THE PREDICTABILITY OF TREE DECAY BASED ON VISUAL ASSESSMENTS

by Deborah K. Kennard, Francis E. Putz, and Meg Niederhofer

Abstract. A field study was conducted to measure the predictability of tree decay based on visual assessments. Predictions made by individual arborists, tree surgeons, and forest ecologists were compared with the actual amounts and distributions of decay in 10 hazardous laurel oaks *(Quercus hemisphaerica)* that were dissected. The mean deviations of predicted area of decay and predicted loss in strength from actual values were 0.4% and 2%, respectively. The interquartile range for predicted decay area was +12 to −15%; for strength loss it was +8 to −8%. Accuracy of the predictions improved with feedback. The results of this study suggest visual assessment can be a reliable means of predicting the internal extent of decay and hollow in potentially hazardous urban trees.

Urban trees provide shade, improve air quality, lower noise levels, provide habitat for wildlife, protect soil, and are aesthetically pleasing (2,8). However, such trees can be hazardous, particularly when they are large, old, and partially decayed. Although city managers are responsible for removing or otherwise treating hazardous trees growing on city property, they are also responsible for maintaining urban canopies and therefore minimizing unjustified tree removal (5). The difficulty arises in predicting which trees are actually hazardous and should be removed.

Trees are deemed hazardous on the basis of their predicted likelihood of failure, commonly estimated by examining trees for defects and associating those defects with observed patterns of failure. Identifying hazardous trees is and will continue to be a somewhat subjective process. Although information on tree biomechanics has increased greatly in the last few decades, the nature of tree failure remains largely unknown (4). The capacity to predict which trees will fail is also limited by the ability to visualize the amount of internal defects in trees. Commonly, external signs such as cankers, fungal fruiting bodies, cracks, and wounds are used as indicators of tree defects. Visual assessment can give an idea of the state of a tree's overall health (4,5) but may not always predict the extent of internal decay accurately. External signs of decay may be misleading, or trees may show no signs of internal defects.

In response to the need to predict more accurately the extent of decay and hollow in trees, several tools have been developed in the past few decades. Nonintrusive methods such as stress wave timers or x rays are designed to detect the presence of decay with minimal damage to the tree (5). Intrusive methods include simple tools, such as drills or increment corers, and more sophisticated tools, such as the Shigometer, Resistograph, and Vitamat (1,5,7). Each of these methods is not without drawbacks. Intrusive methods wound trees and may allow spread of decay into uninfected parts. All but the most simple methods are expensive and not always practical for field use. Only the Shigometer has been frequently tested, but reports on the reliability of this method are conflicting (1).

Until technical methods of assessing tree decay become less expensive and more practical for field use, urban tree managers will continue to rely primarily on visual tree assessment in designating hazardous trees. The question remains: How accurately can tree decay be predicted by visual assessment? The present study tested the predictability of wood decay on the basis of external characteristics. Predictions made by a number of individual arborists, tree surgeons, and forest ecologists were compared with the actual decay in hazardous trees that were cut down and dissected. The distribution of decay can affect stem strength more than might be expected from the amount of decay, e.g., peripheral decay causes more loss in stem strength than centrally located decay. Therefore, in addition to the total amount of decay, the actual strength loss calculated using the distribution of decay was also compared with predictions made by the evaluators.

Methods

This study was conducted in Gainesville, Florida (29° 30'N, 82° 15'W) and focused on laurel oaks *(Quercus hemisphaerica),* the most common species on City of Gainesville rights-of-way and the most common species classified as hazardous (3). Laurel oaks were planted extensively in Gainesville from 1930 to1960, because they are relatively fast growing, full crowned, and evergreen. However, laurel oaks are not very resistant to decay and are, therefore, frequently found in hazardous condition.

Ten laurel oaks (24 to 88 cm diameter at 1.4 m) that had been previously designated as hazardous and slated for removal were used for this study. Prior to removal, 5 to 11 cross-sections were paint-marked on each tree at potentially critical points, e.g., at branch bases and along the trunk. Stem sections with obvious decay, as well as sections where decay was not apparent, were marked. Prior to tree removal, 10 tree experts involved with hazardous tree evaluation (Gainesville's city arborist, the head tree surgeon, 2 assistant tree surgeons, a consulting forester, a botany professor at the University of Florida, a plant ecology graduate student, 2 utility foresters, and a horticulturalist) independently predicted the extent of rot and hollows at each cross-section. Each evaluator diagrammed predictions on a standardized form (Figure 1).

Sample trees were felled and dissected during fall 1995 by either the city tree crew or a private tree surgery company. During tree removal, branches and stems were cut at each marked point, and the extent of decay and/or hollow at each cross-section was diagrammed and photographed.

A measure of the predictability of decay was developed by comparing the actual percent area of decay with the percent area of decay predicted by each of the 10 evaluators for each stem section. The decay areas were determined using a leaf area meter with prediction diagrams transferred onto acetate sheets.

Estimated strength loss caused by decay was also calculated. Percent loss in strength was calculated using engineering formulas for the second moment of area *(I),* the strength of a structure based on the distribution of material within a cross-sectional area. *I* is calculated as the sum of each infinitesimally small area multiplied by the square of the distance of each area from the neutral or bending axis, or $I = \Sigma AD^2$, where A is an area of stem cross-section and D is the distance of that area from the bending axis. Note that on the basis of this formula, areas of decay near the stem periphery detract substantially more from overall strength than do similar areas of decay located in the center of the stem. Percent loss in strength for each cross-section was calculated as *I* of the decayed and/or hollow area, divided by *I* of a totally solid stem cross-section. These calculations assume that decayed areas do not contribute to stem strength.

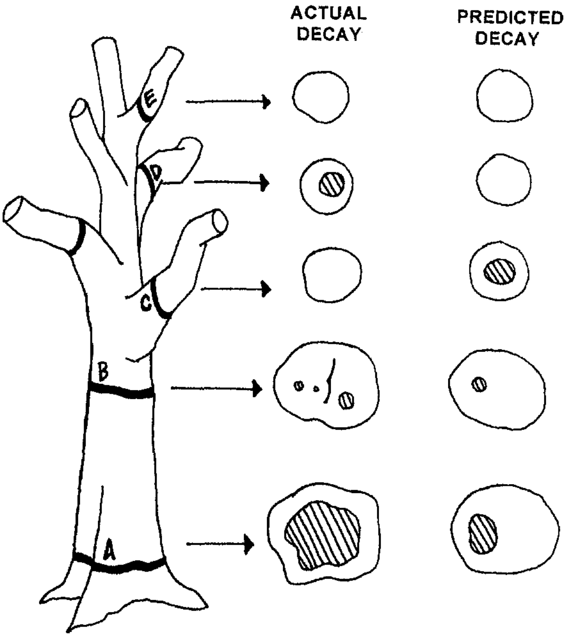


Figure 1. Method used to compare predictions by evaluators with the actual extent and distribution of decay in cross-sections of the 10 study laurel oaks.

Seven of the evaluators participated in a preliminary study involving 3 tree dissections. These evaluators were able to compare their predictions to the actual decayed areas before evaluating the 10 laurel oaks used in this study. The results of the preliminary study were

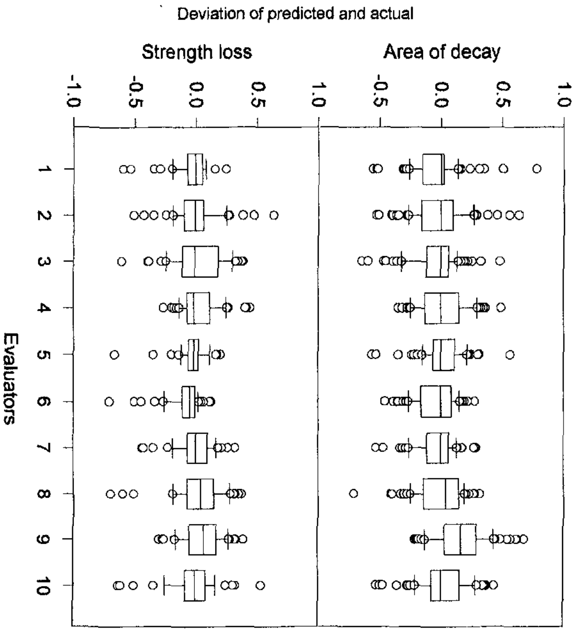


Figure 2. Deviation of predicted proportion of decay from actual, and predicted proportional strength loss from actual, for each of the 10 evaluators (A: Gainesville city arborist; B, C, D: assistant tree surgeons; E: consulting forester; F: botany professor; G: plant ecology graduate student; H, I: utility foresters; J: horticulturalist).

compared to the results of the final study to determine whether their predictive abilities improved with feedback.

Results

Of 79 stem sections used in the study, 32 (40.5%) were solid, 26 (32.9%) were decayed, and 21 (26.6%) were decayed and hollow. The mean deviation from actual of both predicted decay area and predicted strength loss approached zero (means = 0.4% and –0.7%, respectively). The interquartile range for predicted decay area was 12 to -15%; for strength loss it was 8 to –8% (Figure 2). There was no trend of over- or underpredicting either area of decay or strength loss (Figure 3). Some participants overpredicted the amount of decay in a stem cross-section, yet underpredicted the strength loss caused by the decay, and vice versa (Figure 3).

Seven evaluators who participated in the preliminary study involving 3 tree dissections

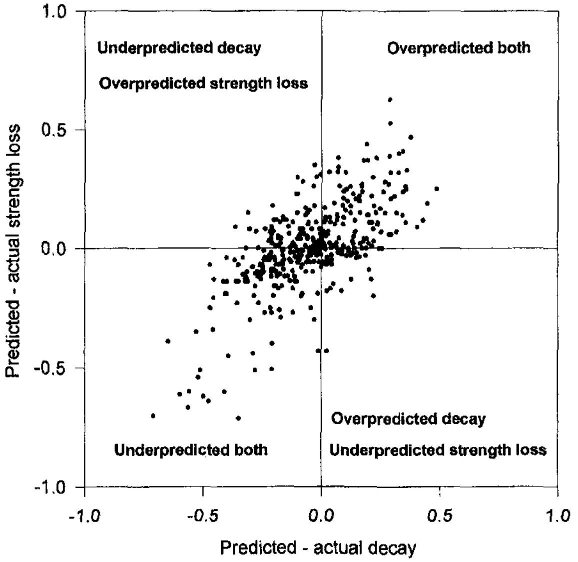


Figure 3. Deviation of predicted and actual proportion of decay plotted against the deviation of predicted and actual proportional strength loss of all evaluators.

improved the accuracy of their predictions of decay area with feedback by a median of 9% (Figure 4; Wilcoxon signed-rank test, Z = 2.2, P = 0.03).

Discussion

The results of this study suggest that visual assessment can be a reliable means of predicting the internal extent of decay and hollow that may be hazardous in urban trees. Evaluators were able to predict the amount of decay and loss in strength of stem cross-sections with a fair amount of accuracy. Additionally, evaluators did not tend to over- or underpredict the amount of decay or loss in strength. It is also noteworthy that providing evaluators with feedback of their predictions of 3 trees in a preliminary study improved the accuracy of their subsequent predictions. This finding suggests that in-service training has high potential for improving the ability of tree managers to predict tree decay.

There are likely to be limits, however, to the accuracy of prediction of tree decay based on visual assessment alone. The wide range of accuracies with which tree experts that participated in this study predicted the amount of decay and strength loss in laurel oaks indicates

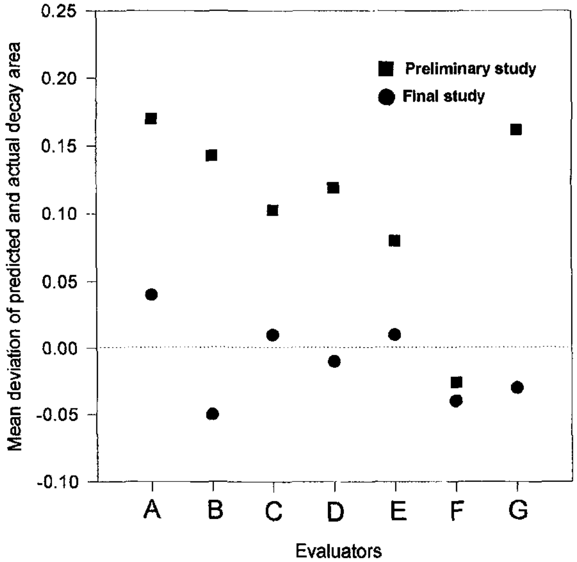


Figure 4. Mean deviation of predicted and actual decay areas of 7 evaluators who participated in a preliminary study (3 trees; solid squares) and the final study (10 trees, solid circles). (A: Gainesville city arborist; B, C, D: assistant tree surgeons; E: consulting forester; F: botany professor; G: plant ecology graduate student.) Dotted line indicates a mean deviation of zero between predicted and actual decay. Means > 0 overpredicted decay areas; means < 0 underpredicated decay areas.

the inherent difficulty in predicting the internal condition of trees based on external characteristics. It is also important to consider that predicting the exact amount and distribution of decay is not equivalent to predicting a tree's fate. Other factors like trunk lean, uneven distribution of crown weight, and root health influence the likelihood of such tree failures as breaking or uprooting. Improved means of determining likelihoods of tree failure are as vital for tree managers as are developing accurate means of assessing tree decay. Failure criteria that indicate at what level of decay or strength loss a tree is likely to fail need to be developed.

Methods for estimating strength loss of tree cross-sections are useful in predicting the likelihood of tree failure only if a critical loss in strength can be identified. Critical strength loss values depend largely on the safety factor of structures. Mattheck (5) proposed a safety factor of 4.5 for trees. In other words, the normal load of stress can increase by a factor of 4.5 before the tree fails. However, applying a single safety factor to all trees is problematic. A tree's normal stress loads may change. For example, a tree's canopy may be lightened.

Because of difficulties in calculating a critical loss in strength value for trees, the best approach to developing failure criteria may be deductive methods that compare the strength loss of failed sections with standing sections. Several failure criteria have been identified using these field methods (Table 1). However, the applicability of these failure criteria to laurel oaks and other species is not clear. More studies of tree failures are needed to determine the critical loss in strength for other common urban tree species.

Another possible approach to determining the critical loss in strength of trees is by conducting experimental biomechanical tests (for example, measuring at what loads trees with different degrees of decay fail). Although these experiments will most likely be expensive, given the tremendous value of urban trees and liability costs of property damage caused by hazardous trees, the expense of these experiments seems justifiable.

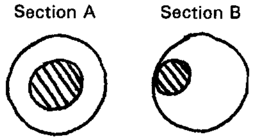
Decisions to remove large trees from public property often engender community conflict. Many citizens are justifiably anxious about tree removals. Some fear hazardous trees may be allowed to stand, thus endangering their property or lives. Others fear majestic trees will be removed as a consequence of unrealistic fears of government liability. Urban tree managers must balance the responsibility for public safety against the aesthetic and environmental values of trees.

Gainesville is unique in the state of Florida and perhaps the nation in having a voluntary Tree Appeals Board appointed by the City Commission to act as an intermediary between the government and citizens on removals of "regulated" trees (6). When a street or park tree is to be removed, a sign is posted explaining why. Any citizen not convinced that the removal is necessary can appeal the city arborist's decision to approve the permit. When an appeal is filed, the Tree Appeals Board, a panel of 3 experts, is convened at the site. They weigh evidence presented by the city

Table 1. Equations used to evaluate strength loss associated with wood decay, adapted from (5).

Source	Equation	Strength loss threshold	Strength loss calculated for section A (below)	Strength loss calculated for section B (below)	Comments
Coder (1989)	$(d/D) * 100$	220–44% caution > 50% hazard	13%	4%	Does not account for asymmetric decay
Wagener (1963)	$(d/D) * 100$	33%	22%	9%	Does not account for asymmetric decay
Smiley & Freadrich (1992)	$(d + r[D-d]) / D * 100$	33%	22%	14%	Accounts for lateral decay, but underestimates strength if internal decay is larger than indicated by external cavity opening
Mattheck, et al. (1992)	t/R	< 0.30	0.45	n/a	Formula is not applicable to trees with open cavities. For these trees, the strength loss threshold is a cavity occupying > 120 degrees of the stem circumference
Percent loss in I	I decay / I trunk $* 100$	see comment	12%	28%	No failure criteria. Accounts for irregularly shaped decay
Percent area of	$a/A * 100$		35%	18%	Does not account for asymmetric decay

Where:
d = diameter of decayed wood
D = diameter of trunk
t = width of sound wood
r = size of cavity opening/circumference of trunk
R = radius of trunk
I = second moment of area
a = area of decay
A = area of trunk



and the citizen and decide whether the permit authorizing the removal should have been approved. They fulfill this same function when the arborist refuses to remove from the right-of-way a tree that a citizen believes provides a threat. If the Board supports the permit decision, the tree is removed; if they believe pruning can alleviate the hazard, thus allowing the tree to stand longer, the permit is rescinded.

In most municipalities, decisions to remove potentially hazardous trees are based on visual assessment of tree decay (6). Results of this research indicate that careful observation of symptoms by tree professionals can lead to fairly accurate predictions of internal tree decay. The research also suggests that practice improves the accuracy of predictions, indicating the importance of comparing trees' internal conditions with expectations during the removal process.

Acknowledgments. The authors appreciate the willing participation by all of the people involved in this study and the financial support provided by the City of Gainesville.

Literature Cited

1. Coder, K.D. 1989. *Should you or shouldn't you fill tree hollows?* Grounds Mainten. 24: 68, 70–73, 100.
2. Costello, L.R., and J.D. Peterson. 1989. *Decay detection in eucalyptus: An evaluation of two methods.* J. Arboric. 15: 185–188.
3. Franks, E.C., and J.W. Reeves. 1988. *A formula for assessing the ecological value of trees.* J. Arboric. 14: 255–259.
4. Hubbard, W.G. 1993. Street Tree Inventory and Urban Forest Assessment. Prepared for the City of Gainesville, Florida. Unpublished.
5. Matheny, N.P., and J.R. Clark. 1994. A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas. HortScience, Inc. Pleasanton, CA.
6. Mattheck, C., and H. Breloer. 1994. The Body Language of Trees: A Handbook for Failure Analysis. HMSO, London.
7. Niederhofer, M. 1994. Hazardous tree management questionnaire. Unpublished questionnaire covering management of hazardous trees in 9 Florida cities.
8. Shigo, A.L., and P. Berry. 1975. *A new tool for detecting decay associated with* Fomes annosus *in* Pinus resinosa. Plant Dis. Reporter 59: 739–742.

9. Smiley, T., and B. Freadrich. 1990. Hazardous Tree Evaluation and Management. Bartlett Tree Research Lab. Charlotte, NC.
10. U.S.D.A. Southern Region. 1990. Benefits of urban trees: Urban and community forestry, improving our quality of life. U.S.D.A. Forest Service. Forestry Report R8-FR 17.
11. Wagener, W. 1963. Judging hazard from native trees in California recreational areas: A guide for professional foresters. U.S.D.A. Forest Service. Pacific Southwest Forest and Range Experiment Station, Berkeley, California. Research Paper PSN-P1.

D.K. Kennard and F.E. Putz
Department of Botany
University of Florida
Gainesville, Florida 32611

and

M. Niederhofer
City of Gainesville
Parks and Recreation Department
Gainesville, Florida 32601

Résumé. Une étude sur le terrain a été entreprise afin de mesurer la capacité de prédiction de la présence de carie dans le bois à partir d'estimations visuelles. Les prédictions faites par un groupe d'arboriculteurs, de *spécialistes du bois* et d'écologistes forestiers ont été comparées aux taux réels de carie retrouvés dans 10 chênes lauriers *(Quercus hemisphaerica)* qui ont été disséqués. La déviation moyenne sur les prédictions des zones cariées et sur les prédictions de pertes de résistance mécanique par rapport aux valeurs réelles était respectivement de 0,4% et de 2%. L'intervalle de prédiction des zones de carie s'étalait de +12% à –15%; pour la perte de résistance mécanique, l'intervalle était de +8% à –8%. La justesse des prédictions s'améliorait avec la présence d'indices de réaction. Les résultats de cette étude tendent à démontrer que l'estimation visuelle peut être un moyen fiable de prédiction de la progression interne de la carie et d'une cavité pour les arbres dangereux en milieu urbain.

Zussammenfassung. Um die Vorhersage von Fäulnis in Bäumen aufgrund von sichtkontrollen zu messen, wurde diese Studie eingeleitet. Es wurden dabei die Aussagen von Baumpflegern und Forstökologen mit der tatsächlichen Ausdehnung von Fäulnis in zehn gefährdeten Lorbeereichen *(Quercus hemisphaerica)*, die für diesen Zweck gefällt wurden, miteinander verglichen. Die mittlere Abweichung der vorhergesagten Fäulnisfläche und der vorhergesagte Verlust an Standfestigkeit lag bei 0.4 %, bzw. bei 2 %. Die interquartile Spanne der vorhergesagten Faulbereiche lag bei + 12 % bis –15 %, für den Verlust an Standfestigkeit bei +8 % bis –8 %. Die Genauigkeit der Vorhersage verbessert sich durch Rückmeldung. Die Ergebnisse dieser Studie verdeutlichen, daß die Sichtkontrolle ein verläßliches Mittel ist, um die interne Ausdehnung von Fäulnis und Hohlräumen in Bäumen vorauszusagen.