors that influence failure potential include tree health (Hickman et al. 1995), species (Hauer et al. 1993), growth habit (Hayes 2002), branch attachments (Lily and Syndor 1995; Gilman 2003; Meilleur 2006; Kane et al. 2008; Miesbauer et al. 2014), condition of roots (Brakken 1995; Smiley et al. 2000; Gilman and Masters 2010), presence of decay (Smiley and Fraedrich 1992; Kane et al. 2001; Lonsdale 2007; Smiley 2008), maintenance history (Zhang et al. 2007), adverse weather conditions (Duryea et al. 1996; Duryea and Kampf 2007; Hauer et al. 2011), and changes to a site (Jim and Zhang 2013). The two most common types of tree failures are tipping (i.e., whole-tree failures caused by decayed or severed roots, or defects at the root–soil interface) and fractures (i.e., decay and hollows that cause breaking of branches and stems) (Mattheck and Breloer 1999; van Wassenaer and Richardson 2009).

Terho and Hallaksela (2005) assessed the potentially "hazardous" characteristics of *Tilia* spp., *Betula* spp., and *Acer* spp. in downtown Helsinki City, Finland, and found that 50% to 70% of potential failure points in park trees that had been removed were isolated to the lower portion of the tree (e.g., roots, root flare, trunk). Similarly, Terho (2009) examined three species of felled trees from Helsinki, Finland, and found that roughly 65% of the trees had decay in the roots and trunk. In looking at volunteer tree failure data, Edberg and Berry (1999) found that decay of roots or the lower trunk was a contributing factor in 83% of coast live oak (*Quercus agrifolia*) failures. In contrast, Edberg et al. (1994) found the majority of recorded Monterey pine (*Pinus radiata*) failures were limb failures.

It is difficult to accurately predict tree failure, but controlled and observational studies have been conducted to help provide guidance on the tree and environmental factors that lead to overturning or stem breakage (Edberg et al. 1994; Wessolly 1995; Edberg and Berry 1999; Kane 2008; Kane and Clouston 2008). The available body of related scientific research can be used to compliment the past observations and experiences of arborists and urban foresters in identifying the factors that elevate a tree to a higher potential for failure (Kane et al. 2001).

Johnson (1999) found 84% of trees that failed during summer storms in Minnesota, U.S., had pre-existing defects. Most of the defects contributing to tree or branch failure could likely be identified and mitigated with appropriate tree planting and maintenance practices (Johnson 1999). Likewise, following both Hurricane Andrew in 1992 and the 2004–2005 hurricane seasons in Florida, U.S., trees that had been properly pruned (i.e., open and evenly dispersed crowns that had not been topped) withstood the hurricanes better than trees that had been improperly pruned or not pruned at all (Duryea et al. 1996; Duryea and Kampf 2007). In contrast, trees with poor structural forms and/or defects, such as codominant stems, were more susceptible to hurricane forces.

In a more deliberate study, Hickman et al. (1995) evaluated 695 native oak (*Quercus* spp.) trees in a California, U.S., recreational area that had previously been assessed for failure potential. They found that, of the original 695 trees, 60 (8.6%) had failed within seven years of the original study. Of the tree defects and site parameters assessed (decline, soil, wind, butt, trunk, root, limb, irrigation frequency, lean), decline, trunk condition, and lean were identified as being the key factors in predicting whole-tree failure. More recently, Koeser and Smiley (unpublished data) reevaluated trees risk as assessed using the ISA BMP method prior to Hurricane Matthew. Of the 20 trees assessed as having an imminent likelihood of failure, 19 (95%) failed during the storm. In contrast, 38% of the trees assessed as having a probable likelihood of failure, failed. Trees rated as having possible or improbable likelihoods of failure had similar failure rates at 15% and <1%, respectively (Koeser and Smiley, unpublished data).

Consequences of Failure

Consequences of failure can be minimal, such as damages that results in minor repairs (e.g., fixing a small fence or disruption to landscape lighting) or they can be much more severe with regards to public safety (e.g., injuries that lead to hospitalization/death; Smiley et al. 2011). Schmidlin (2009) compiled wind-related tree failures in the United States that resulted in the loss of human life. There were 407 deaths from 1995 to 2007 at an average of 31 deaths per year (1 in 9.7 million). Ellison (2007) cited a study (Anonymous 2006) that estimated the likelihood of being killed by a tree in the United Kingdom was 1 in 5 million. Similarly, Fay (2007) pointed out that the Health and Safety Executive Sector Information Minute equates the likelihood of being killed by a tree in a public space to be 1 in 20 million. This was slightly lower than the 1 in 18.7 million likelihood of being struck by lightning (Health and Safety Executive 2007). Regardless of the estimate, Ball and Watt (2013b) noted that in the UK, deaths and serious injuries resulting from tree failures are extremely rare, and that it is unlikely that the number of these incidents could be reduced without instituting strict measures that might pose adverse effects to both the labor force and the environment.

Visual Tree Risk Assessment

While advanced risk assessment methodologies and technologies exist, the majority of risk assessments are conducted visually. Intuitively, visual assessments may not catch defects that cannot be seen externally on the tree, such as internal or incipient decay (Dolwin et al. 1999; Guglielmo et al. 2007; Smiley et al. 2011). However, research contrasting visual assessments to resistance microdrilling has shown that external signs and indicators of decay can be quite reliable for some species, especially when internal decay is significant (Koeser et al. 2015). Similarly, Terho's (2009) post mortem assessment of decay in urban trees found that fruiting bodies were a common external sign of the presence of internal decay among *Tilia* spp., as well as a good indication that the tree had reached its threshold for strength loss. In addition to fruiting bodies, Kennard et al. (1996) noted that the presence of wounds, cankers, and cracks could be telling signs of decay in a tree. Jim and Zhang (2013) performed basic visual assessments on 352 heritage trees in Hong Kong—based on characteristics such as tree habits, defects, and disorders—and they were able to identify which species were less likely to fall and which species posed the greatest hazards to the public. More broadly, Hickman et al. (1995) conducted visual tree assessments for a range of external defects on 695 oak (*Quercus* spp.) trees in 1987. Upon returning to the site in 1994, the researchers found that the defects noted in the prior evaluation, particularly tree lean, trunk condition, and decline symptoms, could be used to accurately predict the trees that remained standing 83% of the time and the trees that failed 78% of the time (Hickman et al. 1995).

And while some see the often subjective nature of visual assessments as a potential limitation, others have argued that visual assessment can be effective when the user has an understanding of the factors that can cause a tree to fail (Gruber 2008). To date, only a few studies have tested for variation among assessors and assessment approaches (Hickman et al. 1995; Rooney et al. 2005; Koeser et al. 2015; Koeser et al. 2017; Koeser and Smiley 2017). Rooney et al. (2005) demonstrated that even drive-by visual assessments can be effective in detecting severe defects and decline—especially in less treed, urban areas. Koeser et al. (2017) found that the likelihood of failure ratings derived from visual assessments could be less variable than assessments informed by advanced assessment technologies, like resistance microdrilling and sonic tomography. Koeser and Smiley (2017) found that arborists with industry qualifications and certifications tended to have lower risk ratings and prescribe less severe mitigation measures than their non-credentialed peers.

Researchers have criticized the validity of basic visual assessments when attempting to predict tree failure in the extreme winds associated with hurricanes and strong storms (Gruber 2008), or even in the absence of such events (Stewart et al. 2013). In response to the former criticism, Fink (2009) explained that there are no assessment methods that can predict the storm threshold of a sound tree (i.e., one does not know how strong is strong enough in extreme conditions). However, basic visual assessments have been accepted as being an efficient and dependable means of identifying compromised trees, as compared to other trees (Kennard et al. 1996; Pokorny 2003; Rooney et al. 2005; Fink 2009; Dunster et al. 2013). As noted earlier, recent findings from Hurricane Matthew offer some insight into the validity of pre-storm risk assessment (Koeser and Smiley, unpublished data).

TREE RISK ASSESSMENT METHODS IN THE URBAN FOREST

Over the years, several different risk assessment methods have been used by arborists and urban foresters. In addition to changes in systems over time, different regions of the world often adopt different risk assessment methods. Examples of the more commonly used methods are: ISA Tree Hazard Evaluation (Matheny and Clark 1994), Visual Tree Assessment (VTA) (Mattheck and Breloer 1994), United States Department of Agriculture Forest Services Community Tree Risk Evaluation Method (Pokorny 2003), Quantified Tree Risk Assessment (QTRA) (Ellison 2005a), and ISA BMP Method (Smiley et al. 2011). While the above is not a comprehensive list of risk assessment methods, the summary represents some of the more commonly used approaches for assessing risk (Koeser et al. 2016).

In 1991, Matheny and Clark released *A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas*. Later revised in 1994, this publication outlined a systematic method for tree risk assessment and is often cited as the first comprehensive guide for tree risk assessment (Kane et al. 2001; Hayes 2002; Pokorny 2003; Ellison 2005b; Norris 2007; van Wassenaer and Richardson 2009). Matheny and Clark's system focused on three key components to determine the hazard level of a tree: failure potential, the size of the part likely to fail, and the target rating (Ellison 2005a). Each component was given a numerical rating from one to four. The sum of these three served as an overall hazard rating intended to help urban forest managers prioritize their management efforts. Around this time, the VTA system was developed to evaluate tree structure in the presence of stressors (Mattheck and Breloer 1994). Users of the VTA system first look for noticeable defects while examining the overall vitality of the tree. After this initial survey, a more thorough examination of the defects is conducted. Defects are measured and analyzed to assess the general strength of the tree. Later on in 2003, the United States Department of Agriculture Forest Service published a risk management guide featuring the Community Tree Risk Evaluation

Method for use in walk-by inspection and drive-by inspections (Pokorny 2003).

The ISA BMP method is the most recent method commonly used in North America (Smiley et al. 2011). The method first focuses on two main components: the likelihood of failure (ranging from improbable, possible, probable, to imminent) and the likelihood of impacting a target (ranging from very low, low, medium, to high). These are assessed individually and combined in a risk matrix to determine the likelihood that a tree will fail and impact a target (ranging from unlikely, somewhat likely, likely, to very likely). This value is then combined in a second matrix with the user's assessment of consequences of failure (ranging from negligible, minor, significant, to severe) to determine an overall risk rating.

The use of risk matrices is not without its criticisms. Cox et al. (2005) notes that matrix-based systems can assign higher risk ratings to situations that realistically present a low level of risk (reversed rankings) and can label situations where there is a low level of quantitative risk with extreme qualitative descriptors, such as high (uninformative ratings). Additionally, it is a frequent occurrence that these same ratings are also assigned to various situations where the actual present risk can vary many magnitudes from another risk that is assigned a similar rating (range compression). Despite these potential pitfalls, risk matrices do have their place in risk assessment and management (Cox et al. 2005). With regard to design, the ISA BMP method meets the authors' three core axioms of: 1) weak consistency (i.e., not going directly from low to high risk without an intermediary), 2) "betweenness" (i.e., not being overly sensitive), and 3) consistent coloring of categories (Cox et al. 2005). Moreover, Cox was asked to review the ISA BMP Method given his critique of matrix based systems (Lilly, personal communication). In reviewing the system, he expressed that the ISA BMP Method appeared to be an appropriate application of matrix-based risk assessment (Lilly, personal communication).

Regardless of whether numbers or terms are used to categorize risk inputs in the systems noted above, they all represent qualitative assessment methods. In 1990, Helliwell proposed the need for a quantified risk assessment of trees, an idea that was later expanded by Ellison in managing risk from amenity trees (Helliwell 1990; Ellison 2005a). The QTRA system was created to achieve this goal and it remains commonly used by practitioners in the United Kingdom, Australia, New Zealand, and elsewhere. QTRA users assign individual probabilities to occupancy, likelihood of failure, and consequence of failure to calculate the risk of harm (RoH) associated with a tree. This RoH value is then compared to a modified tolerability of risk framework to gauge whether the assessed risk is as low as reasonably practical (ALARP, HSE 2001). In this system, a RoH of 1/10,000 is considered tolerable when imposed on others. Although this method is labeled as quantitative, it is worth pointing out that currently there are no true quantitative approaches. All risk assessments require personal judgment to some extent, especially with regard to likelihood of failure.

Despite some notable differences, all common assessment methods include: an assessment of the tree structure, identification of defects and subsequent evaluation of tree failure probability, an assessment of targets, and an appraisal of the potential damage caused by target impact (Matheny and Clark 1994; Mattheck and Breloer 1994; Ellison 2005a; Meilleur 2006; Matheny and Clark 2009; van Wassenaer and Richardson 2009). Beyond these similarities, methods vary in how they weight each underlying risk factor; how different defects are rated; and how the various components are combined into a final, comprehensive risk determination (Norris 2007; Matheny and Clark 2009).

Rating systems for each of the risk assessment methods assign different numbers or categories in working toward a final, overall risk evaluation. For example, the International Society of Arboriculture Tree Hazard Evaluation (Matheny and Clark 1991) uses a 12-point rating system with four points associated with each of the three main inputs (i.e., failure potential, size of part, target rating). In contrast, the United States Department of Agriculture Forest Services Community Tree Risk Evaluation Method (Pokorny 2003) is based on a 10 to 12 point rating system. The size of the defective part and the probability of target impact are both 1 to 3 points, the probability of failure is 1 to 4 points, and other risk factors total 0 to 2 points. In an earlier assessment of risk assessment methods, Matheny and Clark (2009) noted that there were no peer-reviewed studies that test and evaluate different risk assessment methods. They also noted that there was uncertainty among professionals about the importance and accuracy of assessment methods. In his thesis work, Norris (2007) compared a number of risk assessment methods in a series of controlled experiments. In one experiment, Norris had twelve experienced arborists assess two different sets of trees with a multitude of targets, failures, and consequences. Each arborist used eight assessment methods. In looking at the ratings, Norris (2007) concluded that risk assessment methods can yield a wide range of output values when used on the same tree in the same situation; and that the validity, completeness, robustness, repeatability, base assumptions, and underlying modeling of any risk assessment method must be evaluated if it is to be widely adopted. Norris also noted that the evaluations of arborists varied greatly. This was attributed to differences in each arborist's individual attitude toward risk (Norris 2007). To this point, Koeser and Smiley (2017) noted a correlation between arborists risk tolerances for financial loss and their tree risk ratings. No similar relationship existed between assessed tolerances for physical injury and tree risk ratings.

Few studies have tested the validity and consistency of risk assessment methods (Matheny and Clark 2009; Klein et al. 2016; Koeser and Smiley 2017; Koeser et al. 2017). Despite this, experts have published articles both in support of (Ellison 2005a; Fink 2009) and against (Gruber 2008; Bond 2010) the underlying logic and assumptions associated with a given risk assessment method. More research is needed to compare how risk assessment methods handle scenarios with differing targets and tree defects. More importantly, research should investigate the consistency or risk ratings among trained users and how the various methods used influence actual tree mitigation measures. Research has shown that visual assessment of likelihood of failure using the ISA BMP Method can be both consistent (Koeser and Smiley 2017; Koeser et al. 2017) and accurate (Koeser and Smiley, unpublished data). Future research should identify methods or technologies for reducing unnecessary variation in the assessment of likelihood of impact. Similarly, research is needed to provide meaningful criteria for consequences of failure with regard to injury and death. Lastly, no research has addressed the impact of timeframe (e.g., one, three, or five years) on risk assessment ratings, rating variability, and rating accuracy.

Public Perceptions of Trees and Open Spaces in an Urban Area

Public perception of the risks posed by trees has mostly focused on groupings of vegetation in natural areas or recreational space (Schroeder 1982; Schroeder 1983; Talbot and Kaplan 1984; Smardon 1988; Jorgensen et al. 2002; Roovers et al. 2006; Jorgensen and Anthopoulou 2007; Zheng et al. 2011). Fewer studies explore the perceived risk associated with individual tree failure (Wyman et al. 2012; Davison and Kirkpatrick 2014). Studies that established how people perceive visual aesthetics of plants in landscape settings frequently use photographs and surveys (Schroeder 1982; Schroeder 1983; Talbot and Kaplan 1984; Smardon 1988; Jorgensen et al. 2002; Roovers et al. 2006; Jorgensen and Anthopoulou 2007). Schroeder et al. (2006) explained that research has consistently shown that urban residents have positive perceptions of trees and that the benefits of trees typically outweigh their annoyances.

Contacts with nature are fundamental to human health and the well-being of people in built environments (Rohde and Kendle 1994; Kuo et al. 1998; Ozguner and Kendle 2006). People often rate a positive association with urban vegetation and natural spaces (Miller et al. 2015). In a telephone survey of Charleston, South Carolina, U.S., following the destruction resulting from Hurricane Hugo in 1989, Hull (1992) found that over 30% of the respondents mentioned some component of the urban forest as one of the most important physical features destroyed by the hurricane. Similarly, Wyman et al. (2012) conducted a study where they assessed and compared the perceptions of tree-related risk among community leaders from Hillsborough and Broward Counties, Florida, U.S. They found that even though these areas are highly susceptible to hurricanes and the resulting damage caused by trees, 57% of the respondents agreed it was important to increase the size of their urban forests.

CONCLUSION

Overall, this review found a limited body of literature that focuses specifically on the perceptions of risk as related to tree failure (Wyman 2012; Davison and Kirkpatrick 2014; Koeser et al. 2015; Koeser and Smiley 2017). Though the currently available literature related to risk perception provides insight into the differing perceptions given gender, age, education, and cultural background, there is still a gap in the understanding of how property owners perceive and accept the risk of trees.

Given the global importance of our urban forests and the impact that they have on the bulk of the world's population, there is a need for greater focus on the potential risks and the perceptions of tree risk. In a similar vein, there is a need to survey arborists, urban forest managers, and other tree care professionals to understand how they perceive and communicate risk regarding an urban forest. This information could be useful in future design planning, risk assessment, and risk mitigation.

Currently, there is no one tree risk assessment method that is accepted as the standard for all situations. Standardizing a method would allow for consistency among assessments, and potentially lower the liability of individual assessors. However, differences in application (e.g., private versus public trees) and national legal/cultural norms make acceptance of a single risk assessment method unlikely. Current models of tree risk assessment serve their purpose, but could be improved with testing to assess system biases, accuracy, reproducibility, and overall impact on prescribed mitigation measures.

Future research needs to identify biases inherent to a given risk assessment system. At least with the ISA BMP Method, more effort is needed to reduce unwarranted variability in the assessment of likelihood of impact and consequences of failure. Additionally, research should look at how factors like the time frame of the assessment (e.g., one, three, five, or more years) impact the reproducibility of risk assessments. Ultimately, developing a truly quantitative risk assessment approach might advance our understanding of risks from tree failure.

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Résumé. À proximité d'une cible, la défaillance d'un arbre a le potentiel d'occasionner des dommages à la propriété, de perturber les services ou de menacer la sécurité publique. À travers le monde, plusieurs méthodes qualitatives ont été développées afin de produire une approche systématique pour l'évaluation des risques posés par les arbres et leur gestion. La cohérence et la justesse de ces méthodes, les valeurs inhérentes à l'arbre concerné et à ses cibles potentielles, ainsi que la perception des risques et le niveau d'acceptation de l'évaluateur et du propriétaire de l'arbre influencent la manière dont le risque est géré. Cette revue de littérature explore le concept de risque, examine et met en opposition les méthodes d'évaluation de risques des arbres les plus couramment référencées et résume les recherches sur les perceptions du public sur les arbres et les risques posés par les arbres et les espaces verts dans les environnements bâtis. Ce bilan identifie les points généraux récapitulatifs et les lacunes dans la littérature disponible en vue d'orienter les recherches futures.

Zusammenfassung. In der Gegenwart eines Zieles hat das Versagen von Bäumen das Potential Eigentum zu zerstören, Dienste zu unterbrechen oder die Verkehrssicherheit zu beeinträchtigen. Weltweit wurden verschiedene qualitative Methoden entwickelt, um einen systematischen Ansatz für Baumrisikobewertung und Management zu liefern. Die Konsistenz und Akkuresse dieser Methoden, die auf den in Frage stehenden Baum platzierten Werte, ihrer potentialen Zielsetzungen und Risikowahrnehmungen, der Grad der Akzeptanz durch den Evaluator und Baumbesitzer, all das beeinflusst die Risikobewertung. Dieser Überblick erforscht das Konzept von Risikobewertung, untersucht und kontrastiert die meisten verwendeten Baumrisikoberwertungsmethoden und summiert die Erforschung der öffentlichen Wahrnehmung von Bäumen und deren Risiken und Grünräumen in bebauten Umfeldern. Dieser Überblick identifiziert allgemein zusammengetragene Themen und Lücken in der verfügbaren Literatur, um künftige Forschung zu führen.

Resumen. En presencia de un objetivo, las fallas de árboles pueden dañar la propiedad, interrumpir los servicios o amenazar la seguridad pública. En todo el mundo, se han desarrollado varios métodos cualitativos para proporcionar un enfoque sistemático para la evaluación y gestión del riesgo de árboles. La consistencia y precisión de estos métodos, los valores colocados en el árbol en cuestión y sus posibles objetivos y las percepciones de riesgo y los niveles de aceptación del evaluador y del propietario del árbol influyen en la forma en que se gestiona el riesgo. Esta revisión explora el concepto de riesgo, examina y contrasta los métodos de evaluación de riesgo de árboles más comúnmente referidos, y resume la investigación sobre las percepciones públicas de los árboles y el riesgo de árboles y espacios verdes en entornos construidos. La revisión identifica temas generales resumidos y vacíos en la literatura disponible para guiar investigaciones futuras.