TREE RISK ASSESSMENT
And Hazard Abatement

Living on the California central coast or in other forested areas often brings special concerns for potential tree related risks for life and property. Homes and businesses are situated along the coast and in the forested areas of the coastal mountain range where trees get big and storms can be intense.

Many areas in the Santa Cruz Mountains have a dense population of large native trees which can reach heights of over 150 feet, and have trunk diameters in excess of four feet. Coast redwoods and Douglas firs can grow to a height of 200 feet or more.

A serious concern for property owners living in a forest like this is the potential risk for life and property from falling trees and tree parts. The size of some trees and proximity to adjacent homes creates a potential for property damage and/or personal injury from:

- Limb or top breakage, often associated with heavy winds during storm conditions.
- An entire tree toppling due to up-rooting or decay and structural failure, high winds and wet soil.
- Heavy creek water flow and washing out of the soil around the root system.
- Water saturation of the soil and mud slides carrying the trees with it.

Much of tree risk assessment is common sense observation, spotting of something that doesn't look right. Property owners and managers should do regular inspections of their trees and note irregularities and suspected problem situations.

Call an arborist for confirmation and management suggestions and, if needed, tree service contractor selection.

There is no way to 100% accurately predict or prevent limbs, tops or trees coming down, or where they will land when they do come down; even healthy trees can break or fall under extreme storm conditions.

Tree risk assessment is not an exact science, the determination of hazard potential is based on the professional opinion and judgment of the arborist from

LARGE GROWING TREES OF THE SANTA CRUZ MOUNTAINS

- Coast redwood (*Sequoia sempervirens*)
- Coast live oak (*Quercus agrifolia*)
- Tanbark oak (*Lithocarpus densiflora*),
- Douglas fir (*Pseudotsuga menziesii*)
- California bay laurel (*Umbellularia californica*)
- Big leaf maple (*Acer macrophyllum*).

Some coastal zone areas have stands of:
- Monterey pine (*Pinus radiata*)
- Monterey cypress (*Cupressus macrocarpa*)
- Ponderosa pine (*Pinus ponderosa*)

And the non-native
- Blue gum (*Eucalyptus globulus*).

> *"Tree risk assessment is the systematic process of assessing the potential for a tree or one of its parts to fail and, in so doing, injure people or damage property. All trees have the potential to fail. The degree of risk will vary with the size of the tree, type and location of the defect, tree species, and the nature of the target. Tree risk assessment involves three components:*
> 1. *A tree with the potential to fail,*
> 2. *An environment that may contribute to that failure, and*
> 3. *A person or object that would be injured or damaged (i.e. the target)"*
>
> Nelda Methany and James R. Clark

years of experience, knowledge of tree species, structural and environmental factors.

A certain degree of risk must be accepted wherever there are trees and targets; final decision of acceptable or unacceptable risk is up to the property owner.

RISK INSPECTIONS

Initial technical inspections are based on visual tree and site assessment, sounding (tapping on trunk and scaffold limbs to detect sound variations), probing for decay pockets and root placement, and evaluation of potential targets in relation to the tree in question.

Initial inspections can be used to determine obvious hazards and potential problems, or to identify need for further examination.

To assist in evaluation and rating of risk according to professional standards, ISA certified arborists use the checklist and rating system of the **Tree Hazard Evaluation Form** from the publication ***"A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas"*** by Methany and Clark.

More thorough technical examination can include:
- Excavating around the base of a tree to expose the root collar and major structural roots where decay is often present but unobservable without exposure.
- Climbing of the tree to examine potential structural defects of limbs, stem and top.
- Examination with modern instruments for decay detection and stress assessment: resistance drill, acoustic tomography, radar, and wind load analysis.
- Determining property lines and responsibility for liabilities.
- Measuring heights and distances and calculating possible worst-case scenarios.

RATING AND MANAGEMENT OF HAZARDS

When ***Tree Solutions*** arborists inspect and evaluate trees for risk, we put the hazard potential into certain categories of urgency. Following the determination of risk, recommendations for management of that risk are presented:

The most immediate hazards to identify are trees in the process of uprooting, splitting apart, or with breakage of limbs or stem, representing imminent structural failure.

1. **Imminent Hazard-** Tree structural failure in progress with a target within range:
   - Uprooting with noticeable soil fissures, heaving of the root plate, structural root fractures.
   - Tree trunk or large limb breakage, often associated with overburdened weight distribution or leaning.
   - Advanced decay weakening the structural integrity of the tree.
   - Tree parts broken and hanging.

   Any of the above factors combined with near proximity to a home or business structure, power lines, road or driveway would indicate a dire emergency. Get a tree crew out now for emergency removal, on overtime if necessary.

2. **Urgent Hazard-** Compromised structural integrity, but not as immediate as above, no observed failure in progress:
   - A tree leaning toward a house, overburdened limbs or top over a house, patio or driveway.
   - Big trees in a potential mudslide area above a house.
   - Construction activity or other damage of the trunk, large limbs or structural support roots.

   Schedule removal or safety pruning as soon as possible, before the next storm.

3. **Potential Hazard-** Condition unclear from initial inspection. Root collar exam or other further inspection needed to determine degree of risk:
   - Tree leaning toward house could become dangerous if allowed to continue growth in that direction.
   - Shallow topsoil on rock base creating shallow rooting and vulnerability to toppling.
   - Structural defects- co-dominant stems, or suspected decay conditions that could weaken tree structure if allowed to advance.
   - Dead or declining foliar top or other tree health issues that should be addressed or tree may weaken or die and become dangerous.

   Schedule further inspection, pest/disease control or tree pruning sometime in the near future.

4. **Preventive Maintenance-** Known risk factors are identified that could become an issue if allowed to develop:
   - Schedule crown cleaning and thinning and/or crown reduction pruning.
   - Remove selected overcrowded trees to allow light and space for remaining trees to grow with balanced weight distribution.
   - Initiate pest and disease management program.

TREE RISK ABATEMENT

If a particular tree or group of trees is determined to have hazard potential, specific means of abatement can be recommended.

Pruning can be specified to reduce overall tree height, density or canopy spread. Designated limbs can be relieved of excess weight or length. The direction of growth can be re-directed by selective pruning. Defective structural components can sometimes be removed.

Installation of cables and other forms of bracing, through-bolts and props, can be used to reinforce a structural weakness.

Target removal or re-location if possible should be considered as an alternative to tree removal.

Tree removal is a last resort when all other forms of abatement have been ruled out.

Topping (heavy crown reduction or stubbing) is usually not recommended, but can be a short term, cost effective alternative to removal when immediate safety and not tree care is the priority.

Topping can be ugly and create future problems and risk due to possible rapid re-growth and the nature of the weak structural attachments that form as a result. **If a tree is topped, it necessitates follow-up with an annual inspection and maintenance program or a plan for progressive removal of the tree.**

Moderate crown reduction by selective pruning is preferred when height reduction is indicated.

Pest and Disease Factors: Wood rot fungus infection is the primary disease issue in relation to tree structural failure. It exists in varying stages in many trees and is to be expected in a forest environment. Advanced stages of decay in roots, stems or branches can contribute to structural failure. Pest infestations can create or hasten decline in health and structural defects.

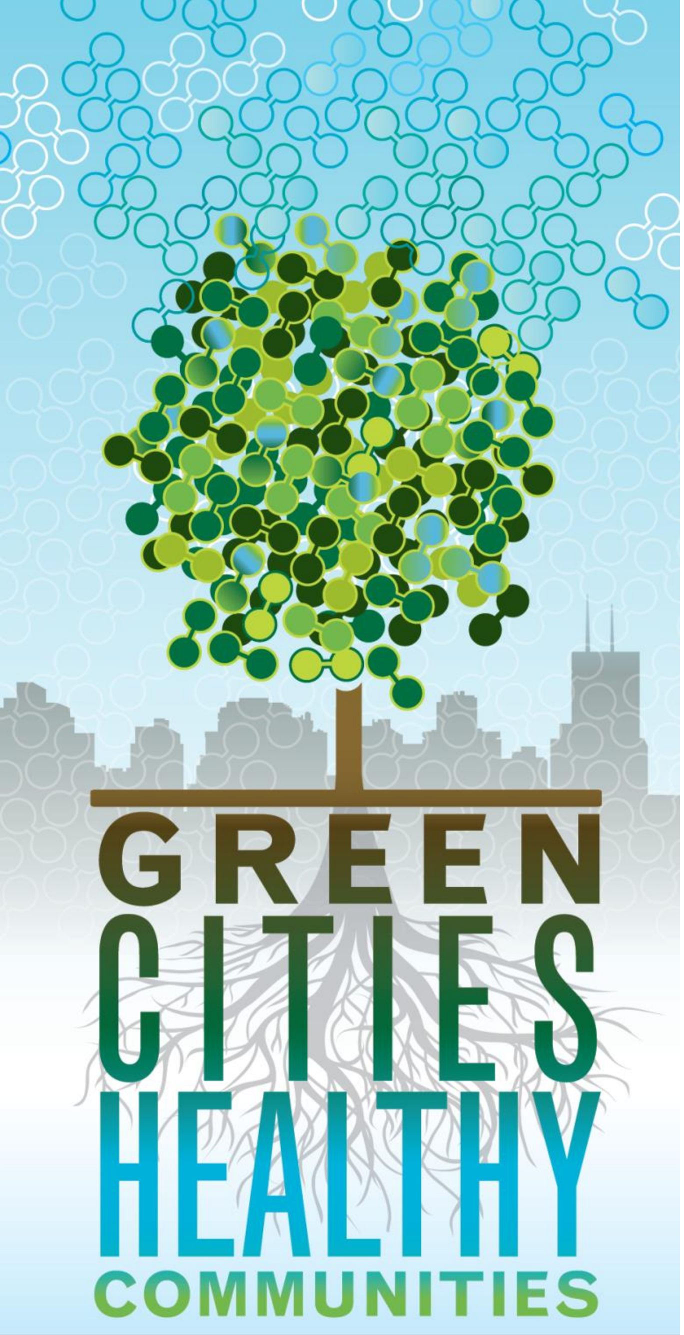
Many of the trees in this geographical area are re-sprouts from old cut stumps due to logging and land clearing. This presents a potential problem in that advanced decay of the parent stump and roots (which may be below ground and not visible in a superficial inspection) could create a compromise to the structural integrity of the standing tree.

Some structural defects (clockwise from top left): 1. Imbalanced weight distribution, leaning. 2. Co-dominant stems splitting apart. 3. Large deadwood. 4. Large wound at critical location.

Forest fires are another major concern with need for preventive maintenance. Regarding fire prevention, fire departments recommend clearing all trees and brush within a 30 - 100 foot distance of the structures to create a **"defensible space"**. Obviously the more distance the better, and some trees and shrubs are more flammable and therefore more important to clear than others. Even beyond this defensible range, clearing of deadwood and lower limbs can prevent fire transferring from grasses and shrubbery to the tree canopies and roofs of structures.

If you have trees near your home it is better to be safe than sorry. Have a ***Tree Solutions*** arborist inspect the trees, discuss findings with you and make recommendations, or write a report with detailed observations and specifications for management of risk.

The cost of prevention is usually much less than the cost of loss and inconvenience of damage.



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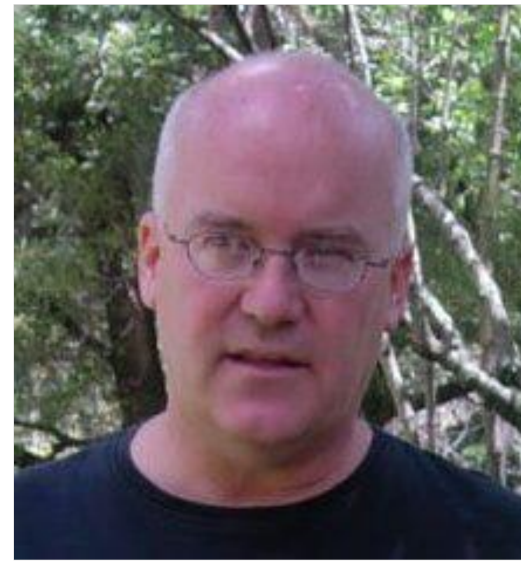

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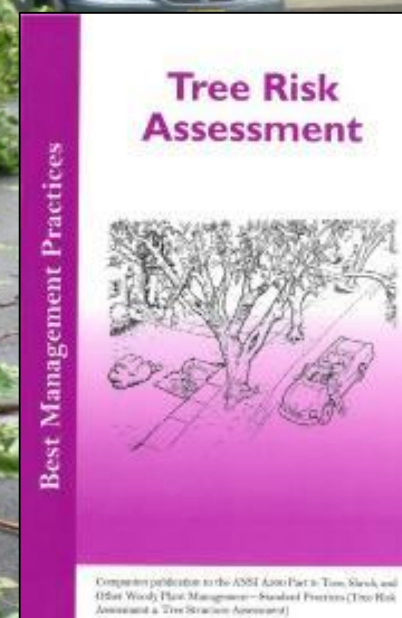
Tree Risk Assessment



Greg Dahle
West Virginia University

Tree Risk Assessment

- ANSI A300 Part 9
- BMP

- TRAQ
  - Tree Risk Assessment Qualification
    - 2 day educational course + ½ assessment
  - Re-qualify every 5 years
    - 1 day refresher + 3 hour exam

Three Levels of Tree Risk Assessment

Level 1 - Limited visual (survey)

Level 2 – Basic (visual exam)

Level 3 - Advanced

All looking at factors that affect the likelihood and consequences of tree failure.

Many of these slides were adapted from a presentation by Dr. Tom Smiley with the Bartlett Tree Research Lab

Likelihood of Failure and Impact (Table 1)

Likelihood of Failure	Likelihood of Impacting Target			
	Very Low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Risk Rating Matrix (Table 2)

Likelihood of Failure and Impact	Consequences of Failure			
	Negligible	*Minor*	*Significant*	*Severe*
Very Likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat Likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Categorizing the Likelihood of a Failure

Within the Specified Time Frame:

- <u>Improbable</u> - the tree is not likely to fail even in severe weather conditions.
- <u>Possible</u>- failure could occur, but it is unlikely during normal weather. <u>High wind failure.</u>
- <u>Probable</u> –failure is <u>expected under normal weather</u> conditions.
- <u>Imminent</u> –failure has started or is most likely to occur in the near future, even if there is no wind or increased load.

Categorizing the Likelihood of Impacting a Target

Very Low- The chance of impacting a target is remote.

Low – It is not likely that the target will be impacted.

Medium – The target may or may not be impacted.

High - The target is likely to be impacted

Likelihood

Failure=Imminent

Impact=Medium

Likelihood of Failure and Impact (Table 1)

Likelihood of Failure	Likelihood of Impacting Target			
	Very Low	*Low*	*Medium*	*High*
Imminent	**Unlikely**	**Somewhat likely**	**Likely**	**Very likely**
Probable	**Unlikely**	**Unlikely**	**Somewhat likely**	**Likely**
Possible	**Unlikely**	**Unlikely**	**Unlikely**	**Somewhat likely**
Improbable	**Unlikely**	**Unlikely**	**Unlikely**	**Unlikely**

Consequences are the effects or outcome of a tree failure.

- Negligible- low value property damage. Personal injury is unlikely.
- Minor – low to moderate value property damage. Personal injury is unlikely
- Significant –moderate to high value property damage. People could be injured.
- Severe - High value property damage. One or more people could be injured or killed.

Consequences of failure = Severe

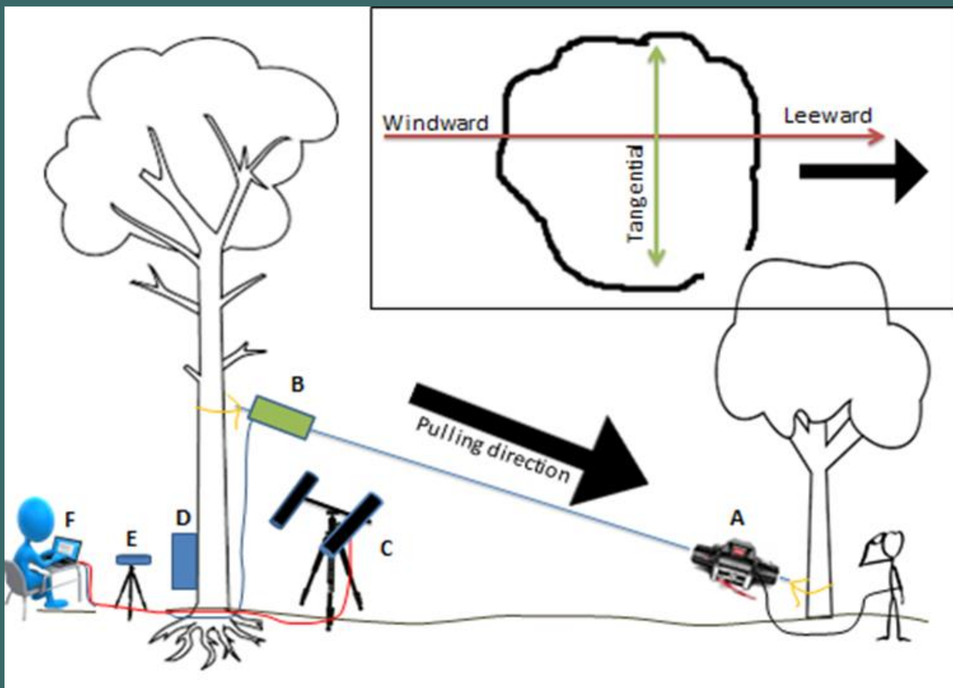
Risk Rating Matrix (Table 2)

Likelihood of Failure and Impact	Consequences of Failure			
	Negligible	*Minor*	*Significant*	*Severe*
Very Likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat Likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Digital Image Correlation

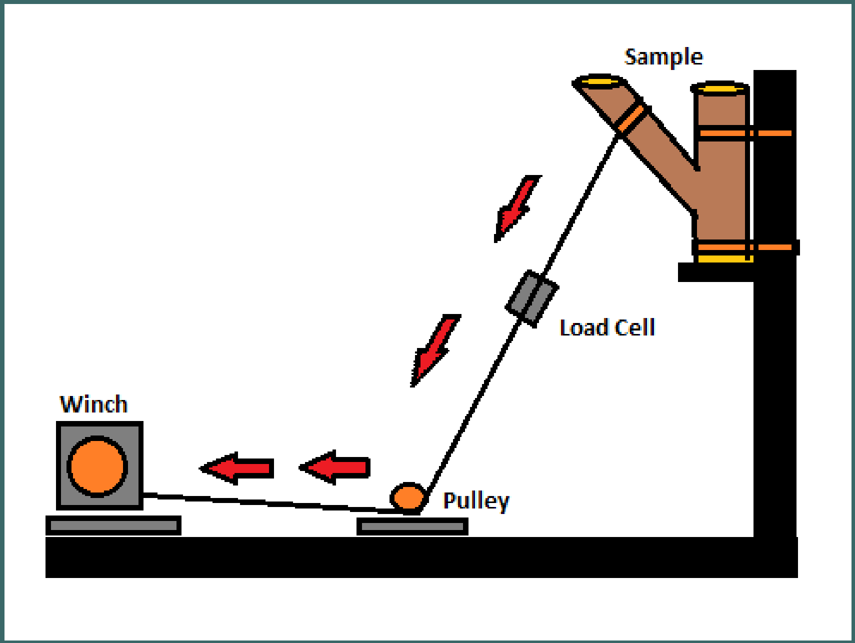
- Stereophotogemetry
- 3D strain maps
- Strain = deformation

Static Load Tests

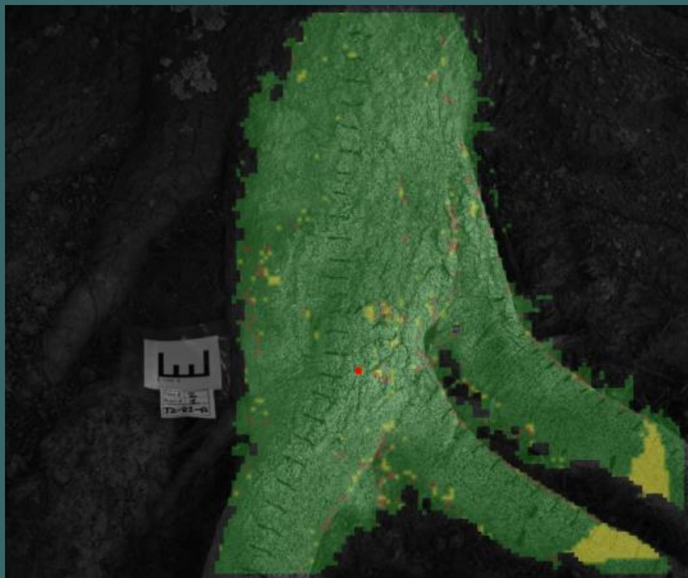


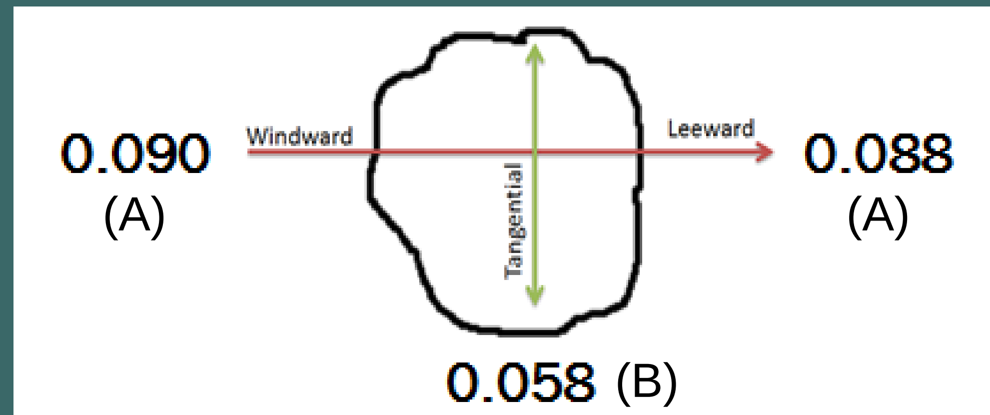
Ken Beezley, M.S. 2016

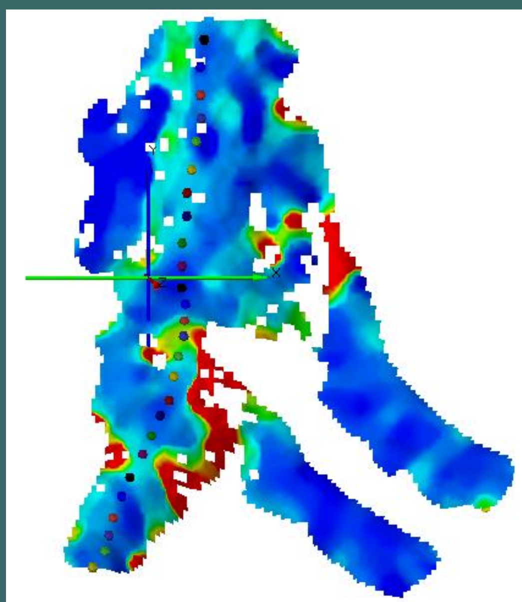
Rob Eckenrode, M.S. 2017



Mean Strain

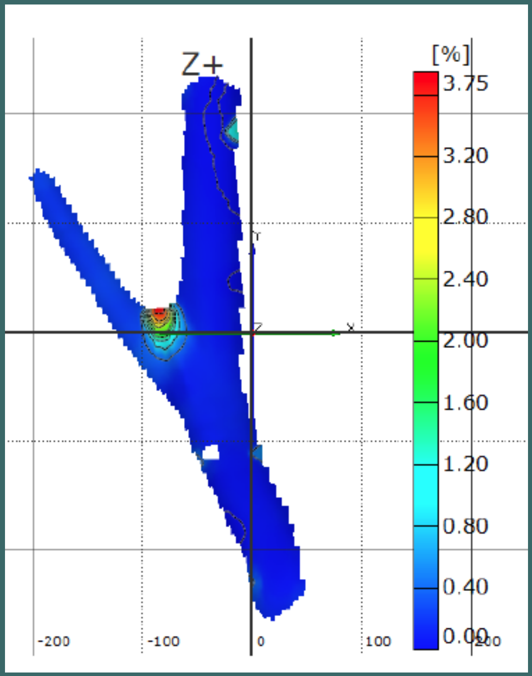






- Windward and leeward were the same
- Tangential was lower
  - Looking at torsion
- Prevailing wind important

The Lateral Branch Attachment

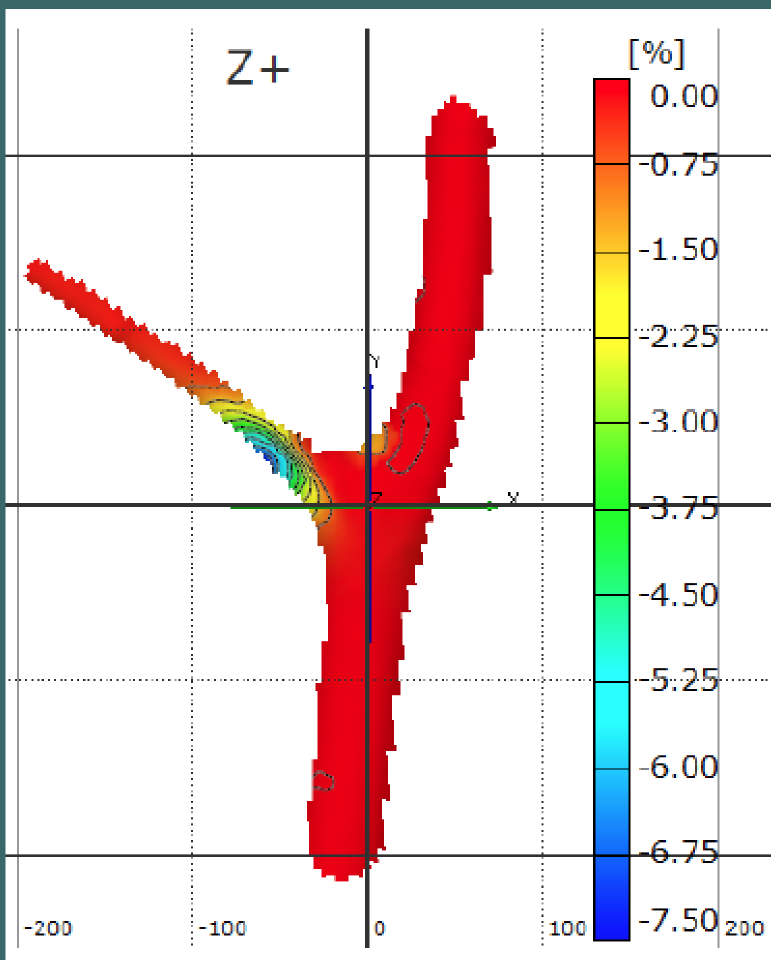


Aspect ratio varied from 0.5 to 1.0

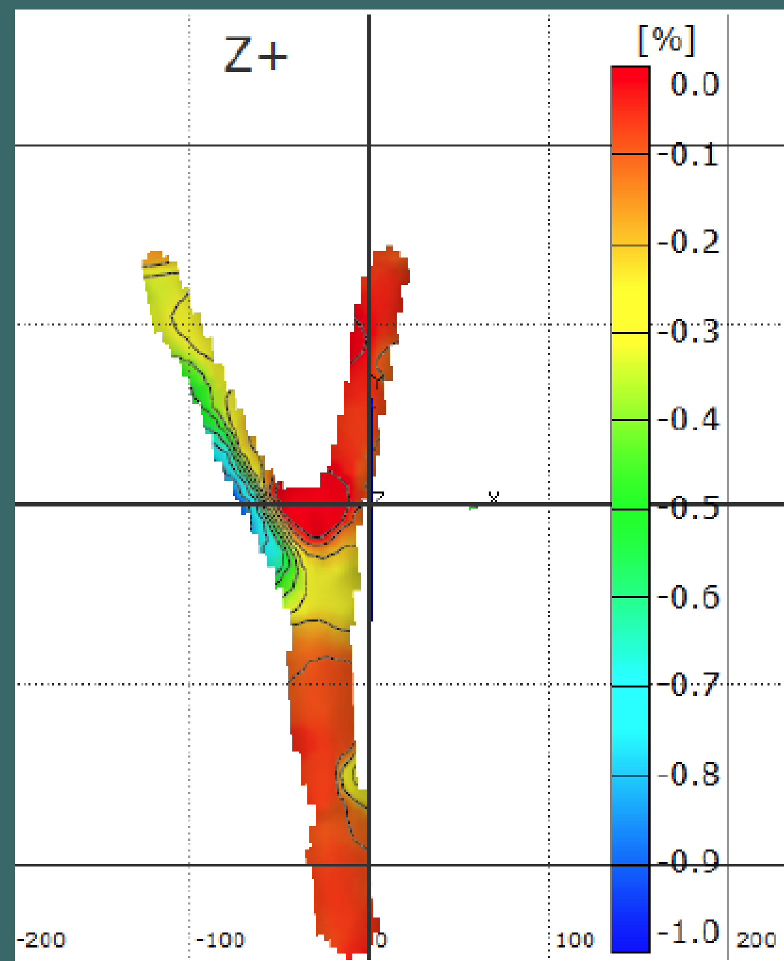
Aspect ratio = branch diameter / stem diameter

Strain moved further into stem in co-dominant

Aspect ratio = 0.6
ball & socket failure

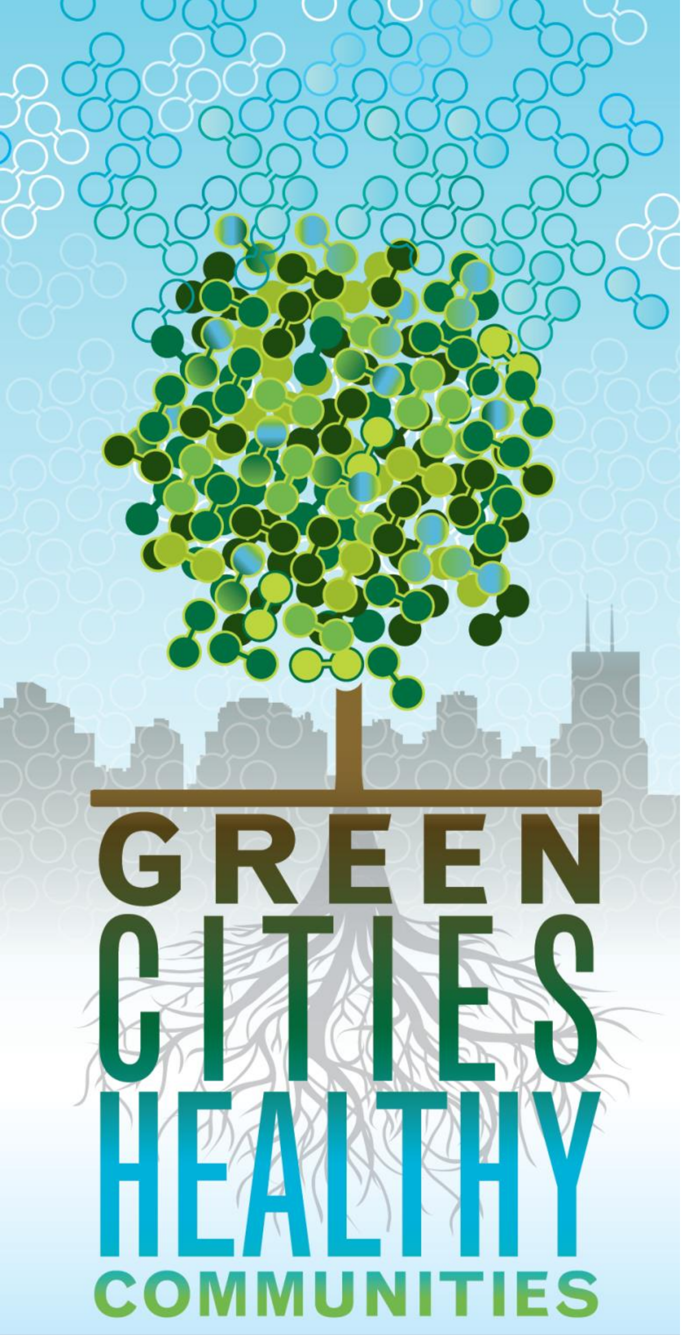


Aspect ratio 0.8,
imbedded failure



Mapping strain and likelihood of failure

- Loads are transferred equally in line with wind direction
  - Yet torsion might be important
- Appears co-dominant begins around aspect ratio 0.8 (mechanical and hydraulic)



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TREE RISK ASSESSMENTS: CUTTING EDGE SCIENCE MEETS PRACTICAL APPLICATIONS

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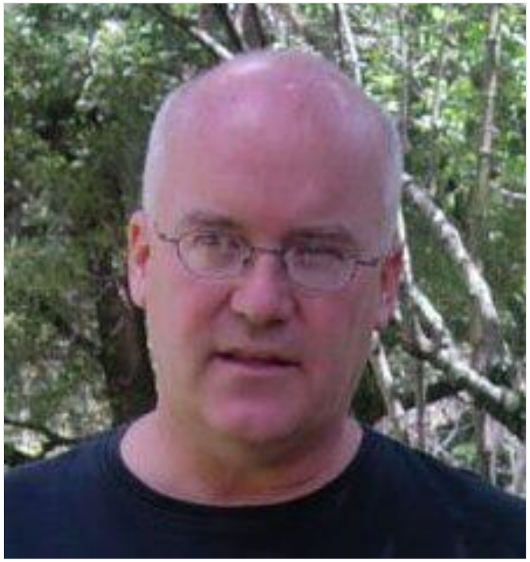

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Risk Assessment in Urban Settings

US Forest Service
Urban Forestry Webinar
May 10, 2017

The Confluence of Risk Assessment and Risk Management

Mark Duntemann
Natural Path Urban Forestry

The Confluence of Risk Assessment and Risk Management

Risk Assessment is the technical process for:

- Evaluating what unexpected things could happen,
- How likely they are to occur, and
- The consequences if they were to occur.

The Confluence of Risk Assessment and Risk Management

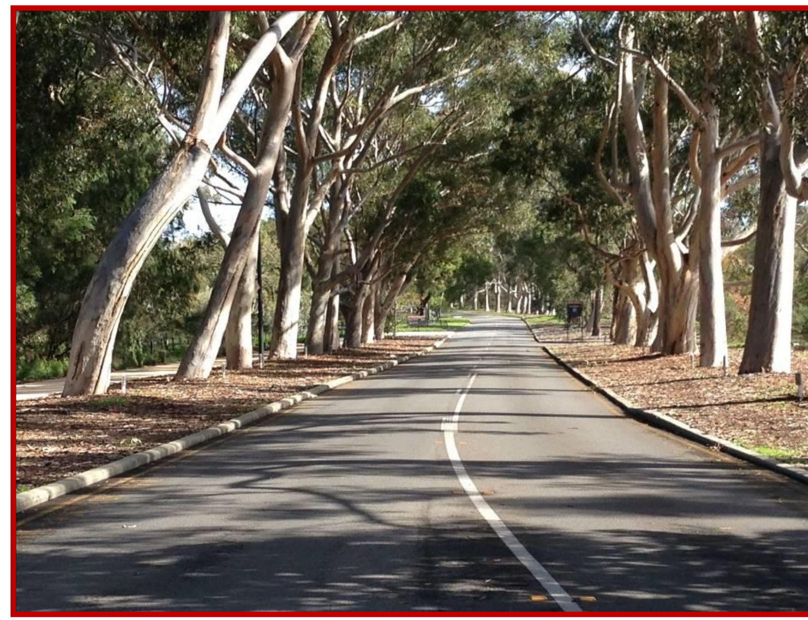
A **Tree Risk Assessment** should result in the following outcomes:

1. An overall risk rating for the subject tree.

2. Mitigation options to address the risk identified.

The Confluence of Risk Assessment and Risk Management

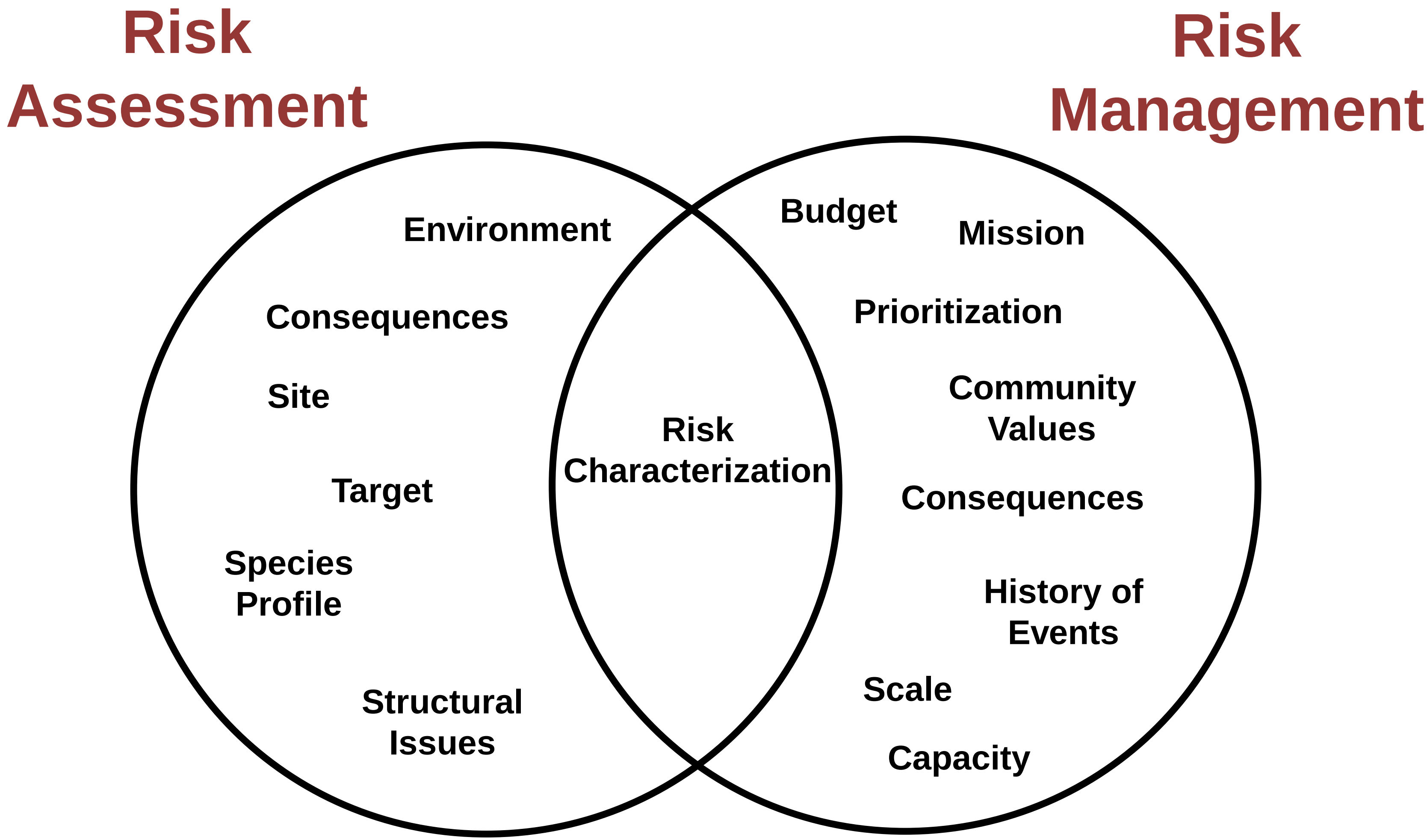
Risk Management is the process by which an agency or company assesses and monitors its risks and selects and implements measures to address those risks.



The Confluence of Risk Assessment and Risk Management

Risk Management is about making choices at the system level in the presence of uncertainty.

The Confluence of Risk Assessment and Risk Management



Risk Associated with Trees

Depends on the likelihood of <u>two</u> events typically happening at almost concurrent moments:

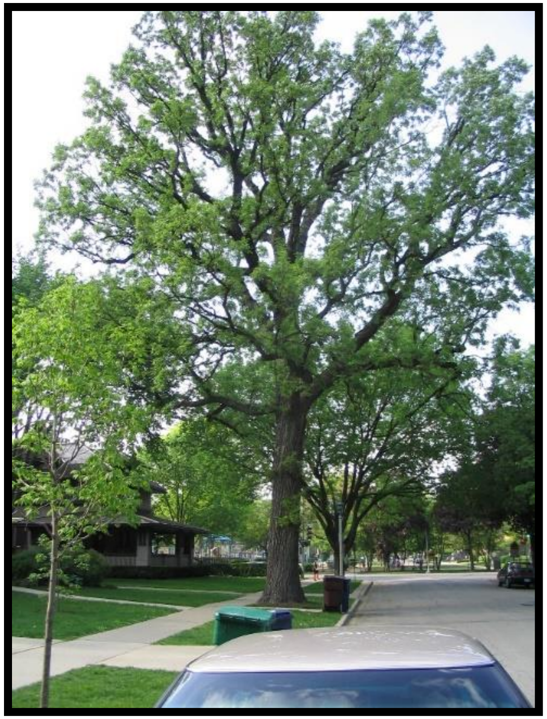
- The likelihood of a tree part failure (1) within a given time frame (2).
- If the part fails, the likelihood of striking a target (3).

Consequences

<u>If</u> the part fails and <u>if</u> a target is struck what are the potential consequences (4).

The Confluence of Assessment and Management in Litigation

1. A tree is viewed as a hazard in absolute terms. In other words, the subject tree was a hazard or not a hazard.



The risk associated with a tree is complex. Every single tree part has some potential to fail.

The Confluence of Assessment and Management in Litigation

2. The context of the non-subject trees are minimized.

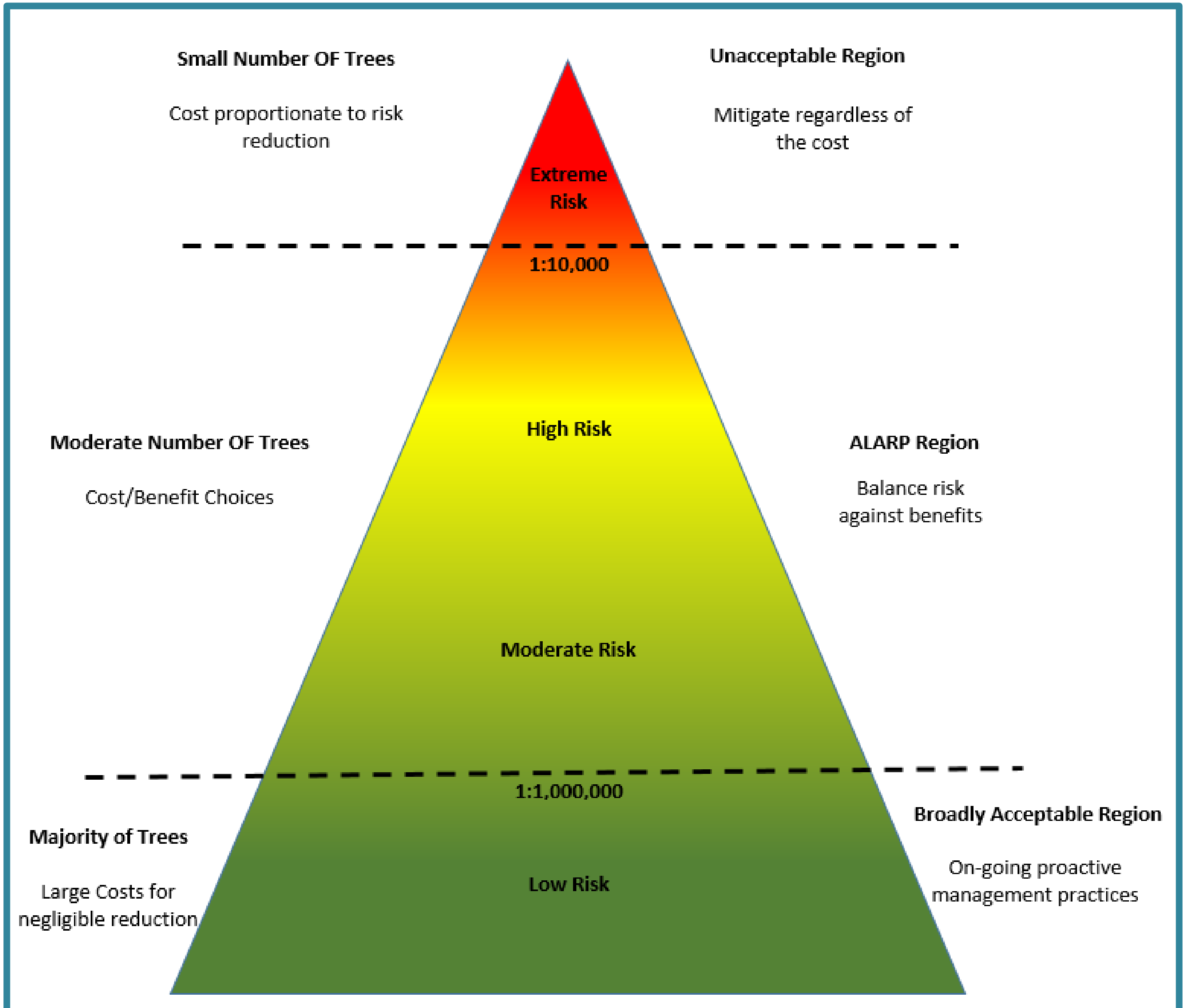
The subject tree is not managed in a vacuum. Choices are made as part of a larger system. (Assessor vs Manager)

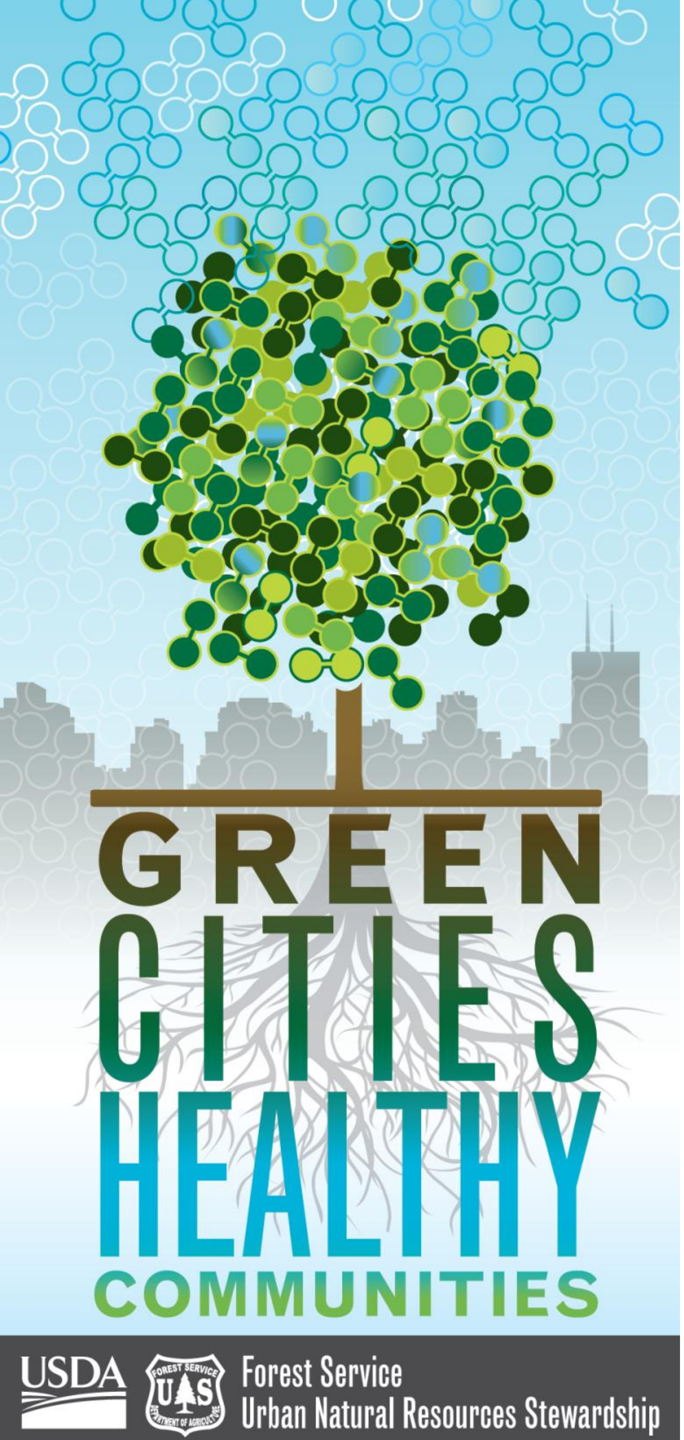
The Confluence of Assessment and Management in Litigation

3. A high inspection and maintenance rigor is assigned to the subject tree.

The resources required to achieve this level of rigor is, at times, unreasonable and impractical.

As Low as Reasonably Practical





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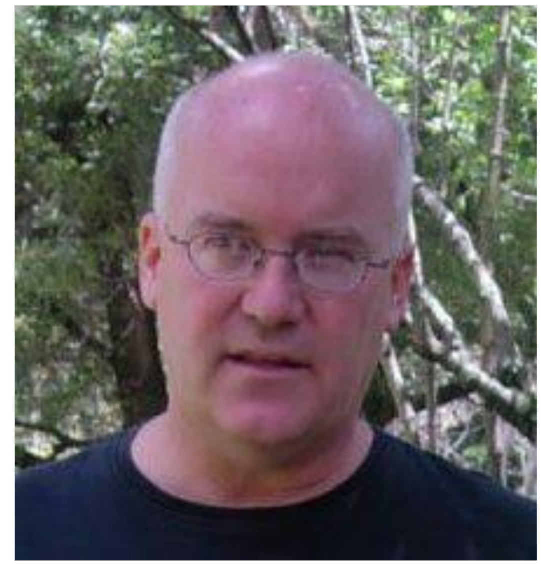

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Tree Risk Assessment – Perceptions, Reality, and Reliability

http://www.louisdallaraphotography.com

Andrew Koeser, BCMA, Ph.D.
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Tree Risk Assessment

Tree risk is ultimately governed by:

- The likelihood a target will be impacted

www.sptimes.com

www.rockymtnrefl.com

Tree Risk Assessment

Tree risk is ultimately governed by:

- The likelihood a target will be impacted
- The potential of a tree or tree part to fail

news.gardentoolbox.co.uk

autonopedia.org

Tree Risk Assessment

Tree risk is ultimately governed by:

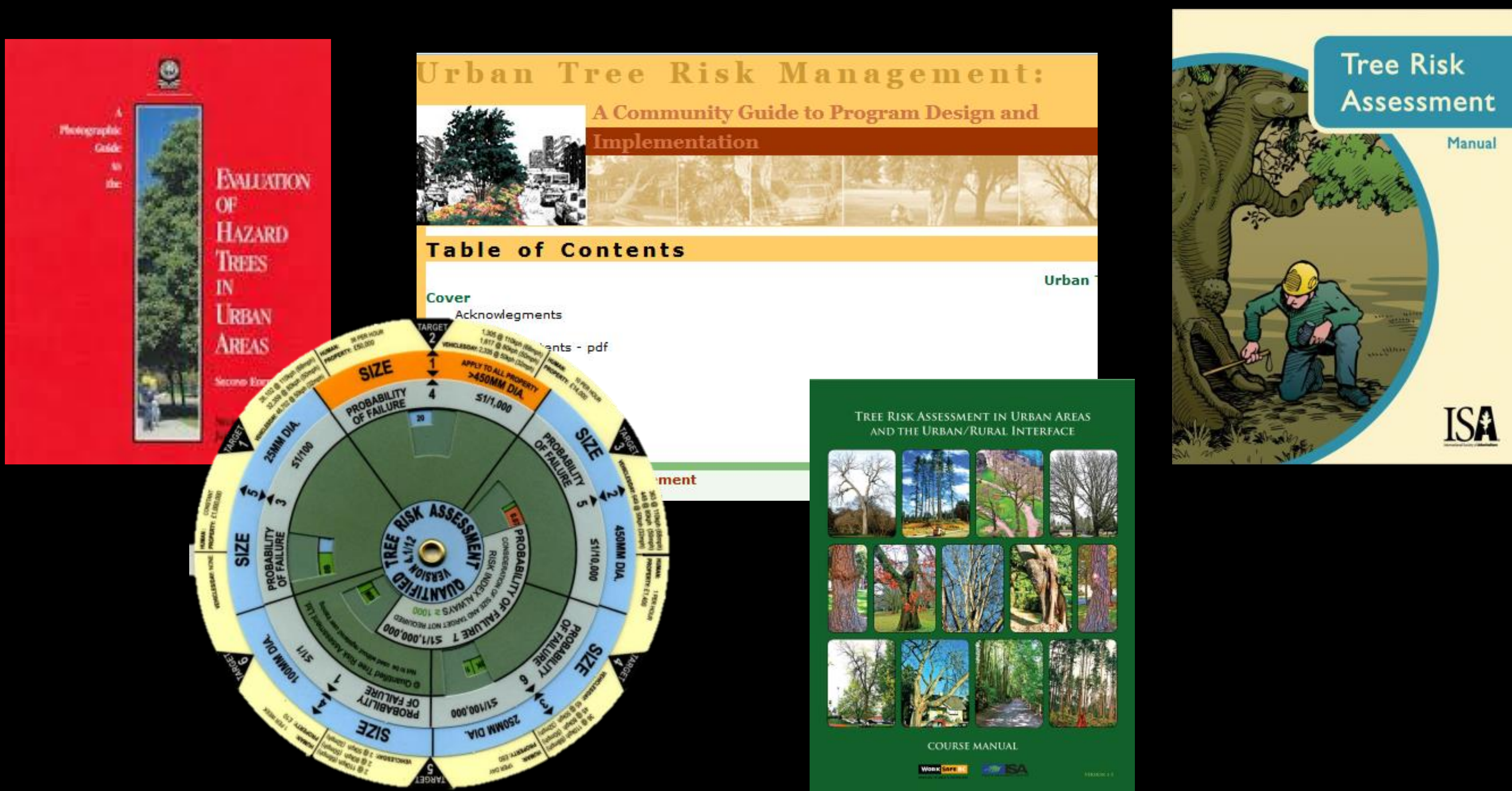
- The likelihood a target will be impacted
- The potential of a tree or tree part to fail
- The consequences should a tree/tree part strike the target

http://www.komonews.com

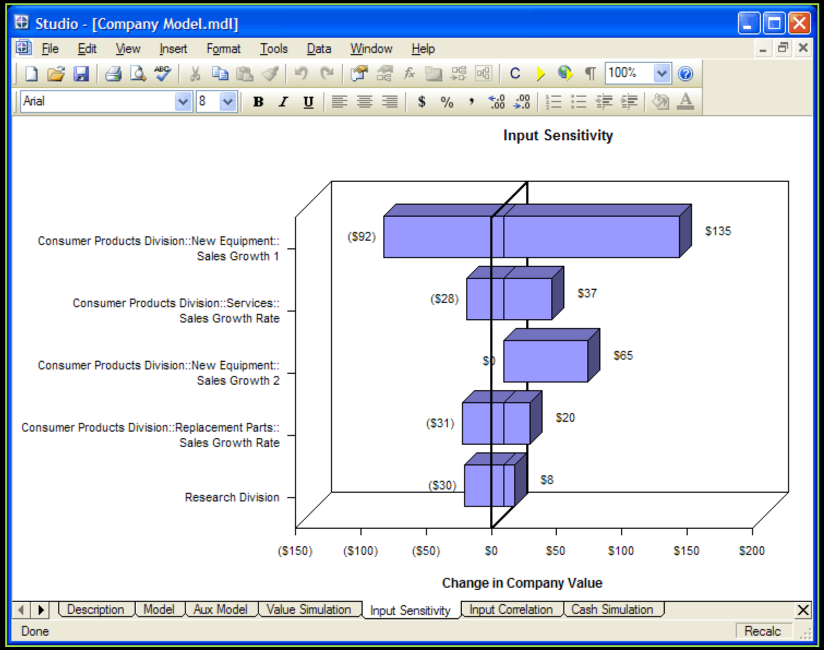
www.dailymail.co.uk

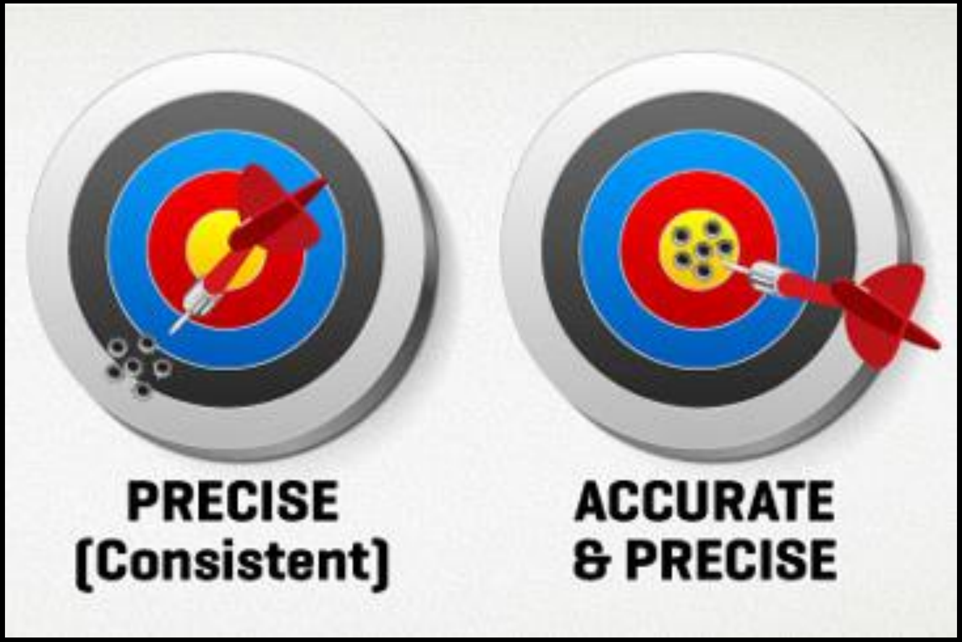
Tree Risk Assessment

3 inputs (target – likelihood of failure – consequences) are shared by all common assessment methods



All currently accepted methods of risk assessment share a common concern…



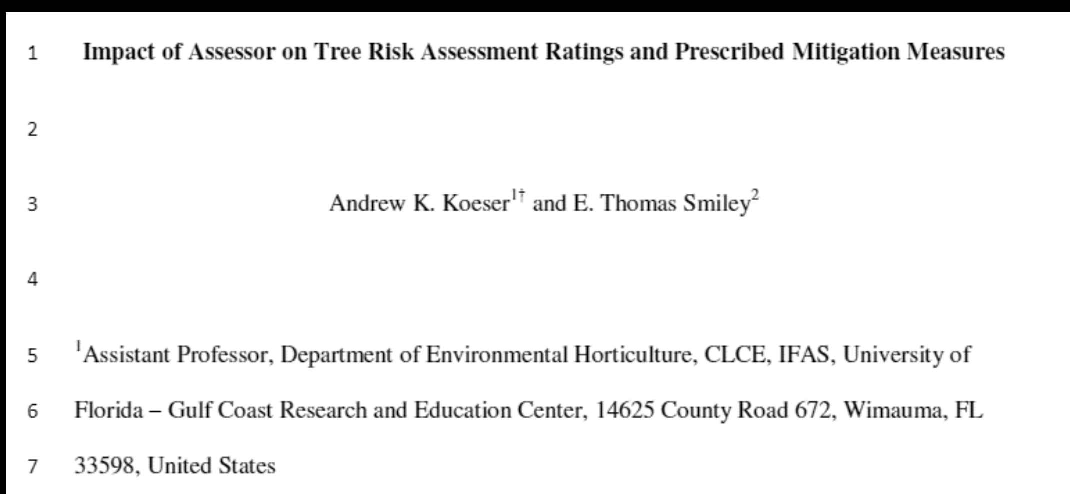


How do we limit the impact of assessor bias and risk perception to make risk assessments more robust and repeatable?

Impact of Arborist on Risk Assessments

296 Arborists assessed three trees each.

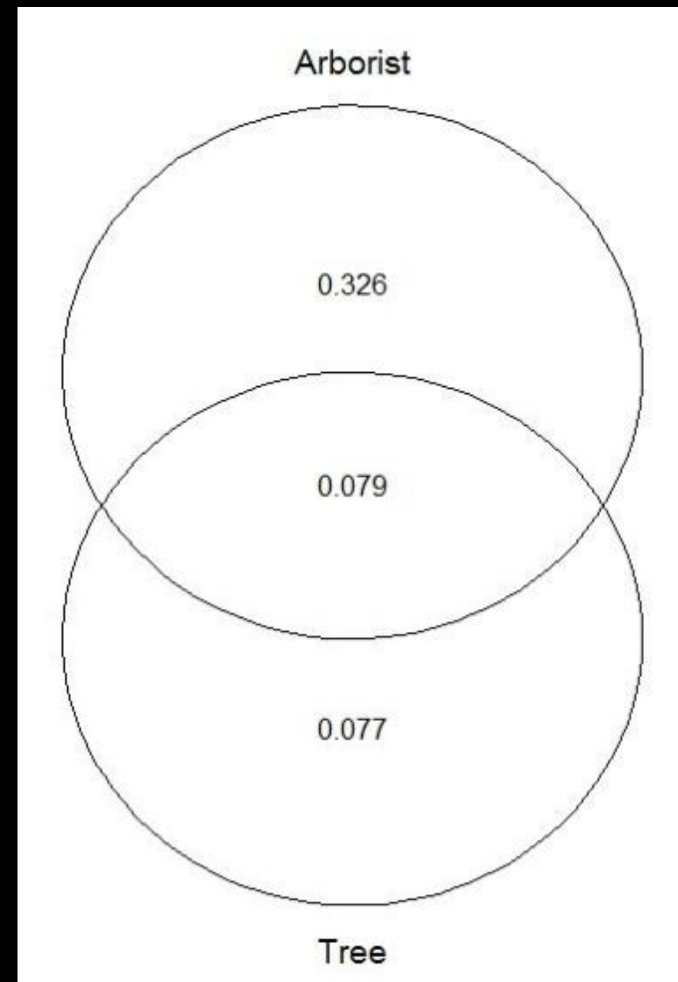
Compared sources of variation among ratings/inputs



Impact of Assessor on Tree Risk Assessment Ratings and Prescribed Mitigation Measures

Andrew K. Koeser[1†] and E. Thomas Smiley[2]

[1]Assistant Professor, Department of Environmental Horticulture, CLCE, IFAS, University of Florida – Gulf Coast Research and Education Center, 14625 County Road 672, Wimauma, FL 33598, United States



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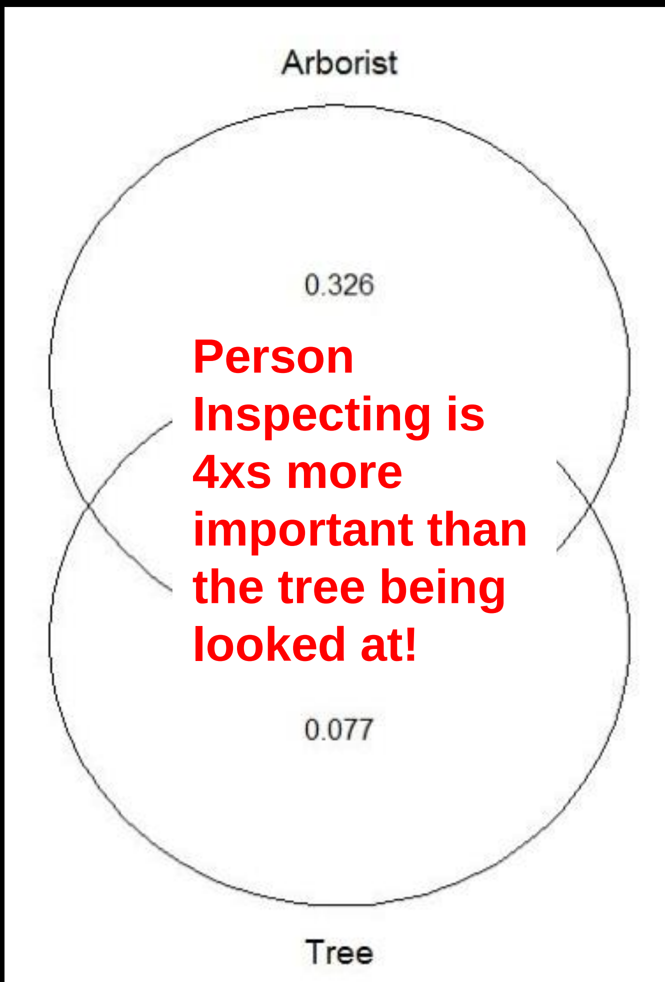


Why are things so variable?

Failure Potential

Journal of Arboriculture 31(2): March 2005

QUANTIFIED TREE RISK ASSESSMENT USED IN THE MANAGEMENT OF AMENITY TREES

By Michael J. Ellison

"Accurately assessing the probability that a tree or branch will fail is highly dependent on the skill and experience of the assessor."

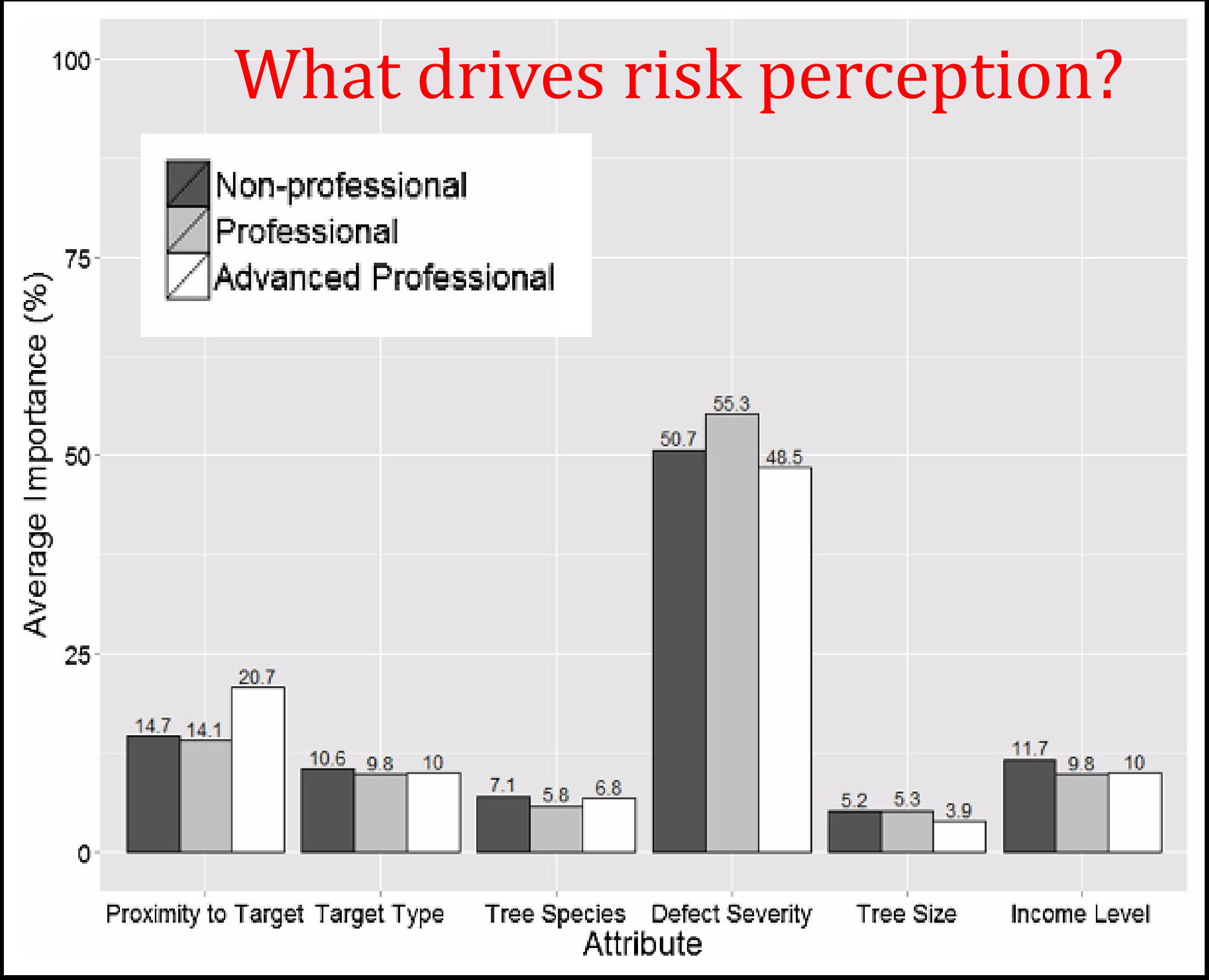
Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Factors driving professional and public urban tree risk perception

Andrew K. Koeser[a,*], Ryan W. Klein[b], Gitta Hasing[a], Robert J. Northrop[c]



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What drives risk perception?

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So, we focus on failure potential…

Next logical question: How well can we assess it?

Detecting Decay With Visual Indicators

Arboriculture & Urban Forestry 42(4): July 2016 217

Arboriculture & Urban Forestry 2016. 42(4): 217–226

ISA

ARBORICULTURE & URBAN FORESTRY

Frequency, Severity, and Detectability of Internal Trunk Decay of Street Tree *Quercus* spp. in Tampa, Florida, U.S.

Andrew K. Koeser, Drew C. McLean, Gitta Hasing, and R. Bruce Allison

153 *Quercus virginiana* (Southern live oak)

86 *Quercus laurifolia* (laurel oak)

Table 3. Comparison of laurel oak (*Quercus laurifolia*) street trees in Tampa, Florida, U.S., with visual decay indicators and internal stem decay (n = 86). Trees were assessed visually prior to advanced assessment with a resistance-recording drill.

Decay severity	Trees with positive/potential decay indicators	Actual number of trees with decay at this level[z]	Percent identified correctly with visual assessment
0%	10	28	64.3%[y]
1%–10%	14	22	63.6%
11%–20%	5	9	55.6%
21%–30%	3	7	42.8%
31%–40%	5	6	83.3%
41%–50%	4	4	100%
51%–60%	2	3	66%
61%–70%	5	5	100%
71%–80%	0	0	n/a
81%–90%	2	2	100%

[z] Based on resistance-recording drill measurement data.

[y] To calculate this percentage, researchers compared the number of trees without positive/potential decay indicators (18) to the actually number of trees without decay (28).

Table 4. Comparison of live oak (*Quercus virginiana*) street trees in Tampa, Florida, U.S., with visual decay indicators and internal stem decay (n = 153). Trees were assessed visually prior to advanced assessment with a resistance-recording drill.

Decay severity[z]	Trees with positive/potential decay indicators	Actual number of trees with decay at this level[z]	Percent identified correctly with visual assessment
0%	7	108	93.5%[y]
1%–10%	4	18	22.2%
11%–20%	1	16	6.3%
21%–30%	1	3	33.3%
31%–40%	0	2	0.0%
41%–50%	0	3	0.0%
51%–60%	0	0	n/a
61%–70%	0	1	0.0%
71%–80%	1	2	50.0%
81%–90%	0	0	n/a

[z] Based on resistance-recording drill measurement data.

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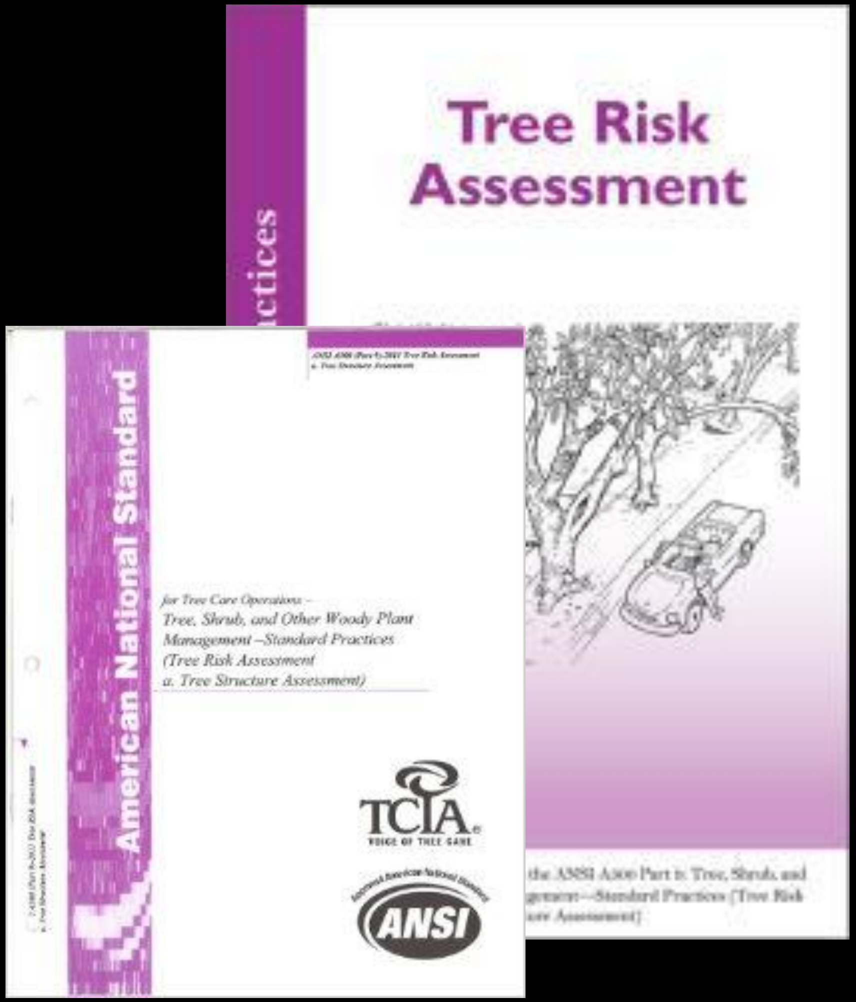
Next Logical Questions…

- How much more does advanced assessment add?
- Was this just one arborist getting lucky? What happens when multiple arborist perform a similar experiment?

Assessment of Likelihood of Failure Using Limited Visual, Basic, and Advanced Assessment Techniques

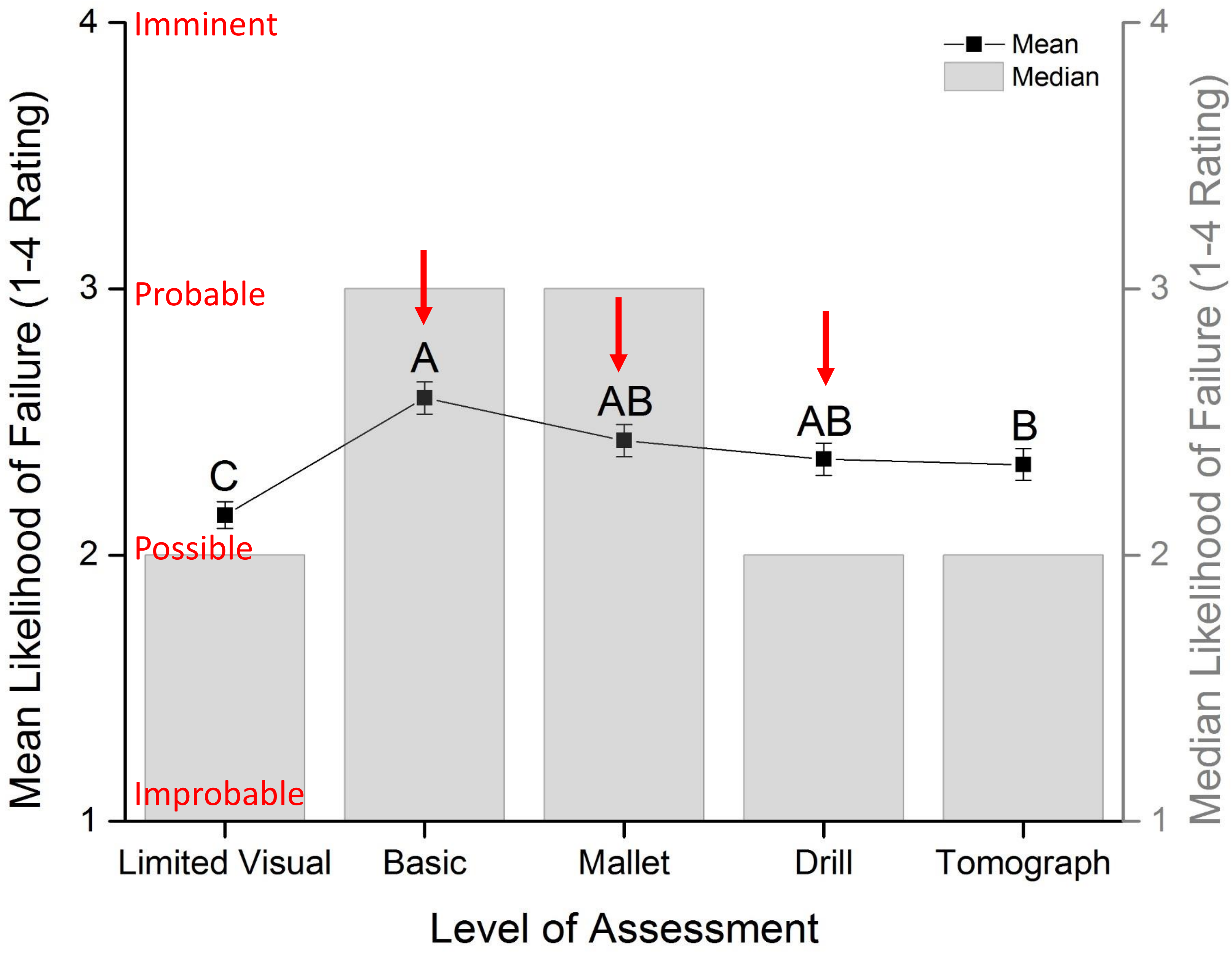
Three Levels of Risk Assessment

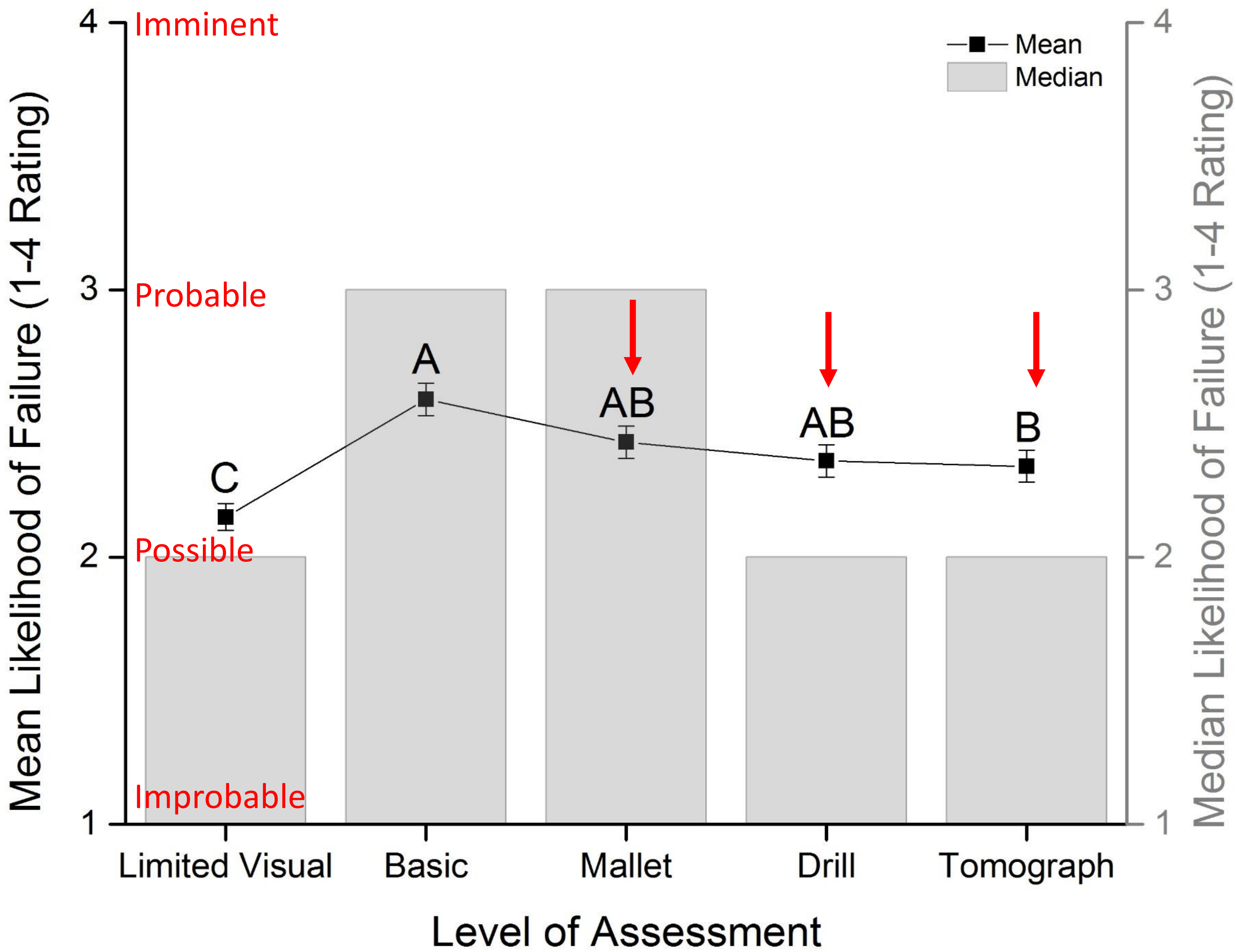
- Level 1 – Limited Visual (Walk- or Drive-by)
- Level 2 – Basic Assessment
- Level 3 – Advanced Assessment



Impact of Level of Assessment on Failure Potential Rating

- 70 Arborists assessed 5 trees going from LV to AA


Imminent
Probable
Possible
Improbable
Mean
Median
A
AB
AB
B
C
Mean Likelihood of Failure (1-4 Rating)
Median Likelihood of Failure (1-4 Rating)
Limited Visual
Basic
Mallet
Drill
Tomograph
Level of Assessment
1
2
3
4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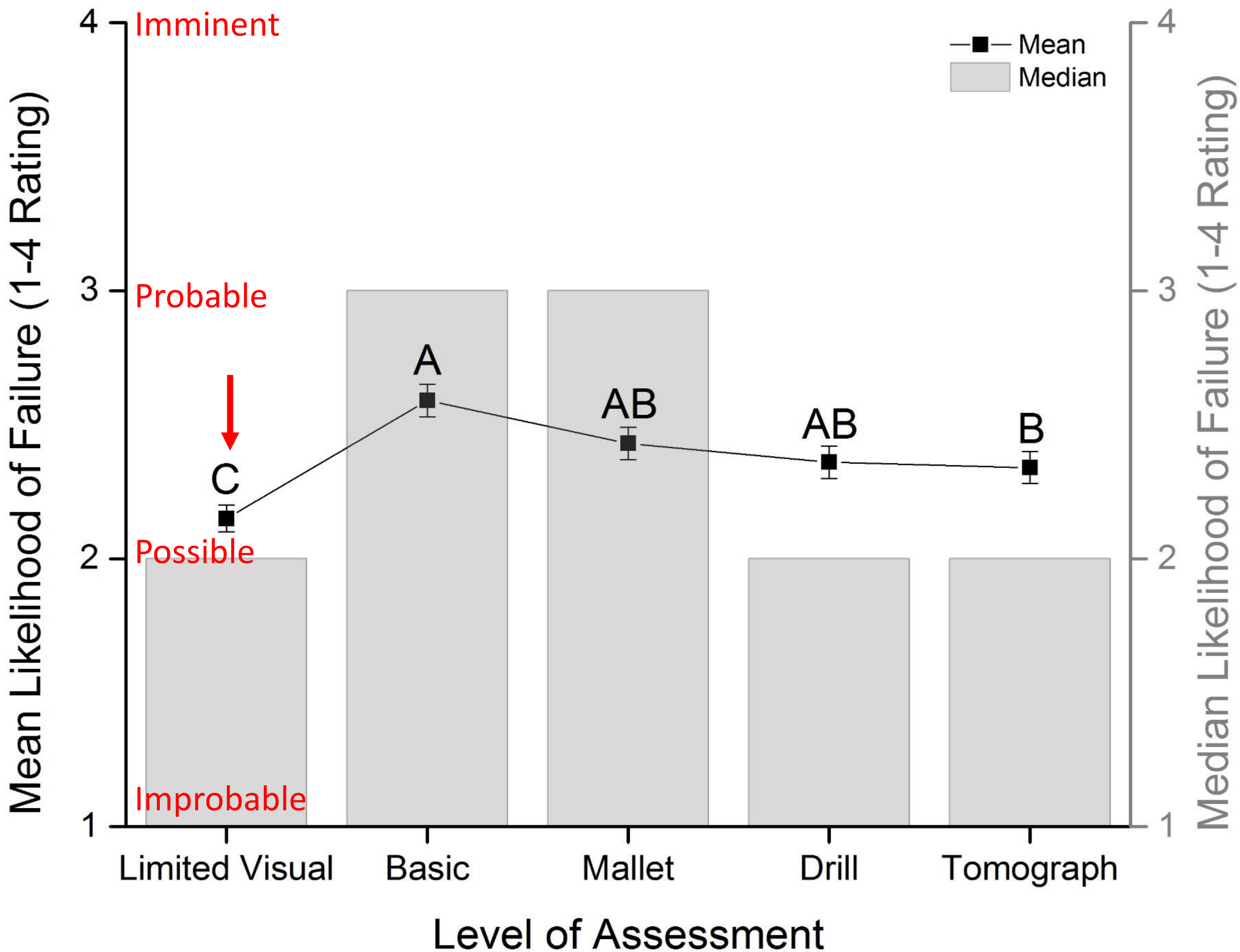
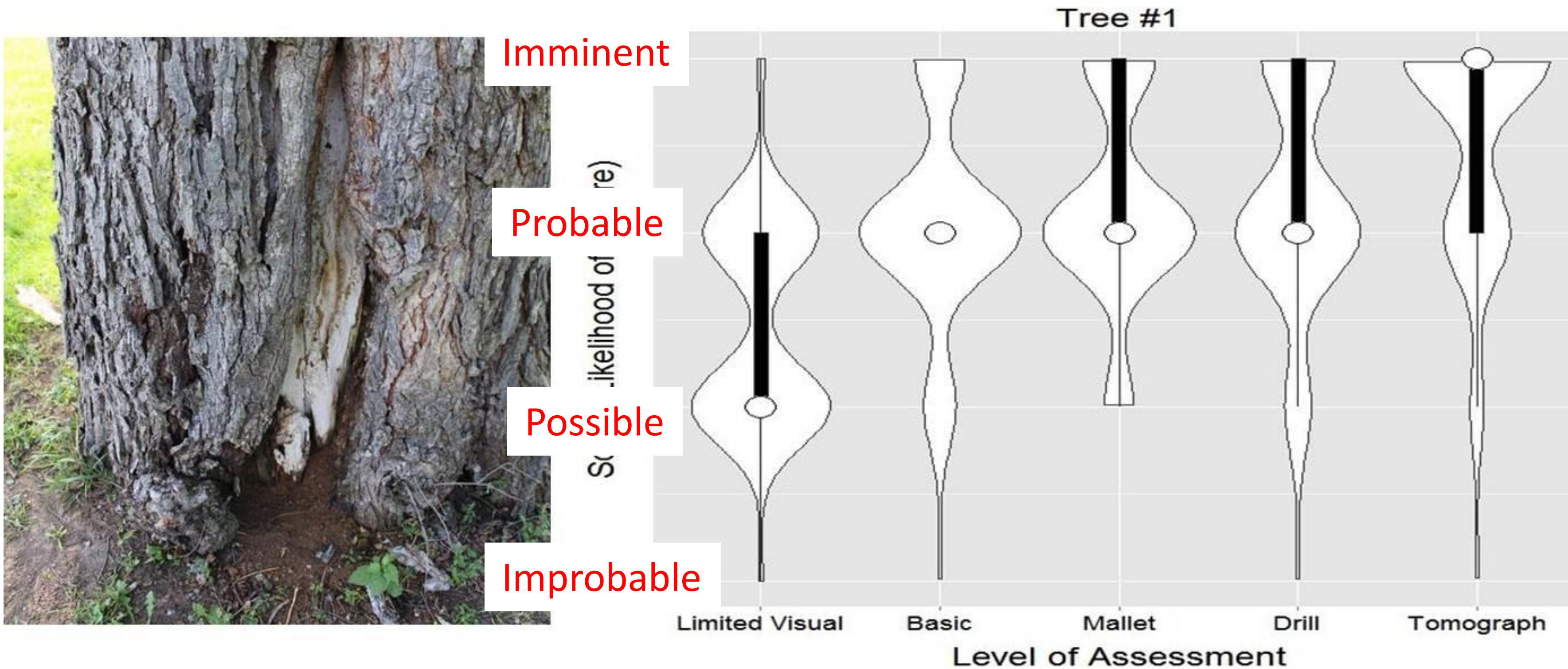
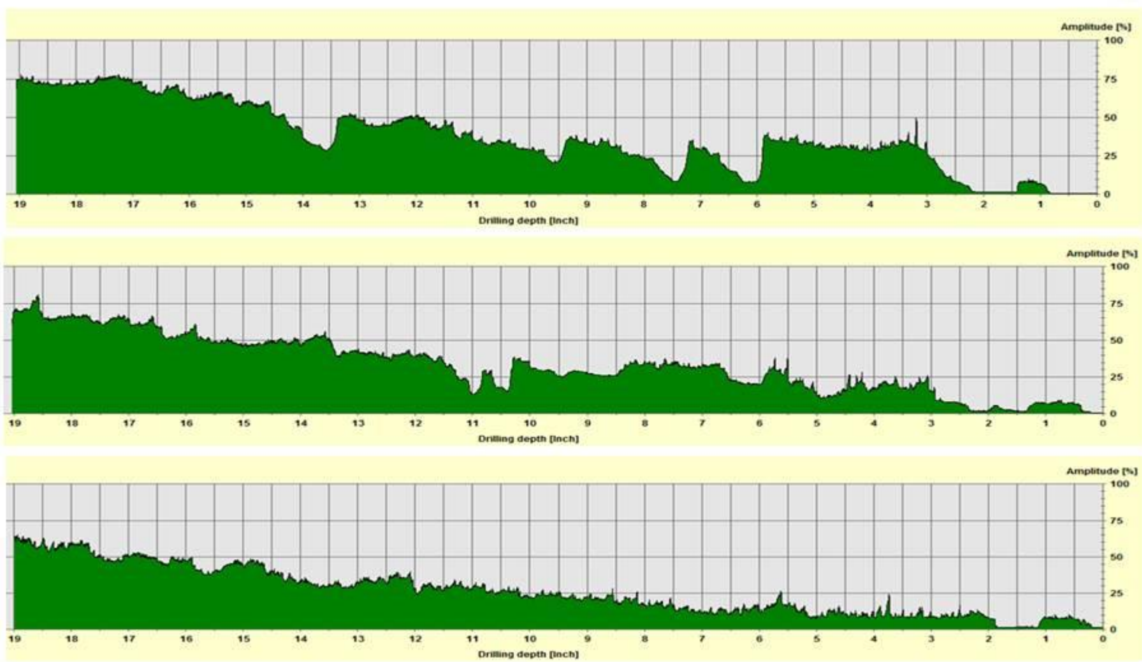
Median Likelihood of Failure (1-4 Rating)
Imminent
Probable
Possible
Improbable
Mean
Median
A
AB
AB
B
C
1
2
3
4
Limited Visual
Basic
Mallet
Drill
Tomograph
Level of Assessment

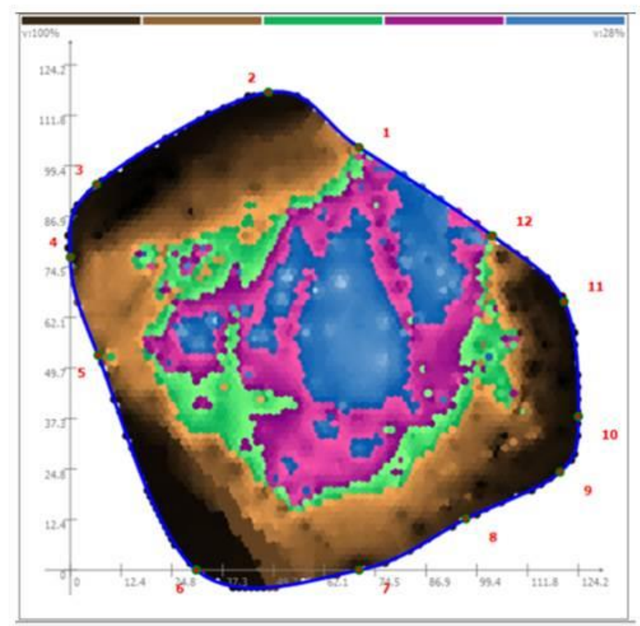


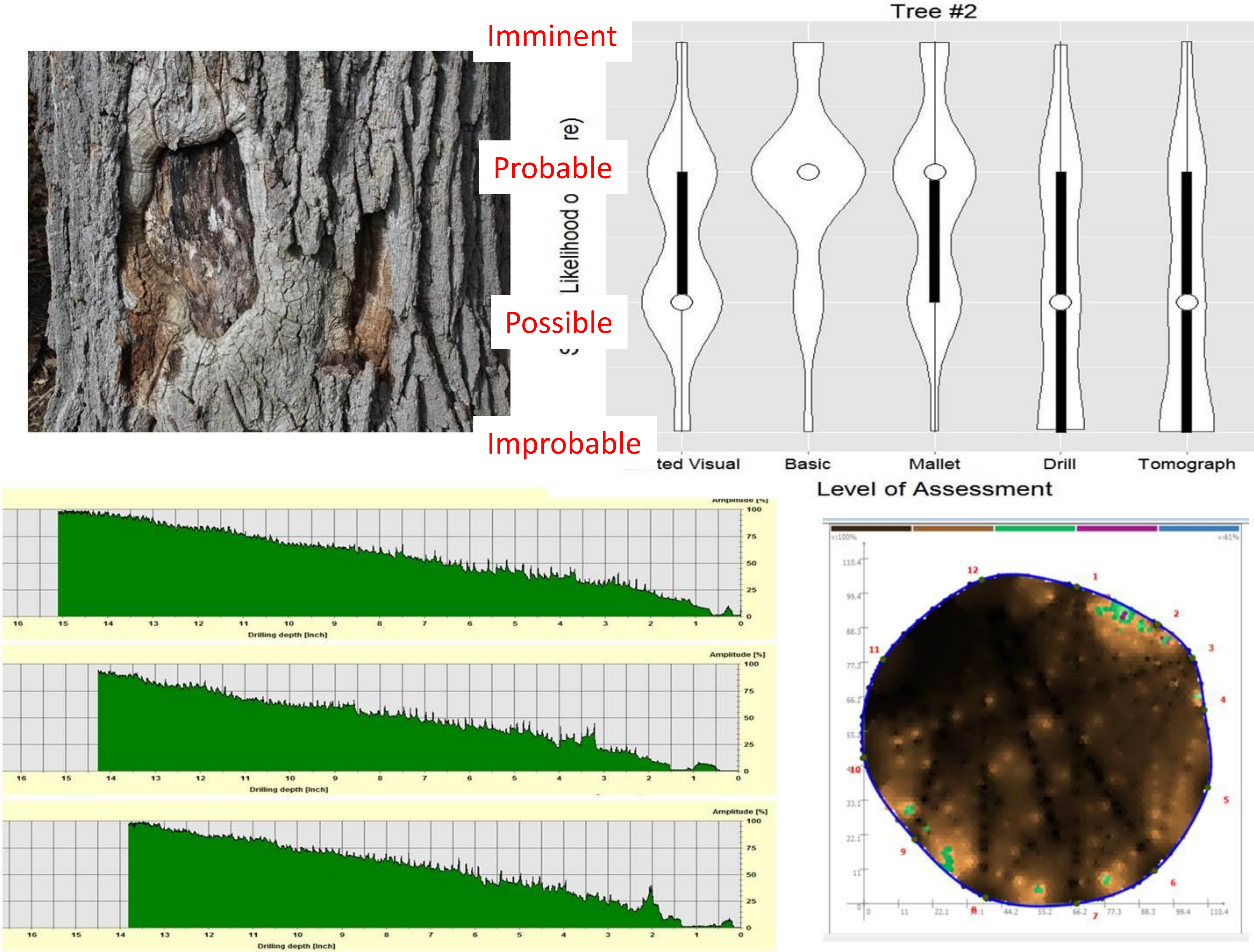
Imminent
Probable
Possible
Improbable
4
3
2
1
Mean Likelihood of Failure (1-4 Rating)
Median Likelihood of Failure (1-4 Rating)
Mean
Median
A
AB
AB
B
C
Limited Visual
Basic
Mallet
Drill
Tomograph
Level of Assessment

What about reproducibility?


Tree #1
Imminent
Probable
Possible
Improbable
Limited Visual
Basic
Mallet
Drill
Tomograph
Level of Assessment


Amplitude [%]
Drilling depth [inch]

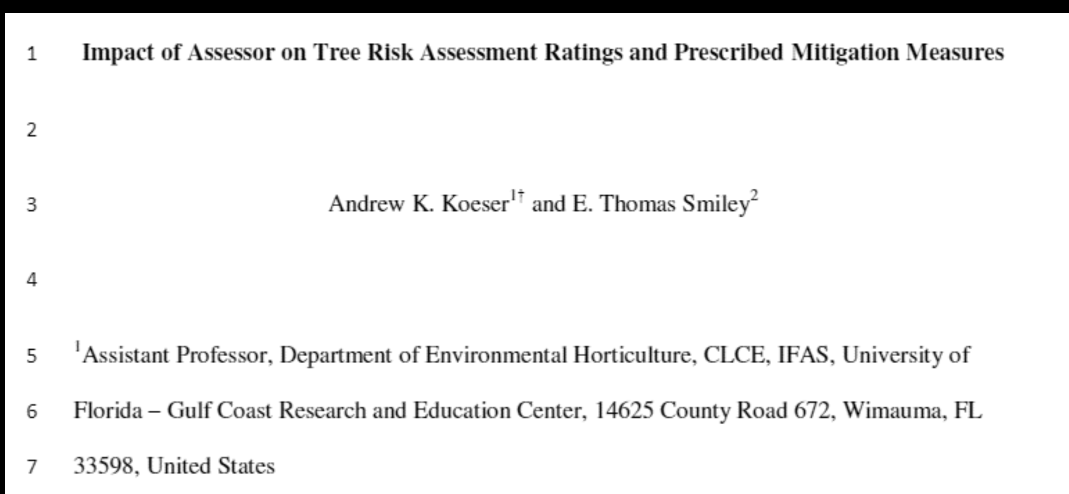



Imminent
Probable
Possible
Improbable
Tree #2
Basic
Mallet
Drill
Tomograph
Level of Assessment
Amplitude [%]
Drilling depth [inch]
Amplitude [%]
Drilling depth [inch]
Amplitude [%]
Drilling depth [inch]

Remember this study? The plot thickens…

296 Arborists assessed three trees each.

Compared sources of variation among ratings/inputs



Impact of Assessor on Tree Risk Assessment Ratings and Prescribed Mitigation Measures

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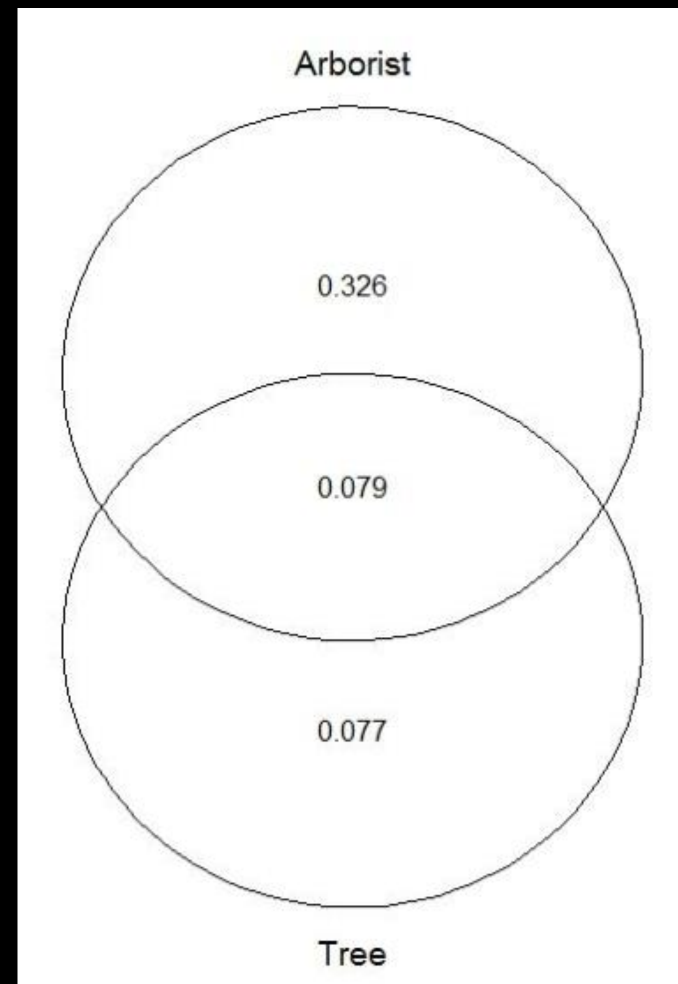

Table 3. Instances where the risk assessment inputs (i.e., likelihood of impact, likelihood of failure, and consequence of failure) were the most variable (only looking at cases where tests of equal variance were significant).

	Statistical Test of Equal Variance		
	Significant Bartlett's Test (n = 46)	Significant Levene's Test (n = 32)	Significant Fligner-Killeen Test Outcomes (n = 30)
Likelihood of Impact	28	21	19
Likelihood of Failure	2	2	2
Consequence of Failure	16	9	9
Significance (*P*-value)	<0.0001	<0.0001	<0.0001



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	Statistical Test of Equal Variance
	Significant Bartlett's Test (n = 46)
Likelihood of Impact	28
Likelihood of Failure	2
Consequence of Failure	16
Significance (*P*-value)	<0.0001

Over half of the 90 assessments had cases were variance among the inputs was unequal.

Look at which two inputs were the most likely to be the most varied…

An Explanation…

The risk ratings from this study were gut-level.

Proper risk assessment forces us to think beyond our comfort zone (tree defects).


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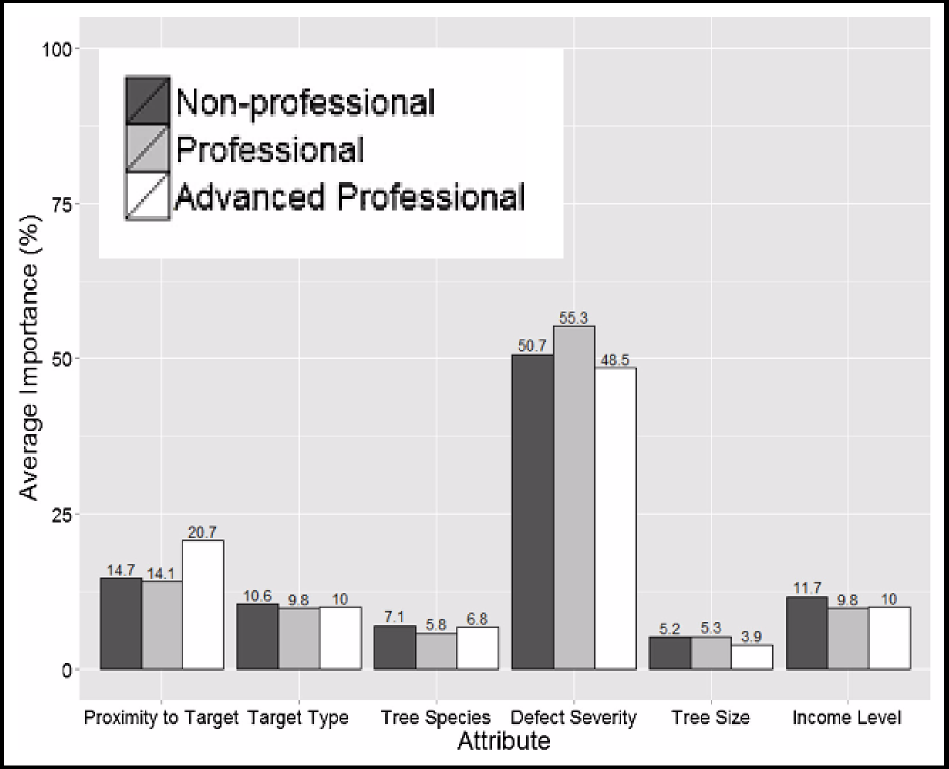
Factors driving professional and public urban tree risk perception

Andrew K. Koeser[a,*], Ryan W. Klein[b], Gitta Hasing[a], Robert J. Northrop[c]



Target Occupancy

Journal of Arboriculture 31(2): March 2005

QUANTIFIED TREE RISK ASSESSMENT USED IN THE MANAGEMENT OF AMENITY TREES

By Michael J. Ellison

- "…target value is the most significant and most easily quantified element of the [risk] assessment"
- Echoed by in ISA TRAQ Training…now multiple targets can be listed

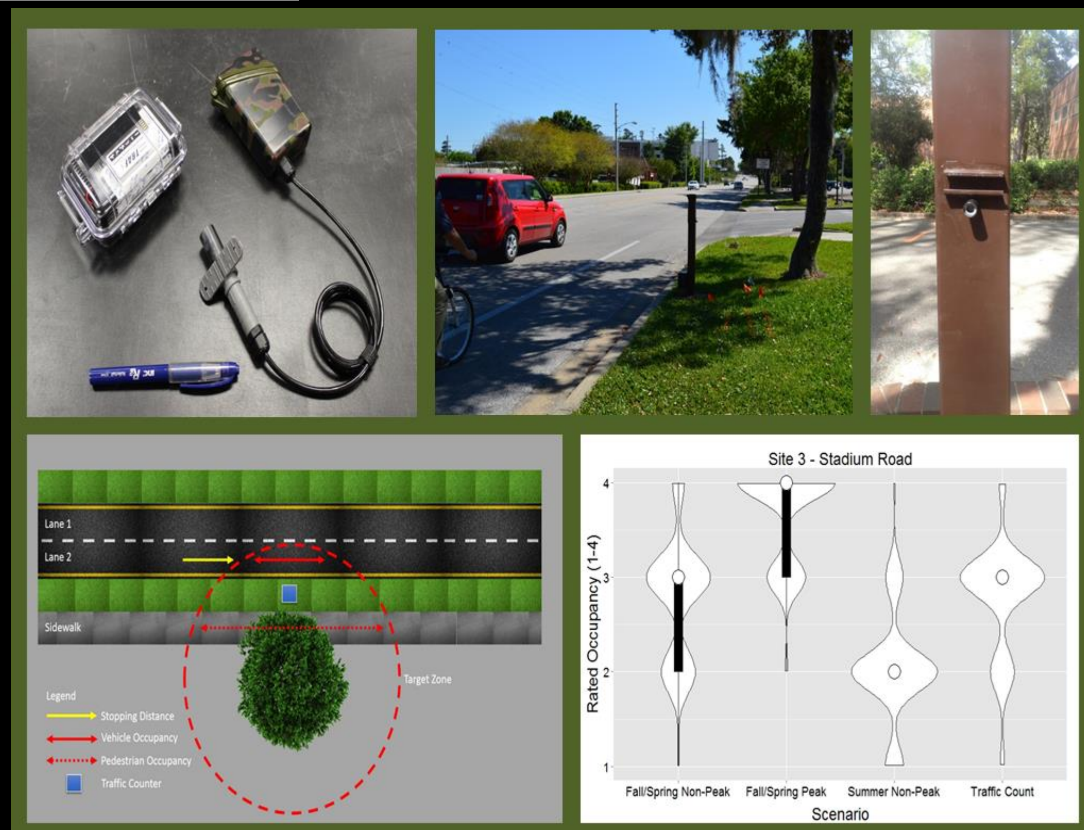
Perceived vs Real Target Occupancy

Urban Forestry & Urban Greening

Volume 19, 1 September 2016, Pages 194–201

Relationship between perceived and actual occupancy rates in urban settings

Ryan W. Klein[a], Andrew K. Koeser[b], Richard J. Hauer[c], Gail Hansen[d], Francisco J. Escobedo[e]



Actual vs real target occupancy

4 sites shown 3 times each

Video clips varied by:

- Time Filmed (peak hours vs off hours)
- Time of year (classes in/out of session)

4 video stills with traffic data shown after clips

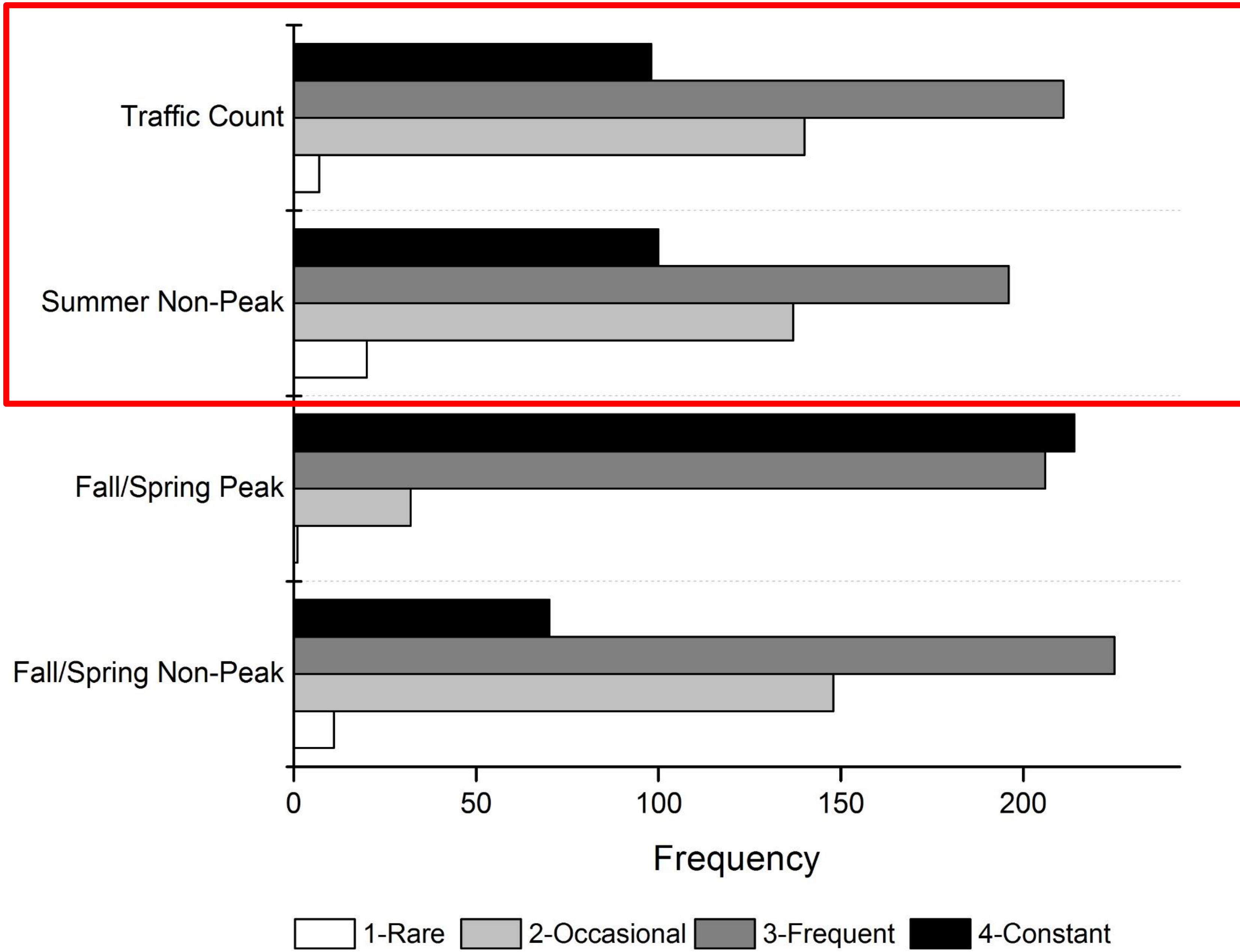
Table 1. Regression model for predicting visual target occupancy ratings given time of assessment (i.e. time of day and season of year), actual occupancy (i.e., daily average with traffic count data), rating index (i.e., median value of all ratings from an individual), and factors related to professional experience.

Factor	Coefficient	Standard error	*P*-value	95% CI lower	95% CI upper
Intercept	2.17	0.08	<0.001	2.01	2.32
Season – Fall/Spring[a]	-0.05	0.04	0.127	-0.12	0.02
Time of Day - Peak[b]	0.63	0.05	<0.001	0.54	0.72
Actual Occupancy	0.07	<0.00	<0.001	0.06	0.08
Certified – Yes[c]	-0.09	0.05	0.058	-0.18	0.00
Risk Experience – Yes	0.02	0.04	0.587	-0.06	0.10
				Adjusted R^2	0.23

[a] Compared to base level "Summer".

[b] Compared to base level "Non-peak".

[c] International Society of Arboriculture Certified Arborist.



Traffic Count
Summer Non-Peak
Fall/Spring Peak
Fall/Spring Non-Peak
0
50
100
150
200
Frequency
1-Rare
2-Occasional
3-Frequent
4-Constant

Conclusions

North American arborists have long focused solely on tree defects. This played out in several studies.

We should take heart in knowing our basic assessments can be quite consistent with regard to failure potential.

Conclusions

- Advanced equipment can give precise estimates of decay and occupancy
- However, without defendable thresholds or decision rules, risk assessments will remain variable (if not more variable).

Conclusions

For ISA TRAQ, LoI and CoF are low-hanging fruit which, if addressed, could greatly increase reproducibility.

Scientifically sound and unbiased research will improve risk assessment.

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

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

Abstract:

Urban tree failures can have significant consequences to public health and safety, and result in property damage. Standardized risk assessment methods are often applied to guide decisions regarding the safety of urban trees and to mitigate the potential impacts of full or partial failure. Worldwide, several qualitative methods are currently being used for performing tree risk assessment. Comparing these methods with regard to consistency and soundness, and ultimately understanding how risk perception can influence assessment of risk, may help reduce preventable tree failures and unnecessary removals. This review offers an introduction to the concept of risk, examines and contrasts the most commonly referenced tree risk assessment methods, and highlights environmental psychology research on public risk perception of trees and greenspaces in urban areas. General themes are summarized and gaps in the available literature are noted as a means of identifying areas of future research.

Key Words:

Decision Making; Hazard Tree; Mitigation; Public Health; Public Safety; Perception of Risks from Trees; Risk; Risk Perception; Qualitative Risk Assessment; Quantitative Risk Assessment Methods; Urban Forest.

Introduction:

Trees can provide a wide variety of benefits, as well as potential risks. While a significant body of research has been conducted on the former topic (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), there is still much that is unknown about the true risks posed by trees, with and without defects, or of the effectiveness of existing tree risk assessment methods (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). Furthermore, little attention has been given to the role professional and public risk perception plays in influencing tree care and management in urban settings. Past research and case studies have shown that there can be significant variability in the final determinations made by risk assessors in general (Ball and Watt, 2013a) and by tree risk assessors using common risk assessment methods (Norris 2007; Stewart et al. 2013). These inconsistencies among assessors were largely attributed to personal bias (Norris 2007), though more research is needed to determine if there is indeed a significant interaction between the method of assessment and the risk perceived by those conducting the assessment.

Interest surrounding tree risk has grown in recent years, and several international research summits have focused on assessment as a whole or on the biomechanics of trees as related to tree failure potential (Koeser 2009; NTSG 2011; Dahle et al. 2014). The research highlighted at the latter event (and in the greater body of biomechanics literature) has often focused on specific techniques or technologies for gauging failure potential. These include, among other things, 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), measuring the strength of different branch attachments or the lean of the trees (Lilly and Sydnor 1995; Kane and Clouston 2008), modeling wind load dynamics (James et al. 2006; James and Kane 2008), and performing comparative assessments of 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).

The aim of this literature review is to highlight past and current research on tree risk assessment and risk perception. Specifically, the paper addresses the relationship between actual risk, risk assessment, and risk perception surrounding trees. The summarization and synthesis that follows can be used as a starting point for future research intended to improve the effectiveness of tree risk assessment methods in urban areas. Additionally, it is worth pointing out that there are several gaps in the current available literature. Some of the questions that remain to be unanswered include: what is the impact of timeframe (i.e., 1, 3, 5, years etc.) on the variability of assessments, do any of the existing risk assessment methods inherently bias results, do any of the existing risk assessment methods lead to more consistent results, do any of the existing risk assessment methods bias the mitigation methods prescribed, do advanced training and credentials impact risk assessment outcomes and consistency, and are their low-tech/no tech ways of accurately assessing target occupancy? Future research on the subject matter could help to fill in some of the deficiencies in our present understanding.

Methods:

For this literature review, *Arboriculture & Urban Forestry*, *Journal of Arboriculture*, and *Urban Forestry & Urban Greening* were searched in their entirety for publications related to tree risk and the perceived risk from trees and greenspaces. Furthermore, the literature review on the topic that was compiled by Matheny and Clark (2009) was referenced. Additionally, we 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; environmental psychology. Articles in the search were not limited to any particular time frame. Throughout the search of electronic databases, articles were first assessed by their title, filtering out those that were unrelated. After this initial screening of roughly 1,000 articles, the abstracts of the remaining article were read, and again those articles that did not pertain to the scope of the review were eliminated, leaving 150 relevant articles. Finally, the 150 articles that remained were read and qualitatively analyzed for inclusion in the literature review.

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 combination of the likelihood of an event occurring and the severity of its potential consequences. 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), 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). These three components of risk are often assessed by careful consideration of environmental factors (soil, precipitation, pests, etc.) that might incite failure, species-specific failure profiles, and site history (Matheny and Clark 1994).

While it is possible to measure some factors that directly influence tree risk (i.e., target occupancy or the size of the tree/tree part of concern), in practice many of these inputs are left to the judgment of the assessor (Pokorny 2003; Ellison 2005a). Recommendations based on the assessment are then passed on to the person or persons who ultimately make the final decisions – typically a homeowner, property manager, or urban forester (Dunster et al. 2013). 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 property (Pokorny 2003).

Risk perception is a social construct influenced by memories and personal experiences (Spangler 1984; Gavin 2001; Botterill and Mazur 2004). It is used as a means to rationalize and deal with one's personal perils and worries (Slovic 1999; Botterill and Mazur 2004). Likewise, Scherer and Cho (2003) found that social networks within communities tend to share similar perceptions of risk. Depending on an individual's background, their perception of risk may or may not correspond with the reality of the situation (Renn 2004). Risk reality, the arborist's assessment of that risk, and the property manager's or homeowner's perception of risk are all interconnected and ultimately influence which risk management strategy is adopted.

In a study on tree risk management and arboriculture in Australia, Davison and Kirkpatrick (2014) explained that several of the arborists they interviewed indicated their aggravation with the great number of individuals that have an illogical fear of trees. Furthermore, they point out that these perceptions of risk can potentially negatively affect their efforts to maximize the benefits trees provide, as well as minimizing the related risks. In extreme cases, the disconnect between risk reality and risk perception can lead to unnecessary tree removal or ill-advised tree retention (Smiley et al. 2011). Accounting for these differences 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). Though all of the current and commonly used risk assessment methods consider similar components (the likelihood that all or part of the tree will fail, the likelihood of the target being present/struck, and the consequences of failure), there is a great deal of variability that can arise between assessors and among individual assessments. None the less, the use of these components is a crucial part of the assessment and, if used properly, can add to the accuracy and legitimacy of a tree risk assessment.

Components of Tree Failure: Likelihood of Impact, Failure Potential, and Consequences of Failure:

LIKELIHOOD OF IMPACT AND TARGET OCCUPANCY. The presence or absence of a target is considered 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). That said, most urban sites have multiple targets present at any given time (Dunster et al. 2013). When evaluating tree risk, it is important to assess a particular target's level of occupation, 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.

In a study on the tree risk assessment used for the management of amenity trees, Ellison (2005a) evaluated the occupancy of vehicular targets based on Great Britain's 1996 transportation statistics. In one example, Ellison calculated vehicular occupancy for a point a motorway (comparable to U.S. highways and freeways) was 27.5 hours per day (on average; 2005a) This was in part due to the intense magnitude of traffic that frequents this particular road classification. While values for occupancy in high traffic areas can exceed 24 hour a day, they simply represent constant occupancy. This means that the probability of a tree failure impacting a vehicle or a vehicle impacting a fallen tree was 1/1.

In calculating vehicular occupancy, Ellison (2005a) considered the minimum stopping distance plus average vehicle length (D), divided by the average vehicle speeds (S), which renders the time a vehicle occupies the space needed to come to a stop (T). T was then multiplied by the average number of vehicles per day (V) to get the total number of hours per day a point on the road is occupied (H). The equation used by Ellison (2005a) to calculate vehicular occupation and the probability of impact (P) was D3600 ÷ S1000 = T; TV = H3600; H ÷ 24 = P. This particular study showed just how important the presence of a target can be when assessing the risk posed by a given tree.

Ellison (2005a) also noted that target occupancy can be easily quantified with the use of 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 5 minute surveys were up to three orders of magnitude less than those derived from the professional judgement of a trained tree assessor. Since elevated levels of risk are so closely tied to human activity, mitigation plans in areas with greater property values and higher levels of human traffic must be devised to help lower any unacceptable threats caused by trees (Pokorny 2003). Despite the potential benefits of traffic counters, many arborists rely on a quick visual assessment of site occupancy. These subjective assessments likely lead to less accurate and more variable estimates of target occupation (Klein et al., 2016).

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 increase 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), 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; Wassenaer and Richardson 2009). Terho and Hallaksela (2005) assessed the potentially hazardous characteristics of *Tilia*, *Betula*, and *Acer* in downtown Helsinki City, Finland, and found that roughly 50-70% of potential failure points in park trees that had been removed were isolated to the lower portion of the tree (roots, root flare, trunk). In a separate study, 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.

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 (Wessolly 1995; 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 forester in identifying the factors that elevate a tree to a higher potential for failure (Kane et al. 2001).

Following an ice storm in the Northeastern United States and Eastern Canada where 84% of the trees that failed had pre-existing defects, it was suggested that most of the defects contributing to tree or branch failure could be identified and mitigated with appropriate tree planting and maintenance practices (Johnson 1999). They believed that the majority of defects could have been easily identified. Likewise, following both hurricane Andrew in 1992 and the 2004-2005 hurricane seasons in Florida, trees that had been properly pruned properly (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). Additionally, the study makes mention that trees with poor structural forms and or defects, such as codominant stems, are more susceptible to the damaging effects of a hurricane. Similarly, Hickman et al. (1995) evaluated 695 native oak trees in a California recreational area that had previously been assessed for failure potential. They found that, of the original 695 trees, 60 (8.7%) had failed within 7 years of the original study. Of the tree defects 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 entire tree failure.

CONSEQUENCES OF FAILURE. When assessing the potential for a tree to fail, it is important to consider the resulting consequences in the event of that failure. Consequences to infrastructure can be minimal, such as damages that result 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). When Schmidlin (2009) looked at wind related tree failures in the United States that resulted in the loss of human life, he found that from 1995-2007 there were 407 deaths at an average of 31deaths per year. Ellison (2007) cited a study (ANON 2006) which 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 (HSE) Sector Information Minute (SIM) equates the likelihood of being killed by a tree in a public space to be 1 in 20 million. This was then compared to the likelihood of being struck by lightning (1 in 18.7 million; Health and Safety Executive 2007) and the likelihood of being killed in an automobile accident (1 in 16,800; http://www.hse.gov.uk/education/statistics.htm). Ball and Watt (2013b) explain 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.

Tree Risk Assessment:

Basic visual assessments may not catch defects which cannot be seen externally on the tree, such as internal or incipient decay (Dolwin et al. 1999; Guglielmo et al. 2007). However, there is some evidence which indicates an experienced arborist may be able to assess the likelihood of tree failure based on an external evaluation with some level of accuracy (Koeser et al. 2016). Hickman et al. (1995) conducted visual tree assessments on 695 oak trees in 1987. Upon returning to the site in 1994, the researchers found that the assessments proved accurate 83% of the time for standing living trees and 78% of the time for trees that had failed. Hickman et al.

(1995) concluded that the data they collected from the use of the proposed assessment system, which evaluates lean, trunk condition, and decline, could be used to predict failure.

Thus, even though visual assessments are inherently subjective, if they are used in conjunction with an educated understanding of the factors that can cause a tree to fail, visual assessments can still prove useful (Gruber 2008). That said, studies where visual risk assessment techniques were found to be scientifically sound, yet practical (Koeser et al. 2016; Rooney et al. 2005; Hickman et al. 1995) should be viewed somewhat critically as they typically used a limited number of assessor(s) to reduce variation in their assessments. As such, it is not clear if the performance of the individuals conducting the assessments is typical of what the larger population of risk-assessing arborists could accomplish or if this approach is abnormally effective (i.e. we are reading about outliers). Studies which compare the results of multiple assessors on the same tree would help address this question.

Terho's (2009) *post-mortem* assessment of decay in trees that were felled as hazardous, found that fruiting bodies at the base of the trunk 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 can 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, they were able to identify which species performed best in the urban environment and which species posed the greatest hazards to the public.

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., we do 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; Fink 2009; Dunster et al. 2013).

Basic visual assessments can be done from the base of a tree, by an assessor on foot (allowing the assessor a 360-degree view in some cases) or from the perspective of a street view when an assessor performs a limited visual inspection, such as a walk-by or drive-by assessment (ANSI 2011, Smiley et al. 2011). Rooney et al. (2005) compared these two levels of visual tree assessments and contrasted ratings from windshield surveys to those derived from traditional walking inspections. The study concluded that, despite the limited vantage point and time frame associated with the limited visual (i.e. windshield) assessments, they were able to accurately identify trees which posed the greatest risk (Rooney et al. 2005). In an urban forest management scenario, managers are often unable to address all the issues they see during an inspection and focus their mitigation efforts on the trees that pose the greatest threat to potential targets (Pokorny et al. 2013). In a study of drive-by assessments, Rooney et al. (2005) point out that limited visual surveys can be an inexpensive and efficient means of assessing large populations of trees, especially for urban forest management or utility vegetation management.

Environmental Psychology and Risk Perception:

As explained above, the risk associated with a tree is related to its potential influence on the health and safety of the public, damage to property, and disruption of any human activities. Sjoberg et al. (2004) defined risk perception as “the subjective assessment of the probability of a specified type of accident happening and how concerned we are with the consequences.” Smiley et al. (2011) noted that the perception of risk and threats to personal safety can vary from person to person. When acting to address this perceived risk, individuals make decisions based on their own risk tolerance (Bechtel and Churchman 2003; Dunster et al. 2013). A tolerable level of risk to one person might be unacceptable to another. As such, when an arborist assesses the potential risk of a tree, a property manager or home owner may opt for mitigation measures that do not reflect the actual risk posed by the tree (e.g. removing a large, but sound tree overhanging their home or retaining a severely compromised tree).

Like risk, many of the costs and benefits of trees used to justify tree retention are framed from a human perspective (e.g., impact on property value, ability to reduce summer cooling bills, providing a sense of place). As such, mitigation decisions are a balance of often competing human needs. The pressing concern of risk, coupled with maintaining an equilibrium between costs and benefits and other aspects of the human relationship with the environment has been explored in detail within the field of environmental psychology (Starr 1969; Fischhoff et al.

1978; DeYoung 1999; Finucane et al. 2000). Developed in the late 1960's, environmental psychology emerged as a field focused on the relationship between human behavior and physical settings, which prior to this had been essentially overlooked (Gifford 2007).

Early risk perception work was conducted in the 1960s, as researchers looked to understand public opposition to policies surrounding nuclear technology (Sowby 1965). Starr (1969) looked at how people justified the use of automobiles and airplanes by weighing the benefits to quality of life against a voluntarily accepted level of risk. In the 1970s, psychologists investigating how people respond towards decision making with respects to risk, continued to look at this idea of "how safe is safe enough", they went a step further and concluded that not only is a person's risk acceptance based of the perception of benefits, but also on things such as control, catastrophic potential, familiarity, and uncertainty related to the level of risk being posed (Sjoberg et al. 2004). Starting in the 1980s (Slovic et al. 1982; Slovic 1987), Sjoberg et al. (2004) explained that some experts believe risk perception can be seen as a deterrent to rational decision making; people have a tendency to see risk in a given situation where, in reality, none actually exists. Botterill and Mazur (2004) noted that expert and public perceptions differ; the public tends to be more alarmed and their perception of risk arises from uncertainty surrounding risky activities. Additionally, they explained that consequences are often seen as extremely negative, even if the probability is low. Lastly, it was pointed out that the public has a tendency to focus in on the issues that experts do not understand fully and are unable to agree on.

Sometimes a person's perception of safety and the associated risks that they are willing to accept have more bearing on a decision than the actual reality of the risk. Pokorny (2003) suggested avoiding decisions based on emotions, perceptions, and local politics, and moving towards a more objective science-based assessment of potential risk. Having a better understanding of where reality is removed from the context of the decision making process and a person's perceptions takes over is key to the consistency of any assessment method, no matter the validity. If a person perceives that a situation poses a high level of risk, then it is likely that their decisions regarding said situation will reflect their possible perception of the situation harboring a great deal of risk. Moore (2014) illustrated that much of the time requests for tree removals are based on unsubstantiated fear; the removal of healthy trees has unexpected consequences and costs associated with it. Moore (2014) suggests that arborists and managers should attempt to make logical decisions based on supported data, consider the long-term consequences associated with such tree removals, and should perform a cost benefit analysis to justify their decision. Smiley et al. (2011) explained that decisions to remove trees are not solely based on the perception of reality; safety, historical and environmental significance, budget, aesthetics, and many other issues may influence the decision.

Tree Risk Assessment in the Urban Forest:

The history of tree risk assessment is still relatively short. Most sources cite Wagener's work with recreational sites in California (1963) as being the first to touch on the idea of trees being hazards to both people and property (Pokorny, 2003; Kane et al. 2001; Norris, 2007). Others cite later work by Paine (1971), who also worked to assess the risk associated with trees in recreational areas (Pokorny 2003; Ellison 2005a; Norris 2007). Tree risk assessment was largely limited to recreation areas through the 1970s and much of the 1980s (Johnson and James 1978; Johnson 1981; Mills and Russell 1981). Helliwell (1990) proposed the need for a quantified risk assessment of trees in his article *Acceptable levels of risk associated with trees*; this idea of quantifying tree risk assessments was further addressed by Ellison (2005a) in his work on the management of risk from amenity trees.

Matheny and Clark (1991) released A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas; the book was later revised in 1994. This publication is generally cited as the first comprehensive guide for tree risk assessment (Pokorny 2003; Kane et al. 2001; Hayes 2002; Ellison 2005b; Norris 2007; Wassenaer and Richardson 2009). The system that they proposed focused on three key components to determine the hazard level of a tree: failure potential, size of the part likely to fail, and the target rating (Ellison 2005a). Many others have since contributed similar efforts to the field and some of the most current and commonly used methods are: International Society of Arboriculture (ISA) Tree Hazard Evaluation (Matheny and Clark 1994), visual tree assessment (VTA) (Mattheck and Breloer 1994), United States Department of Agriculture (USDA) Forest Services community Tree Risk Evaluation Method (Pokorny 2003), Quantified Tree Risk Assessment (QTRA) (Ellison 2005a), ISA Tree Risk Assessment Best Management Practice (BMP) Method (Smiley et al. 2011; Table 1). The methods detailed in Table 1 are not a comprehensive list, rather they represent some of the more well received methods in the tree care industry today.

The International Society of Arboriculture (ISA) Tree Hazard Evaluation (Matheny and Clark 1991), based on Matheny and Clark's (1994) A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas, was devised to help locate and manage the risks associated with trees in an urban area. The method is centered on three main components: 1) the potential failure of a tree, 2) environmental aspects that are conducive to failure, and 3) the potential injuries of people and damages to property. A numerical value from 1-4 is given to each component, then all three components are added together to achieve the trees hazard rating. The assessment method focuses on tree characteristics and health; past and present site conditions; recognizing and assessing structural defects in the root crown, trunk, scaffolds, and branches; evaluating the most probable failure; assessing the targets significance; and developing a hazard rating (Matheny and Clark 1994).

United States Department of Agriculture (USDA) Forest Services Community Tree Risk Evaluation Method presents options for two different survey types, the walk-by inspection and the drive-by inspection. Pokorny (2003) explained that both risk assessment methods are designed to identify the defects of trees within proximity of a target, gauge the severity of the defects, and to make recommendations for mediation prior to failure. There are three risk rating systems for these methods, ranging from low (where no mitigation is needed), to moderate (currently defects do not meet the failure threshold), to high (where corrective action is needed immediately). The risk rating system has three components: probability of failure (1-4 points), size of the defect (1-3 points), and the probability of target impact (1-3). Added together, these factors result in a numerical risk ranking ranging from 3-10 (Pokorny 2003). Pokorny (2003) mentions an additional judgment rating of 0-2 points, and suggests use in situations where the risk should be increased; for example, points might be added to the risk rating for a species that is more prone to failure. The evaluation is based on noticeable defects, surrounding targets, and site conditions, and is useful for all trees within proximity of hitting a target (Pokorny, 2003).

The ISA Tree Risk Assessment Best Management Practice (BMP) method (Smiley et al. 2011) was developed to specifically aid tree care professionals with tree risk assessment, providing the most up to date information on the related science and technology, for the purpose of evaluating risk and recommending mitigation while avoiding issues pertaining to tree risk management (Smiley et al. 2011). The BMP method was designed to allow the user to select from a wide array of assessment techniques, depending on the needs of the assessor, available resources, existing information and data, and the level of expertise required; focusing more on qualitative aspects, but not excluding the use of a quantitative approach (Smiley et al. 2011). The method 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 then collectively using qualitative terms (ranging from unlikely, somewhat likely, likely, very likely) on a table to estimate risk potential. The assessor then categorizes (ranging from negligible, minor, significant, to severe) the consequences of failure based on the value of the target and the damage that is likely to occur.

The Visual Tree Assessment (VTA) (Mattheck and Breloer 1994) method evaluates the tree structure based on the presence of stressors through the use of a three step process. First the tree is visually inspected for any noticeable defects, as well as examining the overall vitality of the tree. The next step is to thoroughly examine any of the defects that had been observed. Finally, the defects are measured and analyzed to assess the general strength of the tree.

The Quantitative Tree Risk Assessment (QTRA) (Ellison 2005a) method is based on the three assessment components suggested by Matheny and Clarks (1994). The most recent version of the QTRA (2015) method adds a fourth component, known as the QTRA Risk Advisory Threshold, which takes into consideration the concepts of 'As Low As Reasonably Practicable' (ALARP) (HSE 2001) and the 'Tolerability of Risk framework' (ToR) (HSE 2001). The addition of this fourth component is to help the assessor customize the assessment and associated management of a tree to meet the preferences of the homeowner or tree manager, and as a means of balancing the costs and benefits associated with the management of a given tree. Once determined, the first three components (target, size, probability of failure) are assigned independent probabilities, combined to determine Risk of Harm. The Risk of Harm is then compared to the fourth component (risk advisory threshold) and assigned an associated action that the arborist can recommend to the homeowner or tree manager. Ellison (2005a) explained that the depth of the inspection for a given tree will depend on the available access in a given area; a high level of access would allow for a more detailed inspection and a low level of access might only permit a general inspection. Although this method is labeled as quantitative, it is worth pointing out that, currently, are no true quantitative approaches, all require personal judgement to some extent. Still, advances are being made to correct this with the use of target occupancy. For example, Klein et al. (2016) used traffic counters to quantify the target occupancy portion, which is commonly used in most current risk assessment methods. The results suggest that there is a possible relationship between an arborist who are ISA certificated and a more accurate understanding of actual occupancy data and that these arborists can apply ratings that mirror such interpretations.

Standardized urban forestry risk assessment methods offer a consistent process for inspecting and documenting potential issues of concern (Hayes 2002). The need for such assessment methods stem from the effects of tree failure on public health and safety legislation (Forbes-Laird 2009), fears of liability and litigation (Ellison 2007), and a recognition of the ecological benefits of trees (Ellison 2005a; Wassenaer and Richardson 2009).

Assessment Method	Main Components	Rating Formula
The International Society of Arboriculture (ISA) Tree Hazard Evaluation (Matheny and Clark, 1994)	The potential Failure of a tree, Environmental aspects that are conducive to failure, and Impacts to people and property	A numerical value from 1-4 is given to each component, then all three components are added together to get the trees hazard rating
United States Department of Agriculture (USDA) Forest Services community Tree Risk Evaluation Method (Pokorny, 2003)	Defects of trees within proximity to a target, gauge the severity of the defects, and makes recommendations for mediation	The three components are added together to render the risk rating, an additional judgment rating of 0-2 points is suggested in situations where the risk should be increased Probability of failure (1-4 points) Size of the defect (1-3 points) Probability of target impact (1-3) Rating system ranges from low (no mitigation is needed) to high (corrective action is needed immediately)
The ISA Tree Risk Assessment Best Management Practice (BMP) Method (Smiley et al., 2011)	Likelihood of failure, the likelihood of impacting a target, and the potential consequences	Three main components are assessed through the use of two matrices' and qualitative terms Matrix 1 combines the likelihood of failure and the likelihood of impacting a target (unlikely, somewhat likely, likely, very likely)

		Likelihood of failure (improbable, possible, probable, imminent) Likelihood of impacting a target (very low, low, medium, high) The assessor then categorizes the consequences of failure (negligible, minor, significant, severe) based on the value of the target and the damage that is likely to occur Matrix 2 combines the likelihood of failure and impact with the potential consequences to render the level of risk (low, moderate, high, extreme)
The Visual Tree Assessment (VTA) (Mattheck and Breloer, 1994)	Visually inspected for any noticeable defects/overall vitality of the tree, defects are examined closely, and then the defects are measured and analyzed to assess the general strength of the tree	
The Quantitative Tree Risk Assessment (QTRA) (Ellison, 2005)	Probability of failure, impact potential, and target value	The three main components are assessed through the use of a range of probabilities (e.g., 1/1 to 1/19 and 1/20 to 1/100) which are then further assessed using the developed QTRA field calculator to render the level of risk

Despite some notable differences, the most commonly referenced and employed risk assessment methods use a framework with a great number of similarities (Table1). At its core, tree risk assessment includes: an assessments of the tree structure, defects, and subsequent evaluation tree failure probability, an assessment of targets, and an appraisal of the potential damage caused should a target be struck (Matheny and Clark, 1994; Mattheck and Breloer 1994; Ellison 2005a; Meilleur 2006; Matheny and Clark 2009; 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). Ratings systems for each of the risk assessment methods assign different numbers to work towards the same results and associated recommendations. For example, the International Society of Arboriculture (ISA) Tree Hazard Evaluation (Matheny and Clark 1991) uses a rating system that goes up to 10 points with 4 points going to failure potential, whereas, the United States Department of Agriculture (USDA) Forest Services Community Tree Risk Evaluation Method (Pokorny 2003) goes up to 12 points and all three inputs have 4 possible points. Matheny and Clark (2009) noted that there are no studies that test and evaluate different risk assessment methods. They also note that there is still uncertainty among professionals about the importance and accuracy of assessment methods (Matheny and Clark 2009). Norris (2007) compared a number of risk assessment methods in a series of controlled experiments. The author used two different sets of trees with a multitude of targets, failures, and consequences, which were assessed by 12 experienced arborists, each using 8 methods of assessment. This work highlighted inconsistencies in current assessment methods and different assessor's perceptions of risk. 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 modelling of any risk assessment method must be assessed if it is to be widely adopted. Finally, the study found that the evaluations of arborists varied greatly and it is assumed that this is due to each arborist's individual inherent attitudes towards risk.

Some studies have highlighted how risk rating systems can be inherently flawed and can present a misinterpretation of posed risk. For example, Cox et al. (2005) explains that, though qualitative risk rating systems are increasingly the basis for real-world risk rating throughout many different fields, these systems can assign higher risk ratings to situations that realistically present a low level of risk (reversed rankings). These systems have a tendency of labeling 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 apart from another risk that is assigned a similar rating. Beyond raising concerns over qualitative methods in general, Cox (2008) suggests that matrix-based risk systems have additional limitations, including poor resolution in relation to selected hazards, assigning the same risk rating to two unequal risks, assigning higher qualitative ratings to risks that pose lower levels of quantitative risk which can lead to erroneous decision making, allocation of resources to mitigate a risk that are unequal to the actual risk, and that decisions based on rick matrix outputs are the result of subjective inputs. Depending on the user, such risk matrices can render completely different ratings of risk and that these systems should be used with caution.

Few studies exist which independently test the validity and consistency of risk assessment methods (Matheny and Clark 2009). Beyond the thesis work by Norris (2007), no research has offered a comparison of competing risk assessment methods. To date, there has been no outside assessment of the new ISA BMP risk assessment method (Smiley et al. 2011). Most of the reviewed studies either support (Ellison 2005a; Fink 2009; Bond 2010) or dispute (Gruber 2008) the underlying logic and assumptions associated with a given risk assessment method.

Matheny and Clark (1994) appears in several risk related articles (Kane et al. 2001; Hayes 2002; Ellison 2005a; Wang and Allison 2008), as does Mattheck and Breloer (1994) (Manning et al. 2002; Kane 2004; Wang, 2008; Fink 2009; Wassenaer 2009). Overall, we found that the United States Department of Agriculture (USDA) Forest Services Community Tree Risk Evaluation method (Pokorny 2003), the ISA Tree Risk Assessment Best Management Practice (BMP) method (Smiley et al. 2011), and the Quantified Tree Risk Assessment (QTRA) (Ellison 2005a), which are discussed here, very rarely show up in any of the tree risk literature.

Public Perceptions of Trees and Open Spaces in an Urban Area:

When looking at risk perception research related to arboriculture and urban forestry, the bulk of the available research shared a similar approach to assessing the public's perceptions for groupings of urban vegetation, not individual trees (Roovers et al. 2006; Zheng et al. 2011). Most studies used photographs and surveys (Schroeder 1982, 1983; Talbot and Kaplan 1984; Smardon 1988; Jorgensen et al. 2002; Roovers et al. 2006; Jorgensen and Anthopoulou 2007) to better understand how people view such areas. Schroeder et al. (2006) explained that research has consistently shown that urban residents have positive perceptions of trees and that their benefits outweigh their annoyances.

It is well accepted by environmental psychologists that contact with nature is fundamental to human health and the well-being of people in urban areas (Rohde and Kendle 1994; Kuo et al. 1998; Ozguner and Kendle 2006). It is therefore rational that people have many positive associations with urban vegetation and natural spaces. In a telephone survey of Charleston, South Carolina 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 feature 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, in Florida. They found that even though these areas are highly susceptible to hurricanes and the resulting damage caused by trees, 57% of the respondents from both counties were in agreement with regard to increasing the size of their urban forests.

Many studies have found that people find urban parks and greenspaces to be relaxing, peaceful, educational, and scenic (Schroeder 1982; Smardon, 1988; Jorgensen and Anthopoulou 2007). Schoeder (1982) illustrated that the urban forest is important because it allows for recreational activities; for those living in metropolitan areas, this might be their only contact with nature. When reading through the related literature, it became apparent that there was a common theme related to how people perceive trees and natural spaces in urban areas. The idea of preference (Schroeder 1982; Talbot and Kaplan 1984; Jorgensen et al. 2002; Zheng et al. 2011) continuously played into people's perception of various natural settings. In their study on preferences and perceptions of natural and designed landscapes in the city of Sheffield (UK), Ozguner and Kendle (2006) found that even when respondents perceived two sites to both be natural, it was their preferences of how they thought the natural area should look that ultimately dictated their perceptions of security. For example, they explained that when the vegetation was unmaintained and more natural in appearance, this resulted in some people having a lower perception of security for a particular natural space.

The perception of safety was a reoccurring issue among most of the research that was examined for this review. Many studies (Schroeder and Anderson 1984; Shaffer and Anderson 1985; Bjerke et al. 2006) mentioned that the perception of safety decreased as visibility decreased due to increased vegetation density and that areas that were better maintained where perceived as being safer. Jansson et al. (2013) elucidated that these commonalities, such as landscape design, feelings of being in control, vegetation density, and vegetation maintenance as they relate to personal safety in woodland vegetation, can be further investigated and applied to studies focusing on urban forests. Linked to this view of personal safety is the perception that green spaces in urban areas are associated with harboring criminal activities (Jansson et al. 2013). Similarly, Jorgensen et al. (2002) commented that some people do not enjoy the benefits of urban parks due to their perceptions of fear. It has also been pointed out that people's perceptions of these areas are affected by their preference between a natural landscape and that of a designed landscape (Ozguner and Kendle 2006; Zheng et al. 2011). The perception of safety is vital to the likelihood of an urban forest being used and appreciated (Schroeder 1990; Pokorny 2003). To reiterate, the majority of these studies were conducted using photographic surveys, Ozguner and Kendle (2006) concluded that how people view settings in photos is different than how they see those same places in person. Therefore, it might be of value to conduct future surveys on site rather than through the use of photographs, as a comparison to test the variances in perception between the two methods.

Conclusion:

Overall, this review shows that there is scarce literature that focuses specifically on the perceptions of risk as related to the failure from an individual tree (Koeser et al. 2015). The bulk of the research addresses the perception of benefits, personal preference, and the safety concerns for urban parks and green spaces. Though the current available literature related to risk perception provides insight into the differing perceptions between gender, age groups, education, and cultural backgrounds, 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 those risks. 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 in the industry. Standardizing a method would allow for consistency among assessments, potential lowering liability, but also better equipping the managers and home owners who make decisions that change the face of our urban forests. Current models of tree risk assessment serve their purpose, but could be improved in many ways; assessing existing methods for effectiveness, biases, and sensitivities could promote the rise of a more efficient method of assessment. In a study that evaluated the impact of assessor training and the related tree care industry credentials of 296 arborist, Koeser and Smiley (Submitted) found that those individuals that had both were more likely to assign a tree a lower risk rating, which resulted in professional recommendations that leaned on the side of less aggressive mitigation (e.g. avoiding tree removal). Additionally, they found there to be a great deal of variability among risk ratings for the various components of the risk assessment (likelihood of impact, consequences of failure) and that this was due to the assessments of the individual assessor.

Future research must continue to tease out biases inherent to a given risk assessment system, inputs that are overly sensitive to assessor judgments (leading to excessive variability). Additionally, research should look at how factors like the time frame of the assessment (e.g., 1, 3, or 5 or more years) impact the reproducibility of risk assessments. Moving towards a more quantitative risk assessment approach will help to advance our understanding of risks from tree failure. When the trees in question are on private property, it is ultimately the home owner that makes the final decision as to the mitigation. This decision is likely based on their own perceptions of risk and also the assessment of the consulting arborist. In the case of a municipality, the decision falls on the local management. Again, it is the perception of risk and the method of assessment that will ultimately lead to the final verdict. Given the importance of both risk perception and a standardized assessment method, future research has the potential to offer a great deal of insight that will further the understanding of the discipline.

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