Urban Tree Risk Management:

A Community Guide to Program Design and Implementation

USDA Forest Service
Northeastern Area
State and Private Forestry

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St. Paul, MN 55108

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Preface

Urban Tree Risk Management: A Community Guide to Program Design and Implementation is a fully illustrated, easy to read training manual written for community leaders, administrators, city foresters, parks and public works staff, and private tree care practitioners. The manual is designed to assist communities design, adopt and implement tree risk management programs, and train field staff to detect, assess, and correct hazardous defects in urban trees.

A team of experts in urban forestry, plant pathology and forest health collaborated to produce this manual. Consulting arborists, city foresters, and educators provided extensive review to ensure the information applies to communities of varying sizes and budgets. Examples of tree defects, risk rating systems, and species selection were chosen to depict tree species and conditions that occur in the Northeastern U.S.

The manual is presented in a three-ring binder format to allow readers to add or update information, or to remove entire sections for use in the field. The authors sincerely hope that readers will find this manual to be a useful resource to improve public safety and protect tree health by assisting them in the design and implementation of community tree risk management programs.

Contents

CHAPTER 4 - Prevention of Hazardous Tree Defects

CHAPTER 5 - Correction of Hazardous Defects in Trees

APPENDICES

List of Tables

List of Forms

Introduction

By Joseph G. O'Brien

Individual trees may appear to be permanent fixtures of our environment. However, all trees, no matter how long-lived, will eventually collapse and decompose, leaving no trace that they ever existed. Trees die from myriad causes including disease, insect attack, drought, uprooting, and catastrophic stem failure in high winds, or from combinations of factors working together. Some trees die and later collapse as their stems and branches decay, and some begin to break up while they are still green. While any large tree poses a risk of failure in high winds, in situations where people and trees must live together in close proximity it is important to identify where a tree has become an unacceptable risk.

Many different kinds of professionals are interested in managing tree risk in communities. Community leaders and administrators; Forestry, Parks, or Public Works staff; and private tree care practitioners need reliable information concerning the identification and management of hazard trees. Until now, no single reference has been developed that provides sound, practical reference information for these professionals, and can also serve as a guide for training new staff in identification and management of hazard trees.

This manual was designed to preserve public safety and improve the health of urban forests by assisting communities in the design, adoption, and implementation of a tree risk management program, and also to aid in training field staff to detect, assess, and correct hazardous defects in urban trees.

To begin a discussion of tree risk management, some definitions are offered to provide a basis for discussion.

Hazard Tree: A tree that has structural defects in the roots, stem, or branches that may cause the tree or tree part to fail, where such failure may cause property damage or personal injury.

Tree Defects: Tree defects can be of two kinds: Injury or disease that seriously weakens the stems, roots, or branches of trees, predisposing them to fail *or* structural problems arising from poor tree architecture, including V-shaped crotches in stems and branches that lead to weak unions, shallow rooting habits, inherently brittle wood, etc.

The concept of tree risk management as a necessary community endeavor has evolved slowly since the early 1960s. The earliest publications concerning the problems of tree failure causing personal injury or property damage addressed the problems of recreation sites, where people camping in our nation's campgrounds were exposed to the risk of sleeping under a canopy of trees with little protection should a branch or tree stem fail and land on their campsite. Willis Wagener, a U.S. Forest Service plant pathologist, at the end of his 40-year career wrote the first manual that comprehensively addressed the problem of tree hazards in recreation sites in 1963 (Wagener 1963). Wagener's publication was followed by others that expanded and improved on this seminal work, including *Accident Hazard: Evaluation and Control Decisions on Forested Recreation Sites* (Paine 1971), *Tree Hazards: Recognition and*

Reduction in Recreation Areas (Johnson and James 1978 and revised Johnson 1981), *Detection and Correction of Hazard Trees in Washington's Recreation Areas* (Mills and Russell 1981), and *How to Assess and Correct Hazard Trees in Recreational Areas* (Albers and Hayes 1993). While these publications provided a sound base of knowledge for tree risk management in recreation areas, it was not 1991 and the publication of *A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas* (Matheny and Clark 1991) that a comprehensive manual was available for evaluating trees in an urban environment. Matheny and Clark's manual, now in its second edition (Matheny and Clark 1994), provides the professional arborist with a very sound and complete knowledge of hazard tree identification and mitigation. The manual provides a tree evaluation form that is comprehensive, but time-consuming, and is most suitable for the evaluation by professional arborists of individual trees that may be hazards.

The educational and reference materials available for hazard tree management deal mainly with the identification of defective trees, and although they can provide valuable insight and information regarding the biology of hazard trees, they do not provide a great deal of information on how or why to set up a tree risk management program. The Matheny and Clark publication is a resource valued by arborists for the inspection and documentation of small numbers of trees that may be hazardous, but the time involved in the inspection procedures would be prohibitively long for communities that need to track thousands of trees for risk.

Missing from the currently available manuals and books on tree risk management and hazard tree identification is a resource that is helpful for communities interested in establishing or improving an existing tree risk management program, and providing a means for rapid and efficient assessment of tree risks. This manual attempts to address such needs by providing information concerning the requirements of a community tree risk management program, a stepwise process to establish a program, and tools and information for assessing trees for hazard.

Most street and park tree management plans or master street plans state the need to remove high risk or hazardous trees (standing dead or nearly dead trees) as a top priority, but stop there. This manual picks up where these plans leave off, and provides communities with a process to systematically detect, assess, prevent, and correct hazardous tree defects.

Tree risk management should be a prominently positioned component of a community forestry program. Tree risk management plans should complement a community's overall street and park tree management program goals, and should be fully integrated with the tree planting, tree pruning and maintenance, and emergency response programs.

Content synopsis:

Chapter 1 of this manual introduces the concept of tree risk management including a discussion of the levels of risk posed by trees with various defects. This chapter also explains the importance of having a tree risk management plan, including the need for a formal process for addressing tree risk management at the community level, and the need for a policy that addresses the risks posed by street trees.

In Chapter 2, the key steps to planning and designing a tree risk management program are outlined, including a comprehensive guide to customizing a program to address the specific needs of a unique community, establishing the goals of the program, formulating and implementing tree risk management strategies, and evaluating the program's effectiveness.

Chapter 3 begins a series of chapters that provide details on how to assess, prevent, and correct trees that may be hazardous. Chapter 3 provides a detailed examination of tree defects that can create hazards, and the methods used for assessing trees for hazard potential. The chapter also provides information on tools that can be used to assist staff workers responsible for tree risk assessment, and provides examples of two evaluation forms and systems that can be used to document tree inspections. Examples of tree defects and risk forms and systems were selected to depict tree species and conditions that occur in the Northeastern U.S.

In Chapter 4, sound practices are described that will help to prevent the development of hazard trees and thus avoid the need to remove large numbers of trees because they become hazards. The methods described include designing a species-diverse, uneven-aged urban forest, matching tree species to site conditions, purchasing high quality nursery stock, implementing proper tree planting and pruning techniques, and protecting of trees from construction damage.

Chapter 5 provides details on the corrective options available once a tree is determined to be an unacceptable hazard. The information provided will help communities to develop strategies to correct trees that become hazardous, and also provides information on how to convert dead and dying trees into desirable wildlife habitat, under certain circumstances.

This manual is provided in a three-ring binder format specifically to allow users to add or update information, or to remove entire sections for use in the field. In particular, chapter 3 is designed to be used in the field to identify and assess hazardous tree defects.

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Tree Risk Management

By Richard J. Hauer and Gary R. Johnson

Introduction

Risk management is a well-established concept in the management of public spaces. Acceptable levels of risk have been recognized or defined for most basic infrastructure elements such as sidewalks, curbs, streets, playgrounds, and utilities. In many communities, these elements are assessed and managed according to acceptable levels of risk that are specified within written policies or enacted through management practices. Although not all pot-holes can be immediately filled in, not all heaving sidewalks immediately repaired, not all burned-out street light bulbs immediately replaced, a successful risk management program provides a community with a systematic approach to implement corrective actions within a reasonable time frame.

An urban community consists of both the gray infrastructure (buildings, streets, utilities) and the green infrastructure — the urban forest. Although gray infrastructure has long been assessed and monitored for acceptable levels of risks, green infrastructure has for the most part not received the same subjective evaluations. The concept of considering or evaluating risks in the context of location and condition is less applied with the green infrastructure. Trees are labeled either as "hazardous" or not. "Weeds" are acceptable or not.

Trees contribute to increased quality of life in many communities.

Some of the benefits of urban trees include (Roloff nd.)**:**

- Energy savings from solar shading and barriers to wind,
- Rainfall interception and tempered release into surface waters,
- Increased usable life of those asphalt streets that are shaded,
- Reduced air pollution through leaf uptake of pollutants,
- Increased property values,
- Positive effects on the psychological health of people,
- Less crime in treed areas, and
- Wildlife shelter and food (habitat).

The urban forest is an integral part of a community's infrastructure, and trees often dominate the landscape or at least are the most visible part of it. Urban trees contribute to increased quality of life for many communities and their residents. Most people prefer to live, recreate, and work in communities of healthy and well-maintained urban forests (Dwyer et al. 1989, Schroeder 1990, Dwyer et al. 1991). Considerable research documents that people not only prefer to recreate in well-maintained parks with trees, but are willing to pay extra for the privilege (Dwyer et al. 1989). Safety, or at least the perception of safety, is paramount if urban forests are to be used and enjoyed (Schroeder 1990).

Healthy trees and urban forests contribute to the overall value of property. As much as 10 to 30 percent of residential property values can be assigned to the entire landscape that includes trees (CTLA 2000). There is also a significant difference between the appraised value of wooded parcels and divided lots that typically sell for more than undeveloped properties without trees. Homeowners regularly invest a significant amount of money in the maintenance of their own landscapes. Businesses and homebuyers are drawn to areas with healthy, well-maintained urban forests, commonly describing those areas as more desirable to live in because they feel these areas appear more affluent, safer, and communicate a higher quality of life.

Figure 1.1 - *Much of the catastrophic damage and tree loss that results from natural loading events is inevitable when structures and trees are placed in close proximity.*

Trees also are one component of an urban infrastructure that appreciates in value. As trees grow, their monetary value increases and their ecological benefits (e.g., storm water management, shade and energy conservation, air pollution amelioration) increase. For example, in Chicago it was determined that it takes 9 to 18 years before a discounted benefit-cost ratio approaches 1 (McPherson 1994). When the benefit-cost ratio equals 1, the accumulated value that trees produce is equal to the costs of planting, establishment, and care. Thirty-year-old trees near homes were predicted through mathematical models to produce 3 times greater value than all costs involved over 30 years. That means if it cost $1,000 to plant and care for a tree over 30 years, the gross value or benefit to society would be $3,000.

Figure 1.2 - *Many conditions make trees susceptible to storm failures, including decay,*

The value people place on their urban forest can be demonstrated following storms such as hurricanes, ice storms, and wind storms where significant tree damage and loss occurs. Residents often mention tree loss as one of the greatest impacts from storms. In fact, over 30 percent of residents indicated this following Hurricane Hugo in 1989 (Dwyer et al. 1991).

Figure 1.3 - *codominant leaders.*

Trees may also have negative impacts, for instance, messy fruits, allergenic properties, and infrastructure damage (e.g., damage to sidewalks). Trees or tree parts can fail and cause damage or personal injury, particularly during natural loading events such as wind, ice, and snow storms (Fig 1.1). The failure of limbs or entire trees, however, is often predictable, detectable, and preventable (Fig 1.2-1.4).

Management of Tree Risk


Figure 1.4 - *and root system dysfunctions.*

Community managers have the responsibility to create and maintain a safe and useful urban forest for their constituents. Urban foresters need the training and expertise to recognize varying levels of risk, and to manage the forest at an acceptable level of risk. There have been significant advances in decay-detection equipment, and formulas and guidelines for assessing hazardous trees. Modern techniques and procedures can be used to minimize the risk of damage to property and personal injury associated with tree failure.

Tree risk management involves the process of inspecting and assessing trees for their potential to injure people or damage property. Traditionally the term "hazard" (or hazardous) has been used in the context of evaluating trees for their failure potential. To many people, "hazard" suggests trees at immediate risk for failure. In this guide, "hazard" trees are defined as trees with structural defects that may cause the tree or tree part to fail, where such a failure may cause property damage or personal injury. Trees will vary, ranging from low- to high-risk for failure and may require attention immediately or in the near future. The threshold of risk acceptable to liable parties is dependent upon their policies and objectives. Trees that surpass the level of acceptable risk are hazards from a programatic viewpoint. An understanding of tree and forest biology is also an integral component of any tree risk management program.

The perception of safety or acceptable levels of risk is equally or sometimes more powerful than the reality of the condition of a tree and the situation that it is growing in. Community leaders, employees, and residents that do not have forestry backgrounds often make forestry decisions that are based on local politics, emotions, and perceptions of safety. In order to make objective, science-based decisions on the safety of trees and the urban forest, individual trees and site conditions need to be evaluated for the level of risk that they do — or do not — present.

Liability and Risk

Community leaders and decision-makers must consider the perceived public liability for tree damage and injury claims. In the extreme, trees are excluded from public rights-of-way to minimize public exposure. In the risk management field this is called risk avoidance. In these cases the public benefits that trees provide, which usually outweigh the perceived costs, are not delivered to the community. Other communities postulate that tree populations can be managed to have zero risk. The leaders of communities in this case do understand the benefits that trees provide and reduce the overall potential urban forest value through their attempts to attain zero risk (which may not be possible). Attempts to attain zero risk often become costly over time, due to premature tree removals, more frequent tree replacements, and loss of benefits that mature trees provide.

Low- to high-risk scenarios only arise when damage or injury can occur. People or property in proximity to a tree at risk for failure are targets. A target must be present for risk of injury or property damage to occur. The tree that loses a limb at a location where no property damage or personal injury could occur poses zero risk. In developed areas, the chance that there are zero-risk situations is low, due to common interactions among people, property, and trees. However, human interactions and the probability and level of risk potential vary greatly across the urban landscape. Areas with frequent human activity and higher-valued property present a greater risk potential than the center of a wooded area in a park. Strategies to reduce the risks trees pose to public safety include:

- Moving the target
- Correcting the tree (pruning or cabling and bracing the defect)
- Converting the tree to a wildlife tree
- Closing the site
- Removing the tree

Communities that choose to manage tree risk through the development of a tree risk management plan can expect many benefits, including:

- Lower frequency and severity of accidents, damage, and injury
- Fewer expenditures for claims, and legal expenses
- Healthier, longer-lived trees
- Overtime, fewer tree removals annually.

Developing a Tree Risk Management Plan

Managing tree risks involves the incorporation of a tree risk management plan into the overall urban forest management master program. The tree risk management plan should be fully integrated with tree planting and tree pruning programs, and share a common goal of promoting healthy and structurally sound trees. The plan should focus on the prevention and correction of high-risk tree defects, and provide a written, systematic procedure for inspecting and evaluating potentially hazardous trees, and implementing corrective treatments. Chapter 2 provides comprehensive information on designing a tree risk management program.

The cost of the program should be weighed against the potential loss. Cost-benefit analysis can be used as a tool to evaluate the cost effectiveness of programs in relation to program costs and current and future benefits from healthier trees less prone to failure and costs associated with cleanup, repair, and reforestation.

The process of developing, implementing, and maintaining a tree risk management program is often a political process that is ideally designed to do what's best for the community. The political process results from the interaction among the tree management professionals, citizens, and decision-makers such as city managers, city council, mayor, city attorney, and others. All of these stakeholders should be involved in the tree risk management program development. A mutually-developed policy encourages learning, understanding, and acceptance.

The policy needs to clearly articulate who does what, what methods will be used, and what resources are available (e.g., people, equipment, and dollars). The responsible agency needs to sign and support the policy. Personnel who administer the tree risk management program need to be supported in their assessments of trees and recommendations. Resources and training of personnel are vital. Conflicts with individuals affected by hazardous trees should be handled fairly. If necessary, procedures should be in place to allow the input of affected citizens.

Reasonable Care and Safety

Communities have differing opinions and policies about who is responsible for the care of trees on and abutting public property. Some communities have left the care of public trees to the property owners whose land abuts the tree lawn. Trees within a parkway in front of a house are an example. The responsibility of care passed onto these property owners through either ordinance, policy, or inaction, under most cases probably does not absolve the public entity associated with the trees from liability if damage or injury occurs. Courts have upheld that the absence of a program to maintain trees does not absolve the responsibility to provide safety to others.

The concept of reasonable care of trees to provide public safety is often cited as a standard to follow with trees. Further, the scientific understanding of trees and how they grow and fail has increased dramatically in recent times, and thus the professional level of expected care has increased. Defining reasonable care, however, varies among towns and states and is often defined by lawyers and courts rather than those who understand trees. A proactive stance for a community would be to define what is reasonable, rather than letting it be defined by default, possibly by someone or a group that is not knowledgeable in the subject.

An ounce of prevention is worth a pound of cure. Healthy, sound, and sustainable tree populations require expenditures of resources. The paybacks, however, are healthier, longer-lived trees, fewer significant insect and disease problems, and minimized risks from failing trees. A tree risk management program, therefore, should be considered an integral component within a comprehensive, urban forest management program.

Developing a written policy is the beginning of defining reasonable care. Regularly scheduled tree inspections to assess potential and real problems (e.g., species, structural defects, size, location) within the tree population, and evaluation of management resources (e.g., personnel, seasonal activities, monetary resources) are the next steps. Given the current tree population and available resources, what can be done to reduce trees at risk for failure? Management strategies should be established that address high-risk trees on a priority basis, through either tree removal or corrective pruning of defective parts. Plans that meet these goals should be implemented through use of current resources, or the allocation of additional resources.

Summary

All trees have a varying level of risk for failure. On the extremes, trees rated as low in their risk for failure can fail during extreme windstorms, while highly defective trees and tree parts can fail during calm days. Trees vary in their level of risk for failure and trained people can best determine these risk ratings. The overall goal of a community tree risk management program is to reduce the risk for injury and damage to people and property to levels that are considered acceptable in accordance to city policies and practices. The remaining chapters will discus how to develop a tree risk management program, criteria important for assessing tree risks, ways to prevent and minimize future tree risks, and acceptable methods for correcting defects in trees. Initiating a tree risk management program is an important step in developing effective tree management programs, and community tree populations that maximize public benefits and minimize community liability.

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Community Tree Risk Management: Program Planning and Design

By Jill D. Pokorny and Jana S. Albers

Introduction

Most of us have witnessed the destruction a tree can cause when it falls and strikes a physical structure. We have all heard about cases of personal injury and death caused by a falling tree or branch. Without question, trees can become hazardous over time and come to pose significant risks to personal safety and property. A key issue facing communities is how to manage the urban forest, both from an ecological standpoint of promoting resource health, and from a public safety standpoint of ensuring reasonable care is being taken to manage the public safety risks associated with hazardous trees. The best way for a community to confront this issue is to develop a tree risk management program. The program should focus on the prevention and correction of hazardous tree defects, and provide a written, systematic procedure for inspecting and evaluating potentially hazardous trees. Tree risk management programs should be designed to complement a community's overall street and park tree management program goals, and should be fully integrated with the planting, tree care maintenance, and emergency response programs (Fig 2.1).

Figure 2.1 - *Tree risk management should be fully integrated with the tree planting, tree pruning and maintenance, and emergency response programs.*

Historical Perspective

Gaining an historical perspective of how and when trees fail can provide key insights into the successful design of a tree risk management program. History documents that most trees fail during storm events, and every year countless storms rage through the United States. These storms and associated tree failures cause deaths and billions of dollars in property damage annually. Severe storms can also cripple community public service and emergency response systems. As destructive as these storms are, valuable lessons can be learned from them. Post-storm surveys of damaged trees provide forensic evidence about tree failure patterns and structural defects that are commonly associated with tree failures. By knowing more about how and when trees fail, we can more accurately assess the degree of risk associated with specific tree defects, and make well founded tree risk management decisions.

Post-storm surveys strongly demonstrate the value of investing community resources to prevent the formation of structural defects through proper tree planting and pruning

Figure 2.2 - *Planting trees too deeply is a primary cause of lower stem decay and subsequent failure. Note there is no root collar flare visible at the base of the trunk. Properly planting this tree so the root collar was level with the soil surface could have prevented this stem failure.*

Figure 2.3 - *Weak branch unions and the presence of included bark (darkened stem tissue where the old branch union existed) are leading causes of branch failures. Early formative pruning could have prevented this branch failure.*

practices, and to inspect trees on a regular basis to detect, assess, and correct hazardous tree defects before they cause tree failures. Aerial and ground examination of trees damaged by Hurricane Andrew (Florida 1992) revealed that inappropriate species composition and improper planting and maintenance practices in urban and suburban areas resulted in extensive and unnecessary tree losses and associated property damage (Dempsey 1994). Field observations following the January 1998 ice storms that struck northern New England, New York, and eastern Canada noted that branch breakage and overall tree damage was much less on trees that were well pruned and well maintained. Johnson and co-workers (1999) found that 84 percent of the trees damaged during high wind storm events had pre-existing defects that resulted in tree and branch failures. They found that most of the pre-existing defects that contributed to tree or branch failure could have been prevented through proper tree planting (Fig 2.2) and pruning practices (Fig 2.3), and could have been detected and corrected if the trees had been inspected for the presence of hazardous defects (Fig 2.4).

Figure 2.4 - *Regularly scheduled tree risk inspections are a valuable tool to detect, assess, and correct hazardous defects, before the tree fails.*

Although storms are commonplace, and the risks trees pose to public safety are often high, many communities operate under a mode of crisis management when it comes to tree care maintenance and correcting/removing trees with hazardous defects. Information from many U.S. cities shows that the cost per unit of maintenance is generally twice as high with crisis management than it is when maintenance is performed on a scheduled or programmed basis (World Forestry Center 1993). Few communities are adequately prepared to deal with the prospects of removing and storing tons of tree debris, surveying remaining trees for hazardous defects, and implementing corrective tree care treatments. In addition to higher maintenance costs, relying on crisis management may lead to injuries or deaths caused by falling hazardous trees or branches, and result in huge litigation costs.

Figure 2.5 - *This vehicle was injured by the fallen tree in the background. Note the presence of included bark on the tree's stem (darkened stem tissue where the old branch union existed) that led to the branch failure.*

Lessons Learned

History teaches us that properly maintained trees develop fewer hazardous defects and pose less risk to public safety. Communities can avoid crisis management and establish tree risk management plans that are designed to prevent and correct structural tree defects, before they become hazardous. This management approach requires community leaders and residents to recognize that tree risk management is an issue critical to public safety, and similar in importance to other essential public services such as traffic light maintenance, roadway construction and repairs, sewage disposal, and clean and abundant drinking water. It requires communities to view tree risk management as an investment that can literally save lives (Fig 2.5), and reduce the catastrophic impacts of future storms on community budgets (Fig 2.6) and the health of the urban forest (Fig 2.7).

Figure 2.6 - *After major storm events, many trees must be removed, replacement trees planted, and extensive sidewalk reconstruction is often necessary.*

Figure 2.7 - *Major stem or limb failures cause large wounds that result in poor tree architecture and predispose trees to wood decay.*

Most street and park tree management plans or master street plans state the need to remove high-risk or hazardous trees (standing dead or nearly dead trees) as a top priority, but fail to identify a process to systematically detect, assess, and correct hazardous defects in trees. A tree risk management program fills this information gap and provides the community with a systematic approach to accurately identify moderate to high-risk trees, and initiate the timely removal or corrective treatment of hazardous trees. A tree risk management plan integrating sound tree planting and tree care maintenance practices, regularly scheduled tree inspections, and the timely implementation of corrective maintenance actions will prevent or correct many structural defects, before the trees become hazardous to public safety.

A tree risk management plan fills this information gap and provides the community with a systematic approach to accurately identify moderate to high-risk trees, and initiate the timely removal or corrective treatment of hazardous trees

A tree risk management program should complement a community's emergency response plan by increasing the community's level of storm preparedness and its ability to respond rapidly to a natural disaster. Most communities have some sort of plan for responding to emergencies and for taking immediate action to address life-threatening situations and to clear away debris and downed trees that block emergency access routes and medical facilities. However, few communities are prepared to conduct post-storm surveys to assess the extent of damage to the remaining tree population, and to effectively manage the public safety risks associated with highly hazardous trees in need of immediate removal or corrective pruning. Post-storm tree damage surveys should be a top priority after a major storm, and should be conducted by staff or contractors trained in tree damage assessment and risk evaluation methods. Authors of various crisis management texts stress the paramount importance of having emergency response teams in place and trained before a crisis hits. If a tree risk management program exists, the community will have a tree risk evaluation system in place, and a ready source of trained staff or contractors to conduct post-storm tree damage and risk surveys.

This chapter will outline a process that communities can use to design a comprehensive tree risk management program for trees located on public property. We will discuss how to customize the program to address specific needs and fiscal resources within the community, establish program goals, formulate and implement tree risk management strategies, and evaluate program effectiveness. We will follow the basic format of a planning model suggested by the International Society of Arboriculture (ISA), with proven success in the development of effective urban forest management plans and programs. This planning model poses four core questions and identifies key steps to address the core questions. We modified the model by adding three steps that are specific to the subject area of tree risk management. The modified planning model is as follows:

Tree Risk Management Program Planning and Design: A Ten Step Approach

What Do You Have?

Step 1. Assess the tree resource

Step 2. Review current tree management practices

Step 3. Assess fiscal and human resources available to manage the tree resource

What Do You Want?

Step 4. Identify program goals

How Do You Get What You Want?

Step 5. Formulate a tree risk management strategy

Step 6. Prioritize inspection and corrective action needs

Step 7. Select a tree risk rating system

Step 8. Write a comprehensive tree risk management program policy

Step 9. Implement a tree risk management strategy

Are You Getting What You Want?

Step 10. Evaluate and revise

What Do You Have?

Step 1. Assess the Tree Resource

Recently collected tree resource data is essential for the development of a realistic and useful tree risk management plan. Baseline information on general tree location, species, size class, and condition (percent canopy dieback); maintenance needs; and available planting sites is needed to provide a snapshot of the current condition of the tree population and to identify key public safety issues and tree maintenance needs. This information supplies a framework for developing a successful tree risk management strategy that is tailored to the specific resource needs of the community, and provides a basis for estimating program costs and developing budget requests.

A complete tree inventory provides the most accurate data. However, a complete tree inventory is not necessary to collect the baseline data needed for this step, and the high cost of conducting one can be avoided. A partial inventory that surveys a representative sample of the total tree population can quickly and accurately provide an estimate of the total number of trees, species composition, and size and condition classes of an urban street population (Jaenson et al. 1992). A partial inventory offers communities with limited budgets a practical and cost-effective method to assess tree resources.

Identify tree maintenance needs and costs. Compiling and analyzing tree inventory data provides a mechanism to identify tree maintenance needs such as tree removals, pruning, and replanting, and to determine costs associated with implementing needed tree maintenance practices. Corrective tree maintenance needs can be estimated from tree inventory data based on the percentage of trees in need of removal or pruning, and the number of available planting sites. The total cost for the community tree population can be projected by establishing an average cost per tree for each maintenance action, and multiplying that cost by the number of trees needing each maintenance action.

Obtaining accurate cost estimates can be difficult because the average unit cost for each maintenance practice can vary significantly within a geographic region, due to local differences in the cost of materials, labor and equipment, staff training, and overhead administrative expenses. Also, individual tree and site characteristics must be factored into the cost of planting, pruning, or removing trees. For example, proximity to electric wires, buildings, and sidewalks; moderate to high traffic volumes that require additional workers; and the presence of major decay within the tree are all factors that make pruning or felling operations more difficult, time consuming, and expensive.

The best way to estimate program costs is to use cost figures that are representative for your specific locality and program. If your community has a tree planting and maintenance program in place, break down program costs into major program areas such as planting, pruning, and removals, and look at the average cost per tree for each maintenance task over an extended period of time. If a community lacks the ability to track tree maintenance costs, does not have a tree planting or maintenance program in place, or is considering the option to subcontract tree maintenance work, the best guide will be to solicit bid prices from at least three local contractors for each maintenance task, and use the median bid price. Contacting nearby communities that have tree care programs and similar population size may also provide valuable information on tree planting and maintenance costs that are representative for your local area.

Identify tree removal and disposal costs. The percentage of total trees surveyed with extensive or total canopy dieback provides an estimate of the number of very high-risk trees that need to be removed (Fig 2.8). Tree removal is typically the most expensive tree maintenance operation on a per tree basis. Costs are based on tree diameter and size, tree density, accessibility factors such as proximity to overhead utility wires, sidewalks, and buildings, and high roadway traffic volume levels. Factor costs associated with stump removal and wood waste disposal into the budget. Explore opportunities to sell the wood to offset removal and clean-up costs. Recent publications provide useful information on successful community wood waste disposal programs (Bratkovich 2001), and guidelines for marketing sawlogs from street tree removal and municipalities (Cesa et al. 1994).

Figure 2.8. *This tree has extensive crown dieback, with decayed and broken major limbs. It is a high-risk tree that should be removed.*

Managers can identify high risk, problematic tree species by reviewing the percentage of total trees surveyed with extensive or total canopy dieback, broken down by tree species and diameter. Identify high-risk problem species within the tree population, and conduct more frequent risk inspections in areas of the community where problem species occur in high densities.

Identify pruning needs and costs. Tree inventory data that includes recommended maintenance actions provide an estimate of the number of trees in need of corrective pruning. Pruning costs are based on tree age and size, tree density, and accessibility factors such as proximity to overhead wires, sidewalks, buildings, and high roadway traffic volume levels. A comprehensive tree risk management plan includes an assessment of pruning needs, including therapeutic pruning to correct existing structural defects and maintenance pruning to prevent the formation of structural defects. Estimated pruning costs can be viewed as a shared cost between a tree risk management program and a tree planting and pruning program.

Identify planting needs and costs. The number and location of trees to be planted within the community can be determined from the tree inventory data, if information on vacant planting sites was collected. Include planting sites that will become available as other trees are removed. The average purchase cost per tree is dependant on species, caliper, and nursery stock type (balled-and-burlapped, bare-root, or container-grown), and on an average planting cost (dependent on materials, equipment and labor costs). When estimating total planting costs, it is common practice to multiply the nursery purchase cost by a factor of three (Petitjean 1997).

Generating quantitative data on tree maintenance needs will lend credibility to budget requests and garner public support. For example, if you know there are 40 trees within the community that are high-risk trees in need of immediate removal, there is compelling evidence that a tree risk management program should be established to increase public safety and potentially save lives. Stressing the public safety aspects of tree risk management can help elevate its importance to the level of other essential public health services such as such as traffic light maintenance, roadway construction and repairs, sewage disposal, and clean and abundant drinking water.

Determine the value of the urban forest resource. Knowing the economic value of the urban forest can be useful as a leveraging tool to obtain funding for programs and departments responsible for community tree care. Municipal forestry programs compete for funding with community services such law enforcement and fire protection, and the development and maintenance of roads, sewers, and street lights. Most communities document the monetary value of these public services, and elected officials are kept aware of what it costs to maintain the value of these services and improvements. In a similar fashion, the forestry department should document the monetary value of the urban forest, and inform the public and elected officials about the costs required to maintain its value and benefits. For example, when tree maintenance costs, including periodic inspections of trees to detect hazardous defects, are shown as a percentage of the monetary value of the urban forest, the cost of tree maintenance will compare favorably with other public safety costs such as maintaining emergency access routes and roadways, traffic lights, and sewage systems. Over time, properly maintained trees grow in value, while most other urban assets decline in value.

The most widely used method to assess the value of individual trees is a system developed by the Council of Tree and Landscape Appraisers (CTLA), described in their handbook entitled Guide for Plant Appraisal (CTLA 2000). Copies of this handbook may be obtained by contacting the International Society of Arboriculture, PO Box 3129, Champaign, IL 61826-3129. The CTLA appraisal method involves the establishment of a base value for a landscape tree, as determined by local tree replacement cost figures. The base value is a maximum value and is modified by multiplying by percentage factors for tree species, condition, and location. This system relies on the following formula to compute tree values as follows:

Tree Value = Base Value x Species Classification (%) x Condition (%) x Location (%)

This method can be used to establish the value of more than one tree, making it useful for determining the collective value of a community's urban forest. For collective value, the value of the average tree within the community tree population is calculated rather than the value of every individual tree. Based on tree inventory data and the total number trees surveyed, the average size (d.b.h.) replacement tree is determined, and an average rating value for tree species, condition, and location is calculated. These average values are then plugged into the formula above to calculate the average tree value. The value of the average tree is multiplied by the total number of trees inventoried, resulting in a total value for the urban forest (Petijean 1997).

Step 2. Review Current Tree Management Practices

The next step is to review current tree planting, pruning, and removal practices, and any formal documents that affect tree care such as street and park tree management plans, emergency response plans, or tree ordinances. Identify common goals that exist between programs, plans, or ordinances, particularly as they relate to promoting tree health and increasing public safety. Explore ways to integrate efforts, strengthen effectiveness, and leverage community support and funding. Eliminate duplication of efforts between municipal departments, public utilities, and private contractors whenever possible. This coordinated approach to tree risk management can eliminate duplication of efforts between community tree planting and pruning programs. For example, as part of regularly scheduled, systematic tree risk inspections, tree inventory data can be collected along with tree risk data, and the need to conduct separate, periodic tree inventory assessments can be eliminated. A small crew of individuals can be trained to conduct tree risk inspections and collect tree inventory data. Data relating to tree removals, pruning needs, and available planting sites can be shared with the tree planting and pruning programs to direct and schedule the activities of the tree planting and pruning work crews. Empower pruning crews to report the location of all high-risk trees detected in the course of performing their daily work to the tree risk management program. Give these "high-risk tree reports" high priority, and implement corrective actions promptly. This integrated approach to tree risk management provides the community with a way to continuously update tree inventory data, eliminate the need to conduct separate, periodic tree inventory assessments as part of the tree planting or pruning programs, and share tree resource information between the tree planting, pruning, and risk management programs to facilitate more effective scheduling of work crews.

Step 3. Assess Fiscal and Human Resources Available to Manage the Tree Resource

After the tree resource is assessed and corrective tree maintenance costs are estimated, review the community tree care budget to see how these costs compare with the fiscal and human resources currently available to manage the tree resource. Compare the number of trees that are removed, pruned, and planted annually to the estimated number of trees that need to be removed, pruned, or planted as identified in the tree inventory survey. Determine the difference on an annual basis. Calculate cost projections for the maintenance work needed, but not currently completed, based on the average cost per tree for removal, pruning, and planting as discussed in Step 1. These costs reflect "new" or additional funding that is needed to implement corrective tree maintenance treatments, and should be included in budget requests.

In addition to estimating the cost of implementing corrective tree maintenance treatments, factor in the cost of conducting regularly scheduled tree risk inspections. The amount of time required to conduct tree risk inspections will depend on which tree risk rating system the community selects to implement. Step 7 summarizes information on the amount of time needed to conduct individual tree risk assessments for tree risk rating systems that are designed for use in urban areas and currently published in the United States. A small crew can be trained to conduct tree risk inspections. Many communities opt to cross-train existing tree pruning or tree planting staff, and share costs between programs. This can be a very effective way to reduce program costs and fully utilize the skills of existing staff.

For most communities, limited budgets and personnel will require that the tree risk inspections and maintenance tasks be implemented or phased in over a period of years. Prioritize tree maintenance needs, identifying those that are most critical and those that can be delayed with minimal impact on the public safety and tree health. A process to prioritize tree maintenance needs and develop cyclic tree inspection and implementation schedules is discussed in Step 6.

What Do You Want?

Step 4. Identify Program Goals

Establish a broad-based municipal working group to develop a community tree risk management plan. The working group should be in place and active during the entire program design process. It should bring to the table all groups that are currently involved and those that should be involved with the management of the community's urban forest, public safety, and emergency services. Be inclusive rather than exclusive as you establish the membership list for this working group. A tree risk management working group will typically consist of:

- City Forester or tree warden
- Representatives from municipal departments such as public works, parks and recreation, transportation, fire/police/emergency services, planning and zoning, engineering, and the county attorney's office, county commissioner's office, and the mayor's office
- Tree service providers
- Public utility providers
- Private citizens
- Media contact

Local non-profit organizations, non-governmental organizations, and other public agencies may also be involved, depending on the infrastructure of a particular community.

The working group should define what a tree risk management program will accomplish within their community. Establish program goals that address identified community needs and identify management strategies that will produce measurable results. Program goals are the tangible ends that the management strategy seeks to achieve, and provide the basis for formulating, implementing, and evaluating the management strategy.

There is little point in establishing a goal if there is no practical way of determining whether progress is being made towards achieving that goal. For example, while it is most admirable to seek to "protect the health and welfare of the community" or to "improve the health of the urban forest," such goals are very general and tangible results are difficult to measure. However, establishing the goal of "reducing risk to public safety and personal property by mitigating hazardous tree defects," would address a key public safety need. Tangible actions (e.g., establishing tree inspection guidelines) can be taken, and progress can be measured by documenting the dates when risk inspections are conducted and corrective actions are implemented.

Guiding principles and fundamental goals. Although a community tree risk management program can have many goals, two guiding principles provide the overarching context of most successful programs: Increase public safety by reducing risks associated with trees that possess hazardous defects or visually obstruct traffic signs, intersections, or street lighting, and manage the community tree resource to promote tree health and sustainability

The two guiding principles of tree risk management programs are:

- **Increase public safety**
- **Promote tree health and sustainability**

Both guiding principles can be achieved through a two-tiered program that focuses on the fundamental goals of 1) preventing hazardous tree defects through the implementation of proper arboricultural practices that promote tree health and structurally sound trees, and 2) correcting hazardous tree defects through the use of a systematic process to accurately detect and assess hazardous defects, and implement corrective actions within a reasonable time.

Other possible goals:
Goals and specific management strategies will vary by individual communities. They should address specific needs that exist within the community such as identified tree resource needs, staff and fiscal resources needed to implement a tree risk management program, and the need to educate the public.
Other program goals that might be considered include:

- Hiring a full-time City Forester and/or other tree care staff needed to implement a tree risk management program

- Promoting professional development of tree care staff through continuing education programs

- Developing educational outreach programs and demonstration projects to increase public awareness of the need for and benefits of a community tree risk management program

- Increasing awareness of tree risk management among municipal staff through presentations and training sessions (This is NOT just for forestry staff; everyone needs to be aware of the program.)

- Coordinating with public utilities to promote proper pruning and the selection of smaller stature tree and shrub species for planting under utility lines

- Establishing a comprehensive wood waste utilization management plan that focuses on implementing efficient and ecologically sustainable methods

How Do You Get What You Want?

Step 5. Formulate a Tree Risk Management Strategy

A tree risk management plan enables a community to prevent, detect, assess, and correct structural defects in trees, before they endanger public safety or tree resource health. Just as nothing in life is risk-free, every landscape and tree situation involves risk. The goal of a tree risk management program should not be to strive for zero risk, since this is unattainable. Rather, the goal should be to reduce the risks trees pose to public safety to a level that meets professional standards and demonstrates reasonable care. Management strategies should address program principles and fundamental goals, implement actions that address specific needs, and produce measurable results.

Consider actions to prevent hazardous defects. Sound arboricultural practices are the best defense against development of hazardous defects. Choose species that are suitable for the available planting sites, and implement proper planting techniques. Chapter 4 (Prevention of Hazardous Defects) discusses criteria for selecting nursery stock, species selection, and proper planting and pruning techniques. Once a tree is planted, a program of early and regular tree pruning will prevent the development of many structural defects, and reduce subsequent pruning, tree removal, and replanting costs.

Consider actions to correct hazardous defects. A tree risk management plan must provide the community with a systematic process to detect, assess, and correct hazardous defects before they cause tree failures. Procedures to correct hazardous defects in trees range from simply pruning out defective branches to the ultimate step of removing the tree. Chapter 5 (Correction of Hazardous Tree Defects) discusses specific corrective actions. Early detection and correction of tree defects will reduce the number of trees that become hazardous and reduce subsequent tree pruning, tree removal, and replanting costs.

Step 6. Prioritize Inspection and Corrective Action Needs

In all likelihood, a community cannot handle 100 percent of its forestry workload each year. Limited budgets and personnel will require that tree inspections and corrective actions be implemented or phased in over a period of years. The community must carefully evaluate the condition of the community forest and visitor usage patterns within public areas, and target the use of limited community resources where they are needed the most — in the areas with the greatest risk to public safety. Communities should prioritize inspection and corrective action needs, identifying those that require immediate attention and those that may be delayed with minimal impact on public safety and tree health.

Identify specific areas or situations that will be excluded from the program. For example, trees located on private property are often excluded from the jurisdiction of a community tree risk management program. The community must decide to include or exclude borderline trees or trees abutting public property as part of the program. Wooded areas located away from structures or trails, undeveloped green belts or corridors, wetlands, or low use trails might be designated as "natural areas" that will be excluded from the program and will not receive risk inspections. Some tree risk management plans have made it a policy to inspect only trees that are greater than 6 inches in diameter, since most documented tree failures occur in trees greater than 6 inches in diameter.

We will discuss how to prioritize tree inspection and corrective action needs, based on a process that 1) divides the community into tree risk zones, 2) establishes tree risk inspection methods and schedules, according to tree risk zones, and 3) implements corrective actions in a reasonable and timely manner. Both large and small communities can effectively implement this process.

Divide the community into tree risk zones. To assist communities as they prioritize inspection and corrective action needs, the community can be divided into tree risk zones, ranging from zones where trees pose a very high level of risk to public safety to zones associated with low public safety risks. Each zone is managed and inspected on a defined schedule, based on the level of risk posed to public safety. For example, high-risk zones are scheduled to receive more frequent, in-depth inspections, and tree maintenance work is performed on an expedited basis. A color-coded map of risk zones, ranging from very high to low risk, can be developed for use as a management tool for forestry staff, and as a visual aid for educating the public about the levels of risk that trees can pose to public safety.

Determine the level of risk posed to public safety based on risk criteria that assess roadway characteristics (type, traffic volume, and congestion patterns); public use and occupancy patterns (high, moderate, and low) within public areas; and tree resource characteristics including tree condition (risk rating, age, and density), and location factors such as branch interference with pedestrian traffic or utility lines, and root interference with sidewalks. For example, high-use parks and playgrounds should always be considered high-risk zones based on high public use patterns and the presence of relatively large tree populations. Inspect these areas frequently and implement corrective actions on an expedited basis. Similarly, consider trees or tree branches that obstruct pedestrian and/or vehicular traffic very high risk, and dispatch maintenance crews immediately to perform clearance pruning as soon as the problem is identified.

Analysis of tree inventory data can be an effective tool in identifying high-risk zones within the community tree population. For example, if high winds caused tree damage within the community, analyzing tree inventory data that includes tree condition and general location variables can identify storm-damaged areas. Designate storm-damaged areas as high-risk zones, and direct maintenance crews to conduct post-storm tree risk inspections as a top priority. Similarly, a neighborhood with a large number of mature or over mature trees might be red-flagged as a high-risk zone in need of more frequent risk inspections and more extensive corrective pruning. If the community has compiled a list of "problem" tree species (species with the highest rates of tree failures, storm damage, structural decay, repetitive crown dieback, or a short life-span), target neighborhoods or areas that contain a high density of "problem" species to receive more frequent risk inspections.

Identify criteria to define tree risk zones. Below are criteria that can be used to establish and map risk zones within a community.

Criteria to Establish Tree Risk Zones (See Table 2.1)

- **Roadway characteristics:** Prioritize according to key public safety issues such as emergency accessibility, and traffic volume and congestion factors. Top priority areas include:
    - Emergency access routes
    - Congested intersections
    - Major detour routes
    - Roadways or intersections where tree branches obstruct visibility of traffic signs or stop lights, or physically obstruct pedestrian or vehicular traffic
    - Streets that have had major reconstruction or underground utility work
    - Main thoroughfares
- **Public use and occupancy patterns**: Prioritize according to importance to public safety (fulfilling emergency and medical needs) and occupancy patterns. Top priority areas include:
    - Emergency and medical facilities, handicap access areas
    - Extensively used public areas and buildings
    - Neighborhoods with high population densities
- **Tree resource characteristics:** Prioritize by tree condition factors such as high average risk rating, areas with older or dense tree populations; and tree location factors such as branch interference with pedestrian or vehicular traffic, utility lines, or root interference with sidewalks. Top priority areas include:
    - Areas with a high proportion of high to very high tree risk ratings, as determined by the preliminary inventory survey data, tree risk inspections, or "hazard" reports submitted by the public of city staff
    - Areas severely damaged by storms
    - Areas with old growth trees
    - Areas with high a density of "problem" tree species
    - Areas with root injury caused by sidewalk or road construction
    - Areas where tree roots interfere with sidewalks and cause buckling

Table 2.1 provides an example of a color code system and includes examples of roadways, public buildings and use areas, and tree resource characteristics within each tree risk zone category. Very high-risk areas (color coded in red) include emergency access routes, medical and emergency facilities and shelters, school playgrounds, permanent structures, and drive-in campsites within high-use parks. High-risk areas are color coded in orange; moderate risk areas in yellow, and low risk areas in green.

Table 2.1. *Tree risk zone categories; color codes; and examples of roadways, public buildings and use areas, and tree characteristics that pertain to each tree risk zone.*

Hazard Zone Categories	Color Codes	Examples
Very High Hazard	**Red**	1. Emergency access routes 2. Medical and emergency facilities and shelters, handicap access areas 3. School playgrounds 4. In high-use parks/public areas: permanent structures and drive-in campsites 5. Individual trees or neighborhoods with very high-risk tree characteristics such as : • standing dead trees or those with very poor condition class ratings • severely storm-damaged trees • trees that visually obstruct traffic signs, stop lights, or security lights • tree roots causing severe sidewalk buckling
High Hazard	**Orange**	1. Main thoroughfares: congested intersections and visually obstructed traffic signs and stoplights 2. High-use parks, playgrounds, and picnic areas 3. Golf courses 4. Parking lots adjacent to high-use public areas 5. Bus stops along high-use thoroughfares 6. Individual trees or neighborhoods with high-risk tree characteristics such as: • old growth trees • high density of large diameter, mature, or “problem” tree species • root injury caused by sidewalk or road construction • storm-damaged trees
Moderate Hazard	**Yellow**	1. Secondary roadways: congested intersections and visually obstructed traffic signs and stoplights 2. Neighborhoods with a moderate density of large diameter, mature or “problem” tree species 3. Moderate-use parks, playgrounds and picnic areas 4. Parking lots adjacent to moderate-use areas
Low Hazard	**Green**	1. Low-use roads and public areas with dispersed recreation 2. Open areas, woods, riparian zones, and peripheral areas with limited use or access 3. Neighborhoods with a low density of large diameter, mature, or “problem” tree species

Map tree risk zones. The next step is to develop a color-coded map of the community that highlights designated tree risk zone categories. This map will serve as a handy visual reference of tree risk zones within the community, and will be useful in establishing inspection schedules and tree risk assessment methods. Start by constructing a map of the community that contains the roadway system, public buildings, and public use areas. Many city departments have developed computerized data layer or Geographic Information System (GIS) files that contain the information needed to map tree risk zones within the community. For example, the transportation or public works department often has maps or

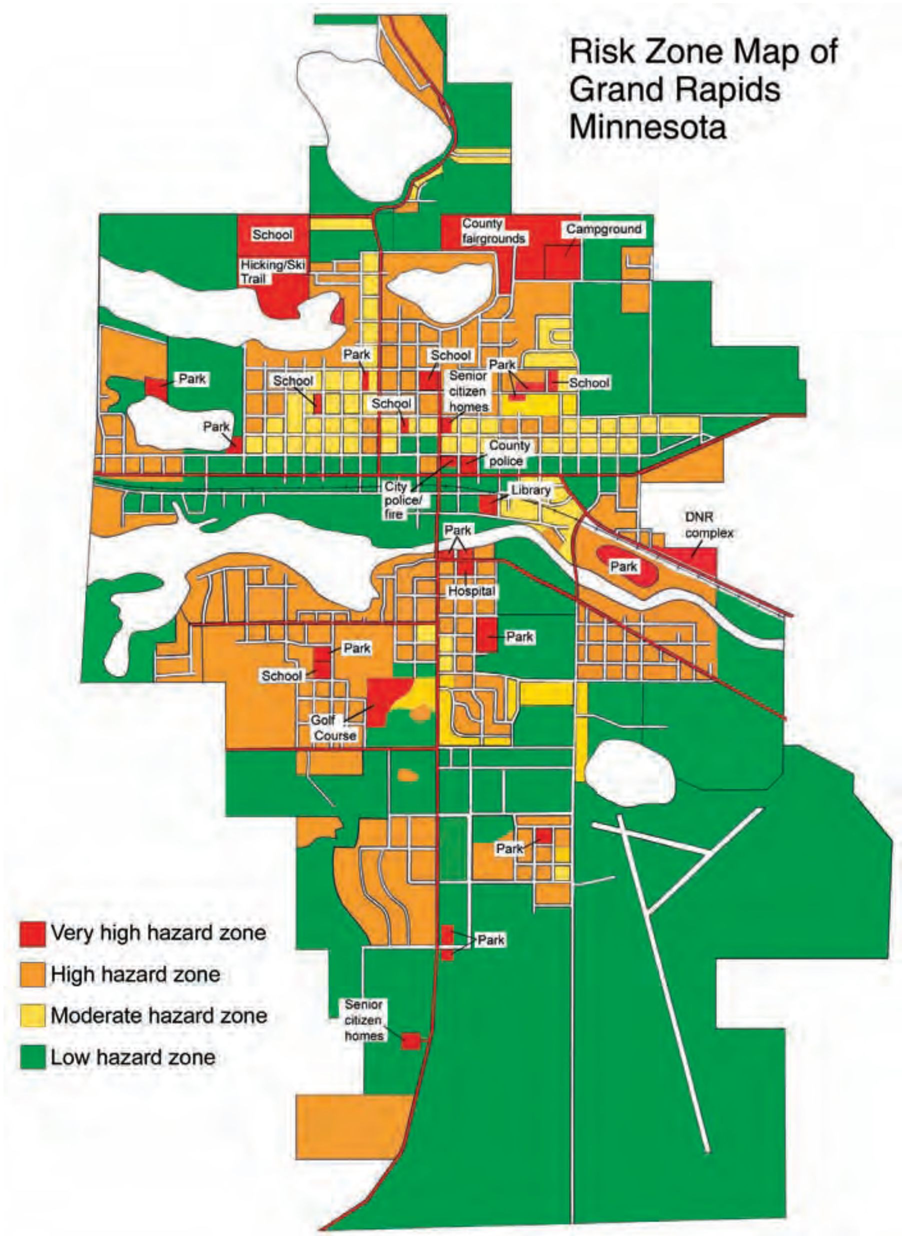

Figure 2.9. *Color-coded risk zone map of Grand Rapids, Minnesota. Very high-risk areas (color coded red), and high-risk areas (color coded orange) represent areas that should receive frequent risk inspections, using in-depth inspection methods, and where corrective actions should be implemented on an expedited basis.*

data layer files of the roadway system and traffic volume and congestion levels. The department in charge of planning and zoning will have information on the location of public buildings such as hospitals, fire, police, and other emergency medical facilities; schools; libraries; city administration buildings and community centers; and public use areas such as golf courses, city parks, and swimming areas. The parks and recreation department will have information on the location and usage patterns of public parks and other recreational areas. If computerized data files are not available to construct a community map, work from a standard city map of the roadways, manually identify public buildings and high use public use areas, and color-code these features on the map, using a different color for each tree risk zone. Using stick pins of various colors to mark the map works well and allows the map to be updated easily to reflect changes in risk levels. Figure 2.9 is a manually generated map that illustrates tree risk zones, using the above mentioned color-code system, for the city of Grand Rapids, Minnesota.

Update the community tree risk zone map to reflect significant changes within the tree population, roadway traffic patterns, or public use patterns. Keep up to date on the incidence of very high-risk trees. Mark very high-risk trees that are identified during ongoing tree risk inspections or post-storm damage surveys, or that are reported by tree planting or pruning crews with red pins on manually produced maps or color code these areas red on computer generated maps. Remove the red pins or color coding when corrective actions are completed. Delineate neighborhoods that have a large number of storm-damaged trees on the map until corrective actions are completed. Some communities red-code neighborhoods with large, mature trees that have undergone sidewalk reconstruction projects because severe root severing has occurred and the risk of tree failure is very high. Roadway repair or construction projects that result in serious congestion traffic patterns problems should also be tracked and coded appropriately.

Establish tree risk inspection methods, according to tree risk zone categories. Tree risk assessments estimate the degree of risk associated with a given tree to fail and potentially injure persons or damage property, and should be capable of measuring risk levels ranging from low to very high. Within a tree risk management program, implementation of more than one inspection method may be useful. In-depth inspection methods that examine the full range of tree defects and site conditions present are most useful when conducting risk assessments to determine the likelihood of a tree to fail and strike a target. Less intensive methods can be effective tools for identifying very high-risk trees and pinpointing high-risk zones within the community, and for conducting post-storm tree damage surveys. We will describe two basic methods: 1) walk-by (individual tree) inspections and 2) drive-by (windshield) inspections, and discuss the appropriate use of each of these methods within the context of a tree risk management program. See Table 2.2

Walk-by (individual tree) inspections. This method requires inspectors to walk through an area and rate individual trees for their potential to fail, based on the presence of defects, evaluation of targets, and other site conditions. All trees located within striking distance of a target receive a 360-degree visual inspection. Diagnostic tests are performed as needed.

Strengths of walk-by inspections. Walk-by tree inspections represent an in-depth evaluation method that provides the level of information necessary to make cumulative decisions about tree defects, site conditions, and the level of risk associated with a given tree to fail and strike a target. To accurately assess the potential risk that a tree will fail, it is important to thoroughly examine the tree and determine the full range of defects and site conditions that are present and could contribute to tree failure. Tree risk assessments should be capable of measuring a variety of risk levels, ranging from low to very high, and should include examination of all sides of the tree including the rooting zone, root collar, main stem, branches, and branch unions. A 360-degree inspection method is especially critical when defects occur on only one side of the tree and might be missed using the drive-by/windshield inspection method. It is not uncommon to find a tree that displays a full, green canopy and/or no major defects when viewed from only one side (Fig 2.10). The same tree, when viewed from the other side, may reveal a serious wound with extensive decay that causes the tree to be at a very high level of risk for failure (Fig 2.11).

Figure 2.10. *This tree, when viewed from one side, displays no serious defects.*

Walk-by inspections represent an inspection method that provides communities with the level of cumulative information needed to conduct tree risk assessments within all tree risk zones. They are the suggested inspection method for conducting tree risk assessments in very high, high, and moderate risk areas.

Defects can occur anywhere on a tree, an inspection method that examines all sides of a tree will provide the most complete information to determine the potential risk for that tree to fail

Figure 2.11. *The same tree, viewed from the opposite side, displays serious defects: a large stem cavity with extensive decay. These defects and the tree's close proximity to a target make it a very high-risk tree.*

Weaknesses of walk-by inspections. Walk-by inspections are more labor intensive and costly to conduct than less intensive methods such as drive-by surveys. Because of the higher cost of implementing walk-by inspections, it may be necessary to limit their use to areas with the highest degree of risk such as very high, high, and moderate risk zones. This could be an effective way to streamline program costs and focus limited community resources to areas of greatest risk.

Drive-by (windshield) surveys. This method involves inspectors visually scanning trees for the presence of hazardous defects while traveling at slow vehicle speeds. It is recommended that a follow-up individual tree inspection be conducted on all trees noted by the drive-by survey to have hazardous defects present. Two people should be present in the vehicle: one to drive and one to assess trees and record data.

Strengths of drive-by inspections. Drive-by surveys are quick and easily implemented, and can be a cost effective planning tool to provide preliminary data on very high-risk trees and to pinpoint high-risk zones within the community tree population. They can detect overt hazards such as standing dead trees, trees with significant numbers of dead branches, or major tree architectural problems visible from the road. They could be used as a scoping tool to conduct a preliminary survey of the community's tree resource and provide an estimate of the number of highly hazardous trees. This information can be very valuable in building community support and documenting the need to establish a tree risk management program. As a supplemental survey tool, drive-by surveys can be used to augment efforts to divide the community into tree risk zones, and assist communities to focus the use of limited resources to the areas of highest risk. Drive-by surveys could also provide a quick and timely response after storms to identify areas where damage to trees occurred and where corrective actions are likely to be needed. This is possible since many storm-damaged trees will have defects in their crowns such as broken branches or cracked branch unions that are visible from the road.

Under situations of limited community resources, it may be feasible to use drive-by surveys to conduct tree risk inspections in low hazard zones and as a supplemental survey method in moderate hazard zones during "off-years" when individual tree inspections are not scheduled. Under conditions of extremely limited community resources, some communities have made a short-term decision to exclude low risk areas from the tree risk inspection program. In this case, tree risk inspections would not be conducted within low risk areas, but rather informal tree risk observations would be made as part of the ongoing tree maintenance program.

Weaknesses of drive-by inspections. Although drive-by surveys are an effective method for conducting preliminary surveys or post-storm tree damage surveys, their usefulness for conducting individual tree risk assessments is very limited. Drive-by surveys collect incomplete data on tree defects, site conditions, and potential targets because they rely on information inspectors collect during a visual scan, while traveling in a moving vehicle, viewing only one side of the tree. Many trees with hazardous defects will go undetected using this method of survey. For example, drive-by surveys will not detect defects (overt or subtle) that occur on the side of the tree facing away from the road. Additionally, more subtle defects such as narrow cracks or girdling roots, even if they occur on the side facing the road, may go undetected simply because they cannot be readily seen from the road. Clearly, defects present in a tree, but not able to be observed with a drive-by survey, can cause a tree to have a high risk for tree failure (Figs 2.12 and 2.13). The data collected with drive-by surveys is limited to what an inspector can readily see from the road, and restricts the usefulness of this method to the detection of very high-risk trees that have hazardous defects visible from the road. Within the context of a tree risk management program, drive-by surveys are best used a preliminary or supplemental survey tool, not as a stand-alone tree risk assessment method.

Establish tree risk inspection schedules based on tree risk zone categories. Frequent inspections are essential for a successful tree risk management program. Tree structure and vigor necessarily change over time since trees are living organisms. Systematic inspections detect and monitor potentially deleterious changes. If tree inspections are not conducted on an ongoing and regular basis, many hazardous defects and situations will go undetected, and the fundamental goal of reducing risk to public safety cannot be met.

Figure 2.12. *This tree, when viewed from one side, displays no serious defects.*

In addition to improving public safety, frequent tree risk inspections provide a continuous source of tree resource data, and can eliminate the need to conduct separate, periodic tree inventory assessments as part of the tree planting or pruning programs. This integrated approach establishes a foundation for making informed management decisions, validating budget requests, and documenting program success.

Tree risk inspection schedules, like tree risk inspection methods, can be established according to identified tree risk zones as discussed in Step 6. High-risk zones should be inspected frequently, using in-depth tree inspection methods. Lower risk areas can be inspected less frequently and may employ the use of walk-by/individual tree inspections as well as less intensive drive-by surveys. This approach allows the community to target the use of limited fiscal resources to the areas of greatest risk. Inspections can be conducted at any time of the year, leaf-on or leaf-off, with the exception of times when snow cover prevents the examination of root conditions.

Figure 2.13. *The same tree, viewed from the opposite side, displays serious defects: a large stem cavity with extensive decay. These defects and the tree's close proximity to a target make it a very high-risk tree.*

Table 2.2 outlines suggested minimum guidelines for inspection methods and inspection schedules within a community tree risk management program. The suggestions contained in this table present a range of inspection options within most

Table 2.2. *Suggested minimum guidelines for inspection methods and inspection schedules within a community tree risk management program.*

Hazard Zone Categories	Color Codes	Timing of Inspections	Suggested Inspection Method	Comments
Very High	Red	Annual	Walk-by/ Individual Tree Inspections	
High	Orange	1-2 years	Walk-by/ Individual Tree Inspections	
Moderate	Yellow	3-5 years	Walk-by/ Individual Tree Inspections	Consider conducting a drive-by/windshield survey on an "off-year" when individual tree inspections are not scheduled.
Low	Green	5-7 years	Walk-by/ Individual Tree Inspections or Drive-by/ Windshield Surveys	
All Rated Zones	NA	After Severe Storms	Drive-by/ Windshield Surveys	If potentially hazardous trees are detected, follow-up with individual tree inspections

The information contained in this table is offered as suggested guidelines and presents a range of inspection options within most risk zone categories. Individual communities must assess their tree resource needs and community resources, and adopt program guidelines that address their specific situation. Communities should always seek professional legal advice when drafting specific language governing inspection methodology and frequency.

risk zone categories. Individual communities must assess their tree resource needs and community resources, and adopt program guidelines that address their specific situations. It is critical to remember that the community is ultimately responsible for maintaining the publicly owned tree resource and shouldering the liability that may result from improperly caring for it. Not having funds to maintain the resource does not absolve a community of this responsibility or accountability in lawsuits arising from personal injury and property damage claims resulting from a fallen tree or tree branch. Moreover, the cost of a judgment against the community or the defense costs in a lawsuit could conceivably pay for a tree risk management program for many years (Tate 1985). Communities should always seek professional legal advice when drafting specific language governing inspection methodology and frequency to ensure that professional standards are met and reasonable care is demonstrated.

Step 7. Select a Tree Risk Rating System

There are many evaluation systems that rate the risk of damage or injury posed by a defective tree or tree part. Some systems define a numerical risk value, while others are categorical and describe the level of risk on a scale ranging from "low" to "very high." The first tree risk rating systems used in the United States were developed for use in recreational sites and were based on tree failure information collected from federal and state recreation areas within the United States. Some state and federal agencies, including the U.S. Forest Service, the National Park Service, and the Minnesota Department of Natural Resources have developed tree risk rating and management program guidelines for recreation sites to reduce accidents caused by tree failures (Paine 1971, Mills and Russell 1981, Wallis et al. 1980, Johnson 1981, Albers and Hayes 1991). Later, tree risk rating systems were developed for use in urban areas, and many of these "urban" systems were modeled after recreational site systems and guidelines. To date, most published tree risk rating systems are designed for use in recreational areas, but a few are designed for use in urban areas (Bartlett Tree Expert Co. 1991, Matheny and Clark 1994, Colorado Tree Coalition 1999, Hayes 2000).

In Chapter 3 (How to detect and assess hazardous defects in trees), two risk rating systems (Minnesota DNR and U.S. Forest Service) are discussed as examples of systems that have been successfully implemented in urban areas. No single risk rating system is perfect or capable of adapting to all situations, nor is there one model system recommended for all communities. For these reasons, this manual does not recommend a particular tree risk rating system over another. A survey was sent to the authors of tree risk rating systems/manuals, designed for use in urban areas, and published in the United States. The survey consisted of ten questions that addressed assessment methods and rating systems used for conducting tree risk inspections, time required to conduct an assessment, and the level of training needed to prepare field staff to conduct assessments. Survey questions were selected based on their perceived usefulness to community decision-makers in selecting a tree risk rating system suitable for their respective communities. Survey questions, and responses provided by the respondents, are summarized in Appendix 1.

Regardless of the tree risk rating system selected, collect all information on a standard form that summarizes the important aspects of the assessment. Store tree risk assessment information so that data is easy to access, update, and retrieve. Most communities can afford the cost of a computer that is capable of managing their tree resource data. Most communities have chosen to use standard PC workstations that may be connected to a municipal wide area network. There are many software programs on the market that can store and manage tree resource data. Most spreadsheet or database programs can be used for this purpose. Tree inventory software programs are commercially available and can be very useful and cost-effective if they do not need to be customized for your community's needs. Whatever computerized database system the community selects, it must be able to manage tree risk assessment data as well as basic tree inventory data and generate management recommendations. Useful information can often be obtained from communities that have already established a tree inventory system or tree risk management program. It may even be possible to purchase a customized spreadsheet or database program from another community forestry program. Take care to ensure that the software is compatible with databases within other city departments.

Although the up-front hardware and software costs are reasonable, they represent only a portion of the total investment. The time and labor needed to update and maintain a computerized system is substantial, and these costs should be factored into budget requests. Consider the internal and external resources that will be necessary to automate the system. Internal resources include ongoing clerical support, hardware and software support, and staff training. External resources include program development, program customization, report writing and network administration.

Figure 2.14. *The removal or immediate corrective treatment of very high-risk trees must be a top priority within any tree risk management program.*

Establish an implementation schedule for corrective actions. Removal or immediate corrective treatment of very high-risk trees must be the top priority within any tree risk management program (Fig 2.14). It is not uncommon for a community to have a large number of high-risk trees, particularly if a tree inventory survey or tree risk inspections have never been conducted or have not been conducted in recent years. For most communities, limited budgets and personnel will require that corrective actions be implemented or phased in over a period of years. In such cases, the question becomes, "Which of the very high-risk trees should receive corrective treatment first?"

Be prepared to explain the rationale for assigning treatments to trees identified as hazardous. Clearly outline the methods used to identify high-risk trees, initiate necessary corrective actions, and implement these actions within a reasonable time frame. Numeric tree risk rating systems provide a justifiable way to prioritize corrective treatments. Trees with the highest numeric risk rating are treated first, and other corrective treatments are implemented later, according to decreasing numeric risk ratings. If integrating the tree risk zone approach with a numeric risk rating system, trees with the highest risk ratings within the highest risk zones are treated first, followed by those within the moderate and low risk zones. Such a system allows managers to identify the highest risk trees and implement corrective actions on an expedited basis, and demonstrates an approach to implementing corrective treatments in a reasonable and systematic fashion.

Step 8. Write a Comprehensive Tree Risk Management Program Policy

The community must write, adopt, and enforce a tree risk management policy that specifies program goals, management strategies, and implementation steps identified in Steps 5, 6, and 7. The tree risk management program policy should include provisions that the community is willing and able to enforce. Consult with the city's legal counsel throughout the process of writing, adopting and enforcing a tree risk management program policy. Timely legal advice, based on current laws and professional standards, will help to ensure that reasonable care is being taken to manage the public safety risks associated with hazardous trees. Once a program policy is written and adopted, the community will be held responsible to enforce the stated policy provisions. For this reason, review policy statements often, preferably on an annual basis, to ensure the provisions provide the level of risk management that is appropriate for the community.

Tree risk management program policy statements should not duplicate or contradict any existing laws. Review copies of other policies, ordinances, codes, rules, or regulations that affect trees in the community, and cross-reference those that are pertinent to the tree risk management program policy. For example: Do the utility department or utility companies have written policies regarding trees and shrubs growing near overhead or underground utility lines? Does the street department have any written policies that require trees to be trimmed to a certain height above streets and sidewalks?

Be aware of industry standards for proper tree pruning techniques, safety requirements for tree care operations, and selecting high quality nursery stock. Implementation of these standards is voluntary, and the community may wish to establish their own set of standards. Whatever tree care standards are selected for implementation, they should be stated or cross-referenced within the tree risk management program policy.

Elected officials, with the designated authority, should sign off on the program policy to officially adopt it as a community tree risk management policy. Once the plan is signed, elected officials should confirm that they will support the personnel who administer the tree risk program and support their assessments of trees and recommendations for corrective treatments. Establish a process to handle conflicts with homeowners, and corrective action appeals presented by affected citizens.

Address the following points in the tree risk management program policy:

- State the community's understanding of its responsibility to maintain the safety of public lands from potentially hazardous trees
- Identify who will administer the tree risk management program and possess the authority to enforce tree risk reduction policies
- Identify the standard (tree risk rating system) to be used to assess the degree of risk associated with a given tree to fail and potentially injure persons or damage property
- Specify inspection methods and schedules to be implemented
- Specify a process by which corrective actions will be implemented
- Identify a process for handling corrective action appeals presented by affected citizens
- Identify a process for handling violations of the tree risk management program policy

An interactive software program (TREEORD) has recently been developed as a tool for communities to draft and write tree ordinances. It contains more than 1,800 examples of text contained in existing ordinances from communities throughout the United States. The example text has application for developing policy statements as well as ordinances. TREEORD is available for purchase from: Tree Trust, 2350 Wycliff Street, Suite 200, St. Paul, MN 55114 (e-mail: http://www.treetrust@treetrust.org)

Step 9. Implement a Tree Risk Management Strategy

Hire and/or train staff. Trained and able staff must be available to implement a tree risk management program. Staff can be cross-trained and shared between the tree planting, pruning, and tree risk management program areas, and every effort should be made to coordinate activities and share costs among these programs. For smaller communities that do not have a City Forester or forestry staff, it may be more cost effective to contract these services by hiring professional forestry consultants to conduct tree risk inspections or implement corrective actions. Out-sourcing services in this way solves the problem of limited in-house staff size, and eliminates the need to provide ongoing staff training in tree risk assessment and management. Professional consultants should provide evidence of accredited training in tree risk management, arborist certification, and extensive field experience in the detection, assessment, and correction of tree defects. Sharing a City Forester position between several communities may also be a feasible approach to administering a tree risk management program within smaller communities.

Some larger communities will have a City Forester and a forestry staff in place who can be trained to conduct tree risk inspections and implement a tree risk management program. Proper training is paramount to ensuring staff possess the knowledge needed to conduct tree risk inspections correctly and make accurate and informed management decisions. Staff require thorough training and proper supervision. At a minimum, training should consist of 1-2 days of intensive classroom and field training, with a heavy focus on conducting actual tree risk assessments in the field. The training program should provide for the continuing education of the staff, and offer refresher courses at least every couple of years. Newly trained staff should work under the supervision of a more experienced staff member to become familiar with the program specifications, and the local tree resource characteristics and conditions. There is no substitute for experience in tree risk assessment, so teaming an experienced inspector with a newly trained inspector should be a top priority. In addition, periodic spot-checking of all trained staff should be done as a quality control measure.

Some communities will train and supervise volunteers to assist with implementing a tree risk management program. This is a controversial practice, and many published texts on the topic of tree risk/hazard management unequivocally state that tree risk assessments should be conducted only by tree care professionals who are specifically trained in tree risk assessment techniques. Clearly this approach is thorough and may be the preferred option, but it may be too limited in its perspective. If volunteers are provided the same level of training as community forestry staff, are teamed and supervised with experienced inspectors, and pass quality control checks that demonstrate proficiency in conducting tree risk assessments in the field, it is possible that volunteers could possess the skills needed to conduct tree risk assessments. Proper training, supervision, and quality control checks to demonstrate proficiency are critical to making this approach succeed, however. Clearly, not all volunteers will be suited for this assignment. As a general rule, communities should confer with a city attorney on issues relating to professional standards, practicality, legality, and economics to receive advice and assistance in drafting specific language to be included in a policy statement.

Here are some key points to consider that relate to the use of volunteers within a tree risk management program:

- Volunteers must be indemnified. The city attorney should determine the process that must be followed to ensure volunteers are indemnified against personal liability while assisting in a community tree risk management program.

- Volunteers should receive proper training and supervision. Volunteers should receive 1-2 days of training, with a heavy focus on conducting tree risk assessments in the field. In addition to training, volunteers should always work under the direct supervision of a local professional to become familiar with the program specifications and local tree resource characteristics. The professional should provide backup assistance on any trees that are difficult to rate or pose other problems. Periodic spot-checking of volunteer work should be done as a quality assurance measure, and the proficiency of volunteers in conducting tree assessments must be regularly assessed.

- Volunteers should be qualified. Whenever possible, an effort should be made to work with volunteers who have a background in urban forestry or have received urban forestry training from State Extension Programs and other programs such as Master Gardeners, Tree Care Advisors, Woodland Keepers or Tree Keepers.

- Volunteers should receive training on how to effectively talk with homeowners about the purpose of the tree risk management program and how to address concerns about tree removals.

Implement risk inspections and corrective actions according to established methods and schedules. Risk inspections should be implemented according to the methods and schedules established in Step 6. Establishment of an implementation schedule for corrective actions is discussed in Step 7.

Document tree risk inspections, corrective actions, and tree failures. It is critical to document the inspection process and maintain records of recommended corrective treatments and the dates they are implemented. Whatever tree risk assessment/rating system is used, a standard data collection form should be used to capture this information. The standard form should include the name of the inspector, date of inspection, tree defect and risk rating information, recommended corrective treatments, the date, and who completes corrective treatments. Information contained on the standard form can be manually filed or entered into a computer database file. Digital photography can a very valuable tool to document and supplement inspection reports. Access to tree inspection data will help managers actively manage their tree resource and make sound, objective, and timely management decisions. For example, all high-risk trees recommended for removal can be identified, and work schedules can be coordinated to remove such trees, on an expedited basis.

Documenting the inspection process and tracking corrective actions will help demonstrate that the community is implementing a systematic procedure for inspecting, evaluating, and managing potentially hazardous trees. Tracking corrective treatments as they are completed can be a powerful tool to document the number

Figure 2.15. *All tree failures and significant branch failures should be inspected immediately, documented, and photographed.*

of high-risk that trees have been removed since the inception of the program, and demonstrates that the community has materially reduced risk to public safety through the implementation of the tree risk management program.

Inspect, document, and photograph all tree failures and significant branch failures immediately (Fig 2.15). This information may prove to be extremely valuable in defending the community against negligence lawsuits. Collect information about the details of the tree failure such as the presence and severity of structural defects, wood decay, or injuries; maintenance history; site conditions; the time and date of the tree failure, and prevailing weather conditions. Document the inspector's opinion as to how and why the tree failed, if any significant structural defects were present, and any other extenuating factors that may have contributed to the failure. Collect this information on a standard form, and store it within the tree risk management computer database program, along with tree risk assessment data. Appendix 2 contains an example form for recording tree failures, developed by the California Tree Failure Reporting Program.

Analysis of tree failure data can help to identify patterns of recurring failure of certain tree species, or failures associated with specific structural defects, site conditions, or management practices. This information can be an invaluable tool for the tree risk managers to pinpoint high-risk "problem" tree species in need of more frequent risk inspections or corrective pruning, and more accurately assess the risk potential of certain defects. Identification of high-risk or "problem" tree species can help tree planting programs make better choices of what trees should be planted in the community, and refine their list of recommended tree species for planting.

Are You Getting What You Want?

Step 10. Evaluate Program Effectiveness

There are a myriad of books and other materials in print that provide in-depth analysis of program evaluations, their designs, methods, and techniques. There are at least 35 different types of evaluation including needs assessments, accreditation, cost-benefit analysis, efficiency, formative, summative, goal-based, process, outcomes etc. (McNamara 1998). Outcome-based program evaluations are being used increasingly for non-profit and community-based programs. An outcome-based evaluation can determine if your organization is doing the right program activities to bring about the outcomes you believe or have verified to be needed by your clients. Outcomes are benefits to clients from participation in the program. For a tree risk management program, two expected outcomes would be 1) increased public safety and 2) improved urban forest health and sustainability. Once the major outcomes are identified, observable measures or indicators of success or failure must also be identified. For example, if the annual number of reported cases of personal injury or property damage due to hazardous trees has been reduced since the inception of the program, the tree risk management program can be credited with improving public safety. An observable indicator of improved urban forest health and sustainability would be a decline in the number of very high-risk trees in need of removal, and fewer trees in need of corrective pruning.

The overall program and all program components should be evaluated to determine how they are performing. For example, the following questions might be addressed:

- Is the risk rating system working?
    - Were most of the trees that failed rated as high-risk trees? If yes, then the tree-risk-rating system is working. If trees with low numeric ratings for failure are failing, then adjustments must be made to the tree-risk-rating system.
    - Review quality control checks to see if the staff are accurately conducting tree assessments. Survey staff to determine what they like or dislike and what they feel is working and not working about the tree-risk-rating system.
    - Has the number of tree "hazard" complaints from the public decreased?
    - Is there a backlog of trees needing removal?
- Is the inspection schedule working?
- Are there any cost reductions as a result of corrective actions taken?
- Is staff training effective?
- Is the use of volunteers effective?
- Are citizens unhappy with corrective actions?
    - Is there a need to have a public review period?

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How to Detect and Assess Hazardous Defects in Trees

By Jana S. Albers, Jill D. Pokorny and Gary R. Johnson

Defects and their risk of failure

There are as many ways for trees to fail as there are trees. An ice storm can overload all the branches on a tree, a blustery wind can blow down a tree if its roots are restricted or a cracked tree can and fail just under its own weight. See Figures 3.1, 3.2, and 3.3.

Figure 3.1. *Branch union failure during an ice storm.*

Trees are designed to easily withstand the normal windstorms and winter storms that occur, yet we have all seen trees that have failed. Trees fail when the load (weight and motion of the crown) exceeds the mechanical strength of their branches, stems or root systems. See Figure 3.4. This is true for both sound and defective trees, but defective trees can only withstand a fraction of the load that sound trees can withstand. Defective trees fail sooner than sound trees.

Figure 3.2. *Blowdown tree due to restricted roots.*

A sound tree becomes potentially dangerous when the tree's woody structure is weakened by one or more defects. Most defects can be linked to past wounding and decay, pest infestations, severe storms, or to growing conditions that limited the root system. Since defects, the old injury sites and nearby wood, are structurally weaker than uninjured wood, the tree is predisposed to fail at the location of the defects (Figure 3.5). During storms, pre-existing defects predispose trees to failure (Johnson and Johnson 1999).

Figure 3.3. *A cracked tree failed just under its own weight.*

Defects are visible signs that a tree has the potential to fail (Figure 3.6) and the location of a defect signals where failure is most likely to occur. Tree failure can be predicted because defects show us where the tree is likely to fail. This manual identifies seven categories of defects: decayed wood, cracks, root problems, weak branch unions, cankers, poor tree architecture, and dead trees, tops, or branches. See Box 1. Seven categories of defects. Examples of tree defects and risk rating systems were chosen to depict tree species and conditions that occur in the Northeastern U.S.

Figure 3.4. *Trees fail when the load exceeds the tree's mechanical strength.*

BOX 1

Seven categories of defects

 Decayed wood

 Cracks

 Root problems

 Weak branch unions

 Cankers

 Poor tree architecture

 Dead trees, tops, or branches

Figure 3.5. *Defective trees fail sooner than sound trees.*

Healthy, well-maintained trees that are growing on suitable sites will be able to minimize the impact of wounding and the extent of decay and other defects. Trees that are site-stressed have reduced energy reserves, and therefore, have compromised ability to deal with wounds and the ensuing decay. Urban trees are more likely to be site-stressed due to a number of factors. Most urban trees survive on construction-altered soils that may be compacted, poorly drained, high in clay, sand, or gravel, very alkaline or littered with construction debris. Quite often, these trees are growing in root-confined spaces,

Figure 3.6. *Defects are visible signs that a tree has the potential to fail.*

Figure 3.7. *When the roots, stem, or branches are defective, a tree can become hazardous.*

such as, narrow boulevards or sidewalk planting pits. See Figure 3.7. Additionally, many urban trees are subjected to chemicals such as deicing salts, herbicides and fertilizers commonly used in landscape maintenance. Poor tree maintenance exacerbates the stresses placed on trees by the above factors. These cumulative stresses all take a toll on tree vitality and structural integrity, increasing the risk of failure for urban trees.

In this chapter, seven common defects are presented along with inspection techniques to assess the risk of failure for trees with these defects. Each type of defect has a distinctive range of symptoms that indicates its severity and the tree's potential to fail. Three risk-of-failure ratings are used: low, moderate and high (See Form 3.1: Defective trees: Risk assessment guidelines). A tree with a low risk-of-failure rating has a defect that does not appear to be currently affecting the structural integrity of the tree. A tree with a moderate risk-of-failure rating may or may not result in eventual failure, but does not warrant immediate corrective action. A tree with a high risk-of-failure rating is in imminent danger of failing or has already partially failed. Corrective action should be taken as soon as possible.

Use the severity levels found in this chapter as guidelines when assessing trees. Remember, these are guidelines; no absolute rules can be made to cover the natural variability of trees and their defects. Although the list of defects and their combinations appears to be lengthy, it is not exhaustive. Inspectors need to use their judgment and local experience when evaluating and assessing tree defects.

Individual tree inspections are enhanced if inspectors have an understanding of the factors that create or accelerate the development of defects in trees. Several species have growth characteristics that make them prone to certain defects (Table 3.1).

Form 3.1. *Defective trees: Risk assessment guidelines (See Forms Section for a full-size copy of the form).*

Defective trees: Risk assessment guidelines

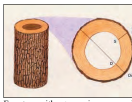
Tree defects	Moderate risk of failure	High risk of failure
Decay = Wood that has rotted or is missing. Indicators of advanced decay are rotten wood, fungal fruiting bodies, cavities, holes, open cracks or bulges in the wood.	• Indicators of advanced decay are found on 25% to 40% of the circumference of any stem, branch or root collar. • Shell thickness is >1 and < 2 inches of sound wood for each 6 inches of stem diameter and stem has opening < 30% of stem circumference.	• Indicators of advanced decay are found on ≥ 40% of the circumference of any stem, branch or root collar. *Note: In order to verify the extent of decay, you may want to use probes or drills to determine shell thickness.* • Stem has advanced decay and the shell thickness meets the following criteria: • Shell thickness < 1 inch of sound wood for each 6 inches of stem diameter, or, • Stem has an opening ≥ 30% of the stem circumference and shell thickness is ≤ 2 inches of sound wood for each 6 inches of stem diameter. • Any large branch with decay.
Crack = crack is a separation of the wood ; a split through the bark into the wood.	• Stem has a single crack and decay.	• Stem is split in two by a crack. • Stem segment has multiple cracks and decay. • Branch has a crack.
Root problems = inadequate anchoring by the root system, damaged roots or stem girdling roots.	• Roots within the area defined by the Critical Root Radius are ≤ 40% damaged, decayed, severed, or dead.	• Leaning tree with recent evidence of root lifting, soil movement or soil mounding. • Roots within the Critical Root Radius are ≥ 40% damaged, decayed, severed, or dead. • Girdling roots constrict ≥ 40% of the root collar.
Weak branch union = An epicormic branch or a branch union with included bark.	• Branch union has included bark.	• Weak union is also cracked, cankered or decayed. • Large epicormic branch on decaying stem.
Canker = An area where bark and cambium are dead.	• Canker or canker plus decay affect 25% to 40% of the tree's circumference.	• Canker affects ≥ 40% of the tree's circumference. • Canker plus decay affect ≥ 40% of the tree's circumference.
Poor architecture = growth pattern indicates structural imbalance or weakness in the branch, stem or tree.	• Branch has a sharp bend or twist. • Large, horizontal branch with several vertical branches on it.	• Tree with excessive lean (> 40°). • Leaning tree has a crack in stem. • Leaning tree has canker or decay on the lower stem. • Leaning tree has a horizontal crack on the upper side of the lean and/ or buckling bark and wood on the lower side.
Dead wood = A dead tree or dead branches.		• Any lodged branch. • Any dead tree, tree top or branch.

Defects : Defects are visible signs that a tree is failing or has the potential to fail. Defects predispose a tree to fail at the location of the defects.
Defective tree : A tree with one or more defects.
Risk of failure : Risk of tree or branch failure can be predicted because defects indicate which part of the tree is structurally the weakest. Since defect severity can change, the tree's risk of failure can change over time.
Moderate risk of failure : Currently, the tree's defects do not meet the threshold for failure. The defects may or may not result in eventual tree failure. "Moderate risk" trees need to be closely monitored to determine if the defects have changed since the last inspection.
High risk of failure : Currently, these defects indicate that the tree is in imminent danger of failing or has already partially failed. Corrective action should be taken as soon as possible.
Risk management : These guidelines are intended to provide the information needed to evaluate the failure potential of inspected trees. They are only guidelines. Absolute rules can not be made because of the natural variability of trees and their defects. ***All of the defective trees can not be detected, corrected or eliminated.*** However, by doing inspections and acting on them, we can successfully manage the risk of tree failure.

Inspections : Be systematic and complete. Inspect annually, except where policy indicates otherwise. Additional inspections should be done after severe storm events. Common sense, experience and professional judgment are required of the trained tree inspector.
Tree species, age, size and condition : These all play a role in the type, extent and severity of defects. Certain species are consistently prone to certain defects. Old trees tend to have more defects. Trees in good condition have the capacity to create more wood which can reduce the severity of some defects over a period of years.
Exposure and crown size : Open-grown trees with full crowns have a higher exposure to winds than trees growing in groups or stands. Recent change in wind exposure or crown size can affect the severity of defects.
Documentation : ALWAYS document inspections and actions. Use a form that records inspection date, tree species, tree location, defects and their severity, recommended actions, action taken and date. It's helpful to map the area. Remember to document the "Low Risk" trees.
Treatment : Correcting defective trees can be as creative as your imagination and resources allow. Treatments include: moving the target, rerouting traffic, closing off or fencing off the site, pruning the defective branches, reducing the crown weight/ exposure and, ultimately, removing the tree.

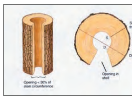
Epicormic branch : Epicormic branches are new, younger branches that replaced injured, pruned or declining branches. They form weak unions because they are not attached all the way to the center of the stem.
Decay : Decay is generally limited to the column of wood present at the time of wounding. Measure shell thickness to determine if enough sound wood remains to support the tree. The risk of failure increases when decay columns expand into the new wood because there is no sound shell of wood near those defects. Continuously expanding columns of decay are the result of inrolled cracks (rams-horning), girdling roots and canker-rot infections.

Minimum amount of sound wood in shell needed:



Need 1" of sound shell for each 6" of diameter	
Stem Diameter	Shell thickness
6"	1"
12	2
18	3
24	4

For stem without openings or cracks.



Need 2"of sound shell for each 6" of diameter	
Stem Diameter	Shell thickness
6"	2"
12	4
16	6
24	8

For stem with openings < 30% of stem circumference.

Critical root radius : The CRR is used to define the portion of the root system nearest the stem that is critical for stability and vitality of the tree. This area is usually beyond the dripline of the tree. The radius of this circular area is defined as

CRR (in feet) = DBH x 1.5.

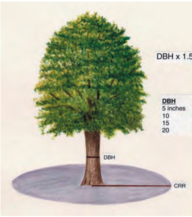


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Table 3.1. *Tree defects by species.*

Species group	Commonly found defects	Comments
Ash	Weak branch unions Poor architecture Branch breakage	Due to included bark and opposite branching pattern Multiple codominant stems Branch shedding in trees > 15” d.b.h.
Aspen	Decay Canker Root problems	Common in older stems due to canker-rot fungus. Stem breakage at canker. Stem girdling roots.
Basswood	Decay Branch breakage	Common in older stems, usually large columns of decay. Branch shedding in trees > 15” d.b.h.
Birch	Decay Root problems Dead tree tops	Canker-rot common in stem. Susceptible to soil compaction, summer soil temperatures. Susceptible to boring insects if predisposed by root problems.
Black cherry	Branch breakage	Rapid decay of dead branches.
Boxelder	Decay Branch breakage	Wood is quickly and extensively decayed. Branch shedding in trees > 15” d.b.h.
Cottonwood	Root problems Branch breakage	Stem girdling roots Branch shedding in large, old trees.
Elm	Dead branches, tree Root problems	Due to Dutch elm disease. Stem girdling roots Included bark
Hackberry	Cracks Weak unions Branch breakage	Common in lower stem. Common due to growth habit of tree. Branch shedding in trees > 15” d.b.h.
Hawthorn	Weak unions	Common due to branching pattern.
Hickory	Branch breakage	Branch shedding in trees > 15” d.b.h.
Honey locust	Canker Root problems Branch breakage	Susceptible to insect and fungal cankers. Stem girdling roots Branch shedding in trees > 15” d.b.h.
Ironwood	Root problems	Shallow root system is easily damaged.
Maples, red & sugar	Cracks Cankers Weak unions Root problems	Wounds during tree’s youth become cracks as trees age. Susceptible to insect and fungal cankers. Codominant stems commonly have included bark. Stem girdling roots.

Maples, silver	Same as maples, above Branch breakage	Wood tends to fracture. Branch shedding in trees> 15" D.B.H.
Oaks, red	Decay Dead branches Dead tree Branch breakage	Susceptible to brown-rot decay. Due to construction damage, borer attack or root decay. Susceptible to oak wilt disease. Branch shedding in trees> 15" DBH, esp. after stand thinning.
Pear	Weak unions	Multiple branching, included bark
Walnut	Branch breakage	Branch shedding in trees > 15" D.B.H.
Willow	Cracks Root problems Branch breakage	Wood is easily fractured. Stem girdling roots. Branch shedding in trees > 15" D.B.H.
All conifers	Decay Branch breakage	Susceptible to canker-rot decay fungus. Due to snow-loading or windstorms.
Balsam fir	Decay Dead top	Prone to stem and root collar decay. Susceptible to insects consuming needles or cambium layer.
Pines, jack & red	Dead top, dead tree	Susceptible to insects consuming needles or cambium layer. Jack pines susceptible to cankers.
Pines, white	Branch breakage Dead branches, tops	Wood in branches is easily fractured. Susceptible to white pine blister rust.
Spruces	Root problems	Shallow rooted and susceptible to windthrow.
Tamarack	Root problems	Susceptible to root rot.

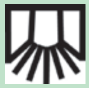
All defective trees cannot be detected, corrected or eliminated

All defective trees cannot be detected, corrected or eliminated. To begin with, our knowledge of trees is less than complete. Although we can readily recognize most defects, there are root problems and some internal defects that are not easily discernable. These trees may require in-depth assessments and the use of specialized diagnostic tools. Secondly, defect severity can and does change with time. Inspection and correction schedules should be consistent from year to year. Finally, trees are masters at covering up problems and surviving. All defective trees cannot be detected; our aim is to find 80 percent or more of the defective trees with each inspection. By doing inspections and acting on them in a timely manner, we can successfully manage the risk of tree failure in our urban forests.

The Seven Defect Categories

 Decayed wood

 Cracks

 Root problems

 Weak branch unions

 Cankers

 Poor tree architecture

 Dead trees, tops, or branches

Decayed Wood

Decayed wood = wood that has rotted or is missing.

Advanced decay and cavities always result in less structural strength and reduced stability. Indicators of advanced decay are rotten wood, fungal fruiting bodies, cavities, holes, open cracks or bulges in the wood. See Figure 3.8.

Figure 3.8. *Advanced decay reduces the structural integrity and strength of wood.*

Decayed wood is the result of the long-term interaction between a tree and decay-causing fungi. The decay process takes wood through several stages of degradation; from stain to decay to cavity. The presence of advanced decay or a cavity results in less structural strength and can reduce the stability of the tree. Decay can occur in branches, stems and/or roots. Root decay will be discussed further in the section on Root Problems. Some tree species are resistant to decay; others decay quickly and more extensively (Table 3.1).

Figure 3.9. *Fungal fruiting bodies indicate advanced decay.*

Wood decay is an internal process with just a few external indications. Indicators of advanced decay are the fungal fruiting bodies—mushrooms, conks and brackets (see Figure 3.9) and rotten or punky wood, cavities, hollows, holes, inrolled cracks, and bulges in the wood (see Figures 3.10 through 3.14).

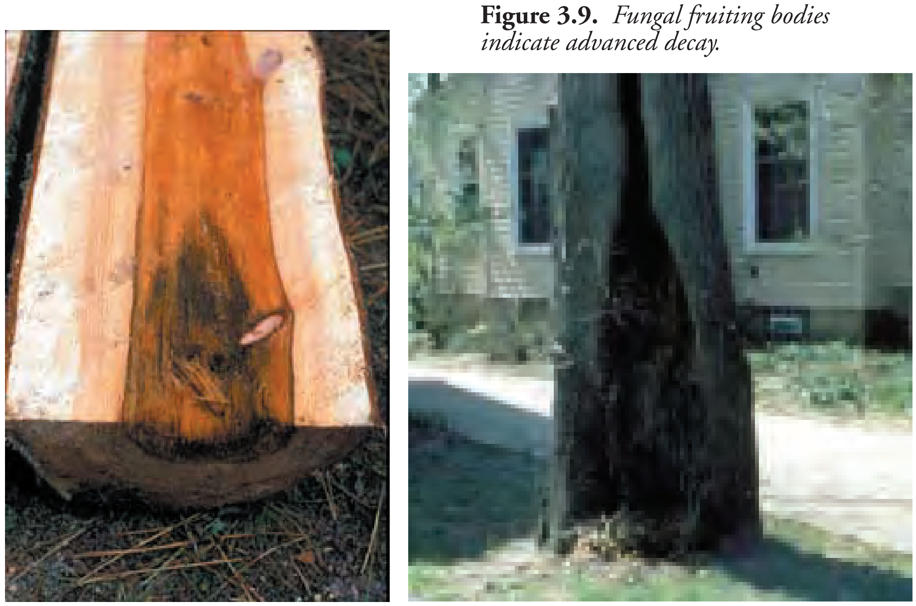


Figure 3.10 - 3.11. *Rotten or punky wood or cavities indicate advanced decay.*

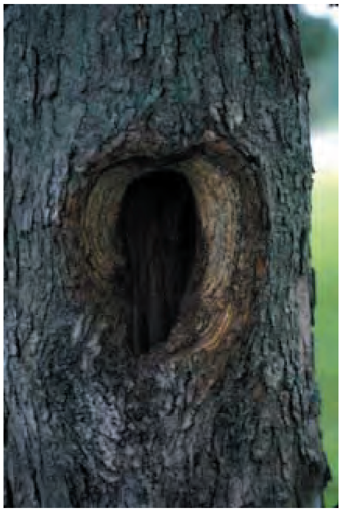


Figure 3.12. *Hole in stem revealing internal column of advanced decay.*

Figure 3.13. *Decay is always associated with inrolled cracks.*

Figure 3.14. *Bulges often indicate decay.*

Wounds start the decay process. See Figures 3.15 through 3.19. Wounds can be caused by storms, vehicles, excavation, improper pruning, vandalism, and by animals and insects.

Figure 3.15. *Wounds start the decay process.*

Figure 3.16. *Old pruning wound with decay.*

Figure 3.17. *Old wound with wood discoloration.*

Figure 3.18. *Lawn mower damage associated with decay.*

Figure 3.19. *Human caused canker with internal decay.*

Wounds expose cambium and wood to air or to soil, if wound is underground (Text Box 2 and Figure 3.20).

BOX 2

What is the cambium?

The cambium is a layer between the bark and wood that sheaths the tree from root tip to branch tip. See Figure 3.20. This is the layer that creates wood and inner bark each year.

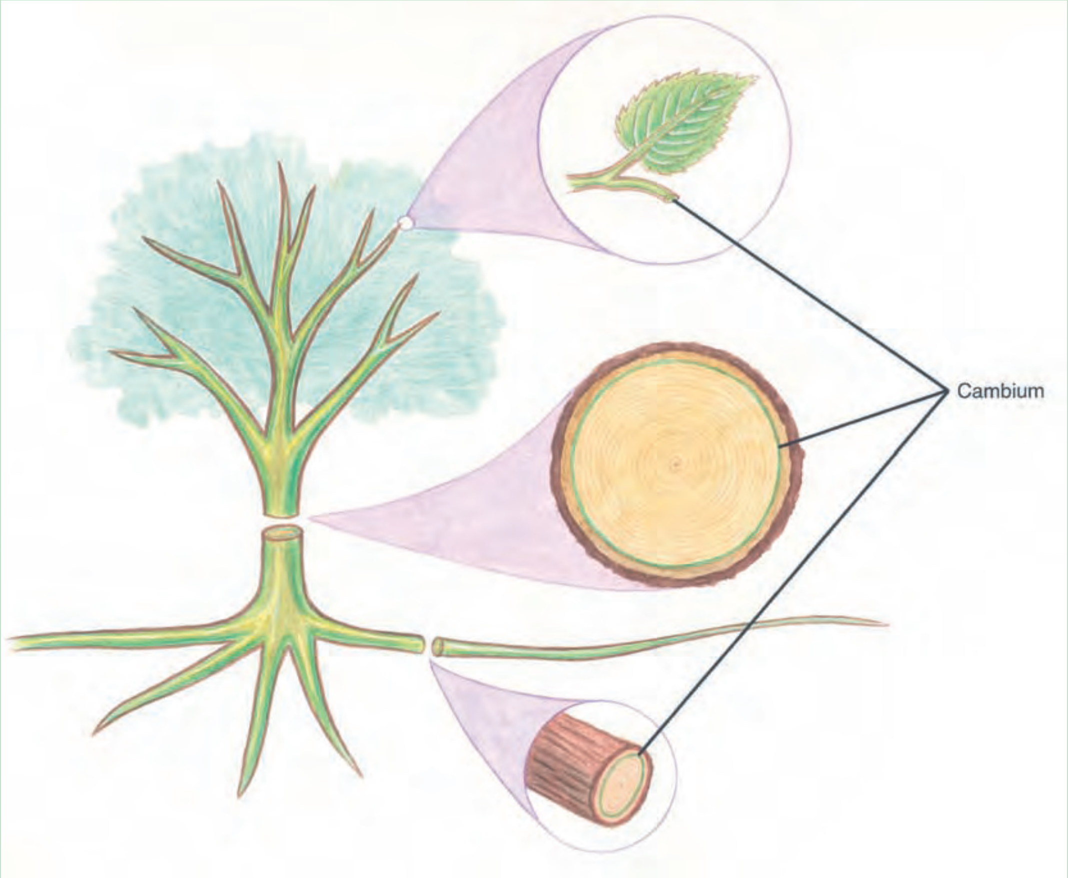


Figure 3.20. *The cambium is a thin layer of cells that sheath the tree.*

Decay-causing fungi infect the wounds and can, in time, cause advanced decay. Trees interact with decay-causing fungi and limit the spread of decay within the tree. See Box 3: Compartmentalization of decay and other defects.

BOX 3

Compartmentalization of decay and other defects.

Compartmentalization explains how wounded trees set boundaries which limit the spread of decay (Shigo 1989). The process of compartmentalization preserves a tree's mechanical strength so that a decaying tree does not fail. Compartmentalization also occurs when wounded trees are infected with canker-causing fungi, mining or boring insects, and other agents.

How does a tree limit decay and other defects?

1. Wounding starts the process. A wound exposes cambium and wood to air (or soil if below ground). See Figure 3.20.

2. The living cells just behind the wound react immediately. If wounding occurs during the dormant season, the cambium reacts very early the next spring.

3. The tree creates a new wall, called the barrier zone, to prevent the invading micro-organisms from spreading out into the new and future wood. It is created by the cambium. It is a continuous barrier, both chemical and physical, which is built right into the current annual ring. The barrier zone persists for the life of the tree in the annual ring in which it was created. See Figure 3.21.

4. A succession of bacteria and fungi are involved in the infection of the wound and they grow into the wood.

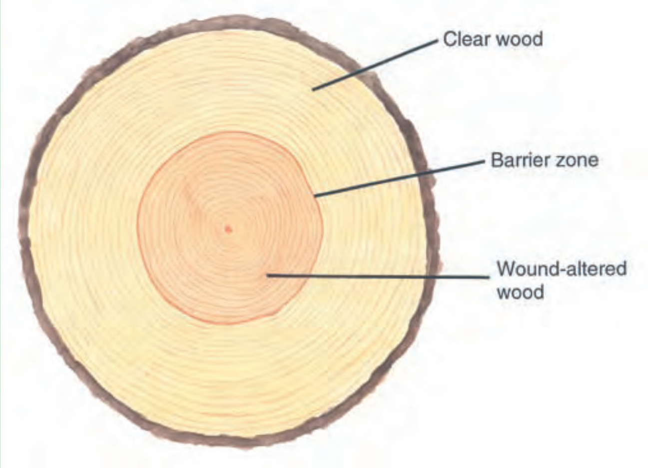


Figure 3.21. *The barrier zone separates wood formed before wounding from wood formed after wounding.*

5. The compartmented tree uses its existing structure to limit the extent and severity of injured and infected tissues.

6. Discolored and sometimes decayed wood results, but it is limited by the barrier zone and other walls. Inside the barrier zone, the tree attmpts to halt or contain the invading fungus. The column of wood is decay-altered, ranging from discolored wood to decayed wood to a cavity. The actual extent and severity of decay within the column is up to the interaction between the tree, the fungi and how long they've been interacting.

7. New wood, laid down in the years after wounding, will be free from decay.

BOX 3 - Compatmentalization *- continued*

The barrier zone separates wood formed before wounding from wood that will form after wounding. The essence of compartmentalization is that trees set the boundaries; trees limit the decay column so that new wood will be free from decay. See Figure 3.22.

Decay will be contained or limited by the barrier zone. If you know the size of the tree when it was wounded, then you know the potential extent of internal decay; all the wood present at the time of wounding.

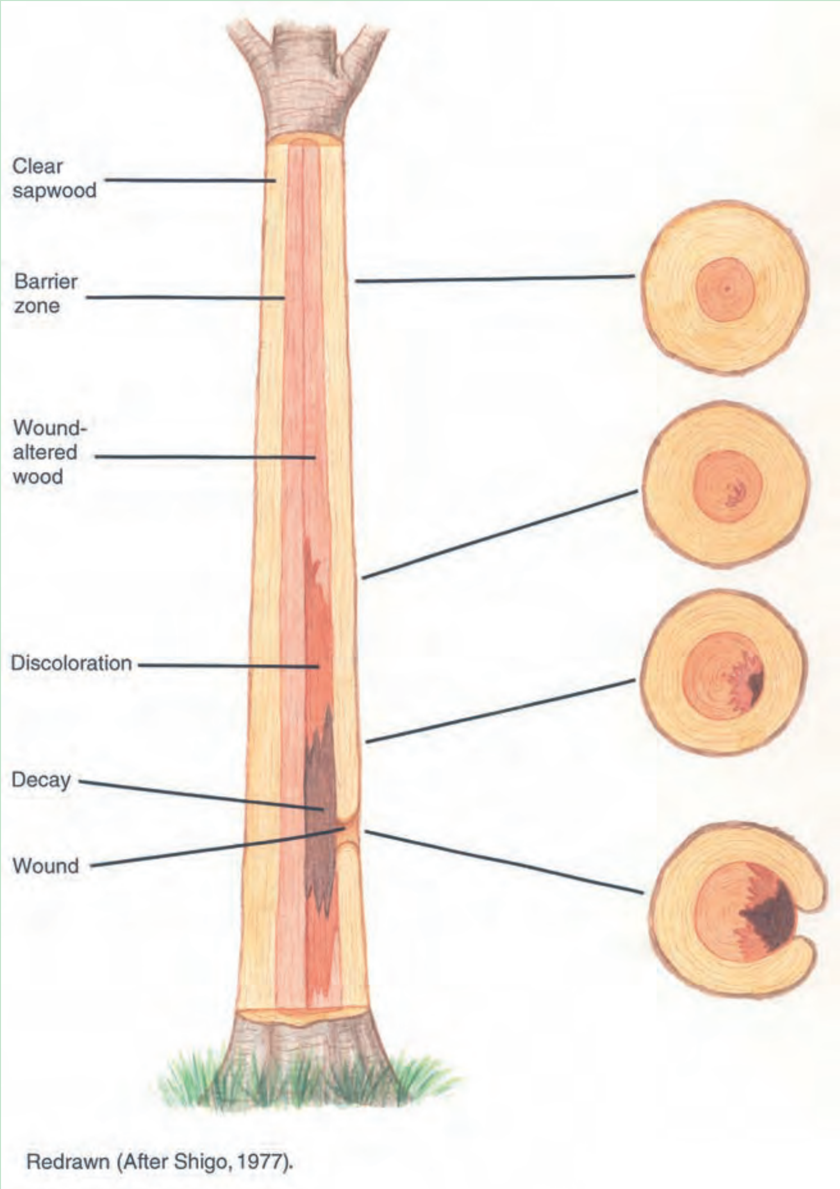


Figure 3.22. *Trees limit the extent of decay so that wood formed after wounding will be free from decay.*

Commonly, the extent of decay is limited to the wood present at the time of wounding. See Figure 23. All wood inside this column could potentially be decayed. In reality, decay is often limited to the location of the wound and only extends a few feet above and below the wound. Wood produced after the year of wounding will not be decayed. However, if a tree wounded a number of times over a period of years, multiple decay columns are created and they often merge. See Figure 24. Only in advanced stages of decay do the fungi produce fruiting bodies.

Figure 3.23. *Decay is usually limited to the wood column present at the time of wounding.*

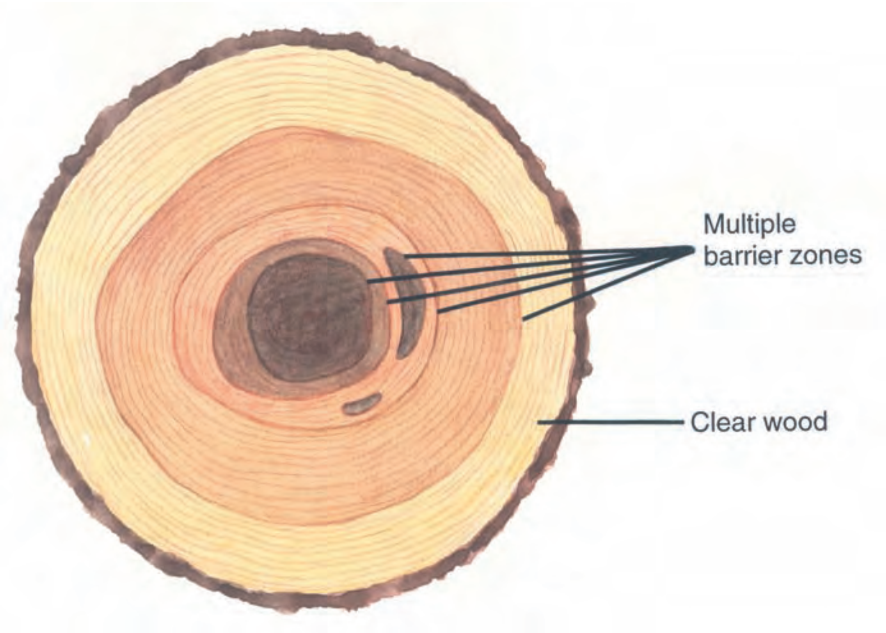


Figure 3.24. *Additional columns of discolored and decayed wood form as the tree suffers additional wounds.*

The undecayed layer surrounding the compartmentalized decay column is called the *shell*. See Figure 3.25. If the shell thickness is thin relative to the size of the tree, the shell is likely to fracture causing the tree to fail. See Figures 3.26. Studies have shown that, if a tree has less than one inch of sound wood in its shell for every six inches of stem diameter, then the tree is very likely to fail (Mattheck 1998). See Figure 3.27 and Table 3.2. Measure stem (or branch) diameter where decay is present. If possible, determine where the shell is the thinnest and take your measurement there because the tree is most likely to fail where the shell is the thinnest.

Figure 3.25. *The outermost layer of undecayed wood is called the "shell."*

Figure. 3.26. *If shell thickness is thin relative to stem diameter, then that area is likely to fail.*

Table 3.2. Shell thickness requirements for closed shell

Closed shells need at least 1 inch of sound shell for each 6 inches of stem diameter	
Stem diameter (inches)	**Shell thickness** (inches)
6	1
12	2
18	3
24	4
48	8

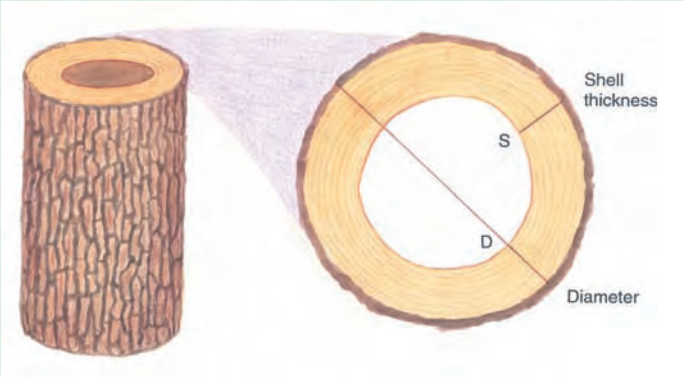


Figure 3.27. *There needs to be at least 1 inch of sound wood in the shell for each 6 inches of stem diameter. Measure in the same location on the tree.*

All trees do not have a sound shell of wood: some have openings in them. See Figures 3.28 and 3.29. An opening can be a hole, and old wound, a fire scar, a cankered area or a wide crack. A tree can have internal decay and an opening and still be structurally sound provided that the shell is thick enough and the openingis not too wide. If an opening in the stem is up to 30 percent of the stem circumference, then the shell needs to have at least 2 inches of sound wood for every six inches of stem diameter (Fraedrich and Smiley 1999). See Figure 3.30 and Table 3.3. Trees with larger openings and/ or thinner shells are likely to fail.

Figure 3.28-3.29. *All trees do not have a solid shell of sound wood. Some trees have cracks or openings in them.*

Table 3.3. Shell thickness requirements for open shell

Open shells need at least 2 inches of sound shell for each 6 inches of stem diameter when the opening is less than 30% of the stem circumference.

Stem diameter (inches)	**Shell thickness** (inches)
6	2
12	4
18	6
24	8
48	16

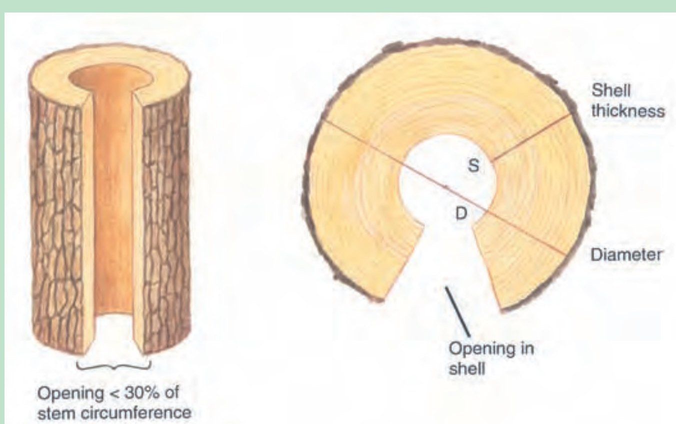


Figure 3.30. *There needs to be at least 2 inches of sound wood in the shell for each 6 inches of diameter when openings occur in the stem. The openings must be smaller than 30% of the stem circumference.*

Shell thickness can be affected by the presence of bulges or swellings on the stem. See Figure 3.31. Bulges in the stem are formed as a reaction to the presence of decay. Bulges and swellings help strengthen the tree and can decrease the likelihood of failure due to the presence of decay. See Box 4: Adaptive growth and decay.

BOX 4

Adaptive growth and decay

Thicker annual rings are created where the risk of breakage is greatest. Where decay fungi are active, the wood's structure is weakened. Each year, as the tree creates a new annual ring, a slightly thicker layer of wood is created in the vicinity of the decayed wood. See Figures 3.31 and 3.32. Over time, the tree creates bulges, swellings, etc. to add wood more quickly to that area, decreasing the likelihood of failure and fracture due to the presence of decay.

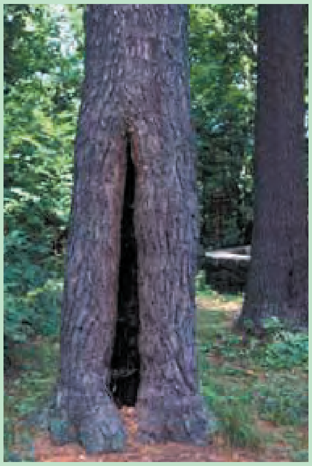


Figure 3.31. *Trees create thicker annual rings in the vicinity of decaying wood. Over time, bulges or swellings develop.*

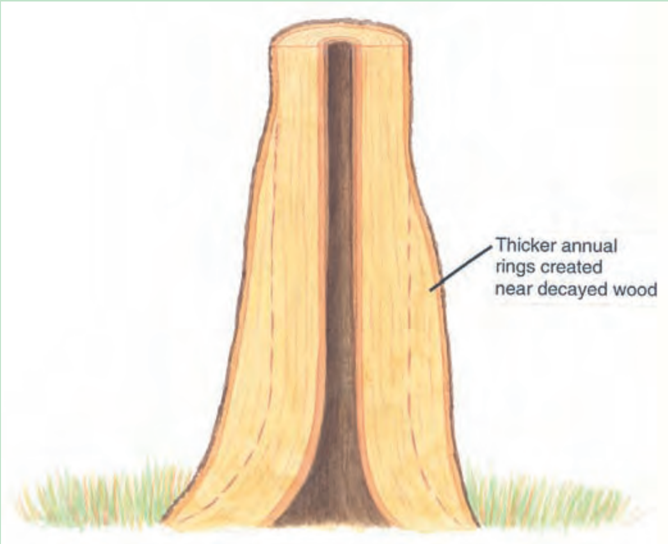


Figure 3.32. *Bulges and swellings indicate advanced decay.*

One group of decay-causing fungi, the brown rotters, do not induce the tree to create extra wood near the location of the decay. Bulges and swellings are not produced. Examples of these fungi are: The velvet-top fungus, *Phaeolus schweintizii*, on conifers, the chicken mushroom, *Laetiporus sulfureus*, and the red-belt fungus, *Fomitopsis pinicola*, on hardwoods and conifers. See Figure 3.33.

Figure 3.33. *Decay caused by a brown rot fungus.*

If a tree is repeatedly wounded by the presence of inrolled cracks, included bark, canker-rot fungi, or equipment (mowers, plows, and weed whips), decay occurs in every annual ring of wood. See Figures 3.34 through 3.36 and Box 5: Canker-rot fungi. These trees should be carefully inspected because their decay is never fully compartmentalized and a sound shell of wood does not form. The tree is likely to fail at or near the location of the crack or wound because a large and ever-expanding column of decay is present there. Again, evaluate shell thickness and opening width to help determine the tree's potential for failure.

Figure 3.34. *Canker rot fungi cause the decay column to constantly enlarge.*

Figure 3.35. *An inrolled crack creates an ever-expanding column of decay.*

Figure 3.36. *Diagram of decay in an inrolled crack.*

BOX 5

Canker-rot fungi

A canker-rot fungus rewounds the tree each year and infects each new annual ring allowing decay to spread. A solid shell of wood cannot be formed at the location of a canker-rot infection. See Figure 3.37.

Some examples of these fungi and their hosts are: *Phellinus pin*i on conifers; *P. everhartii* and *P. robustus* on oaks; *P. spiculosus* on oaks, hickories, and honey locusts; *P. tremulae* on aspens; *Inonotus obliquus* on birches; *I. glomeratus* on maples; and *I. hispidus* and *I. andersoni*i on many hardwood species. See Figure 3.38.

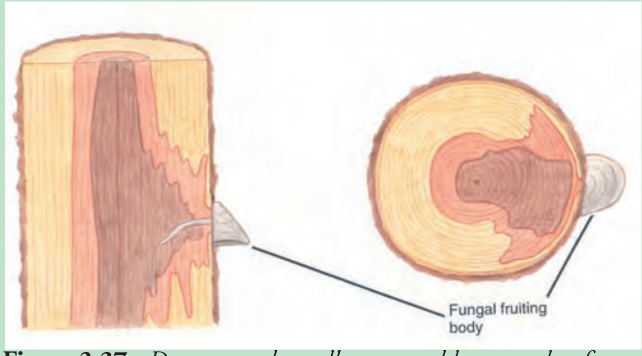


Figure 3.37. *Decay spreads to all new wood layers as they form each year. Decay is not fully compartmentalized.*

Figure 3.38. *Fomes connatus on maple.*

In some situations, wood is missing from one side of the tree due to a combination of causes such as decay, canker, or mechanical wounding. In this case, a tree needs at least 60 percent of its circumference to be sound wood. See Figure 3.39.

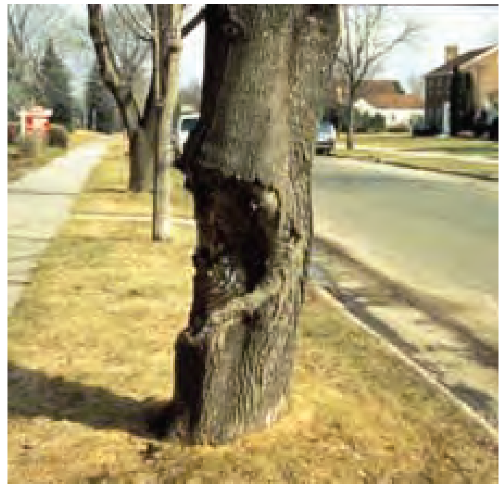


Figure 3.39. *A tree needs at least 60 percent of its circumference to be sound.*

All the situations described for stems also apply to branches and root collars.

Visual assessment of the extent of decay can often be a reliable means of predicting potential risk. However, invasive techniques may be needed to quantify the thickness of the sound shell of wood in comparison to the size of the tree. Use a probe or another tool to test several areas in order to find the location of the thinnest shell of sound wood. The shell will be thinnest between root flares, where the defect symptom is most pronounced, or just behind the bulge of an inrolled crack. If possible, use a metal rod to probe existing holes and cracks to determine shell thickness. Use an increment borer, drill, or other invasive techniques only when there are no other means to estimate the extent of sound wood. See Figures 3.40 and 3.41.

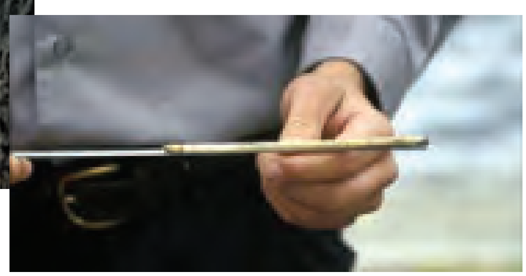


Figure 3.40-3.41. *Invasive techniques may be used to quantify the extent of decay.*

In-depth assessments, using specialized diagnostic tools, may be warranted when additional information about the location and extent of internal decay is critical to assessing the probability of tree failure. See later section in this chapter, Tree risk inspections and the use of specialized diagnostic tools.

Decayed Wood

High risk of failure:

See Figures 3.42 through 3.45.

- Advanced decay affects more than 40 percent of the circumference of any stem, branch, or root collar.

  Note: In order to verify the extent of decay, you may want to use probes, drills, or other diagnostic tools to determine shell thickness.

- Stem has advanced decay and the shell thickness meets the following criteria:

  – Shell thickness is less than 1 inch of sound wood for each 6 inches of stem diameter, or

  – Stem has an opening greater than 30 percent of the stem's circumference, and the shell thickness is less than 2 inches of sound wood for each 6 inches of stem diameter.

- Any large branch with decay.

Moderate risk of failure:

- Indicators of advanced decay are found on 25 to 40 percent of the circumference of any stem, branch or root collar.

  Shell thickness is between 1 and 2 inches of sound wood for each 6 inches of stem diameter, and stem has opening less than 30 percent of the stem's circumference.

Figure 3.42. *High risk of failure: Advanced decay affects more than 40 percent of the stem circumference.*

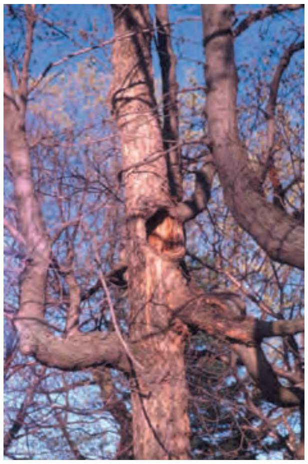
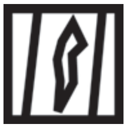


Figure 3.43. *High risk of failure: Shell thickness is less than 1 inch of sound wood per each 6 inches of stem diameter.*

Figure 3.44. *High risk of failure: Stem has opening greater than 30% of its circumference and there is less than 2 inches of sound wood for each 6 inches of stem diameter.*

Figure 3.45. *High risk of failure: Large branch with decay.*



Cracks

Crack = a separation of the wood, a deep split through the bark and into the wood.

Cracks form when the load exceeds the capacity of the stem to withstand the load. The vast majority of cracks are caused by improper closure of wounds, by the splitting of weak branch unions, or by flush-cut pruning. See Figures 3.46 through 3.49. Cracks can occur in branches, stems, or roots. The wood behind the crack may be sound, decayed, or missing (cavity). Several types of cracks can be found in trees and, like other defects, the severity of cracks ranges across a spectrum. Vertical cracks run with the wood grain, along the length of the tree and may appear as shear cracks, inrolled cracks, or ribbed cracks. Horizontal cracks run across the wood grain. See Box 6: Types of Cracks.

Figure 3.46. *A crack indicates that the tree is failing.*

BOX 6

Types of Cracks

Vertical

Shear crack: Separates the stem into two halves along the wood grain.
Inrolled crack: Margins of crack turn inside the stem.
Ribbed crack: Has a raised rib of wood on stem.

Horizontal

Horizontal crack: Cuts acrosss the grain; like cutting a tree down.



Figures 3.47-3.49. *Most cracks develop from improper wound closure, splitting of weak branch unions, or from flush cut pruning.*

Shear cracks, a type of vertical crack, become hazardous when they go completely through the stem and separate the stem into two halves. See Figures 3.50 and 3.51. As the tree bends and sways in the wind, one half of the stem slides over the other, elongating the crack. Eventually the enlarging crack causes the two halves of the stem to shear apart. See Figures 3.52 and 3.53. A shear crack always has a high risk of failure. See Box 7: Shear cracks.

Figure 3.50. *A shear crack always has a high potential for failure.*

Figure 3.51. *The enlarging crack causes the stem to shear apart.*

Figure 3.52. *Codominant stems commonly split, creating a shear crack.*

Figure 3.53. *Aftermath of shear crack failure*

BOX 7

Shear Cracks

Shear cracks are formed when weak, codominant stems break apart. A shear crack always has a high risk of failure. See Figure 3.54.

Figure 3.54. *Cross section of a shear crack. The tree is split into two halves.*

Another type of vertical crack is an inrolled crack, also called a ram's horn. The margins of this type of crack curl inward on each of its sides and forms inrolled bark and wood. See Figures 3.55 through 3.58. The fissure of an inrolled crack may appear open or closed. Serious decay is always associated with an inrolled crack because the crack margins rewound the tree each year allowing decay to spread rapidly. Inrolled cracks often generate other cracks in the same stem segment. See Box 8: Inrolled crack. Trees with an inrolled crack, advanced decay, and another crack, all in the same stem segment, have a high risk of failure. To determine the potential for failure, measure the shell thickness in a few locations around the tree's circumference, determine the width of the crack opening and look for the presence of any other type of crack.

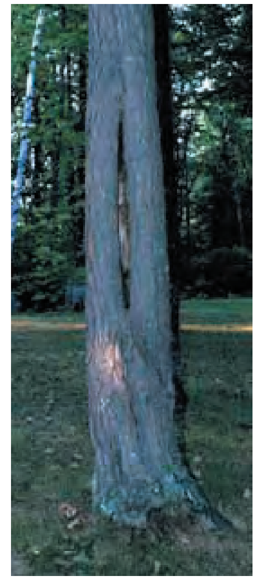


Figure 3.55. *An inrolled crack with crack margins open exposing hollow interior.*

Figure 3.56. *An inrolled crack with crack margins closed.*

Figures 3.57-3.58. *Decay is always associated with an inrolled crack. There may or may not be a hollow column inside the cracked tree.*

BOX 8

Inrolled crack

An inrolled crack is formed when a wound does not close properly. The layers of bark and wood forming the margins of the wound meet but do not grow together and do not seal over the wound. Instead these layers curl inward on each side of the wound and form inrolled bark and wood. See Figure 3.59. The crack perpetuates itsfelf as new layers of wood are added each year to the inrolled bark and wood, increasing the separating force between the two sides and enlarging the crack. Serious advanced decay is always associated with inrolled cracks. Inrolled cracks become more hazardous as they enlarge and generate secondary cracks in the stem.

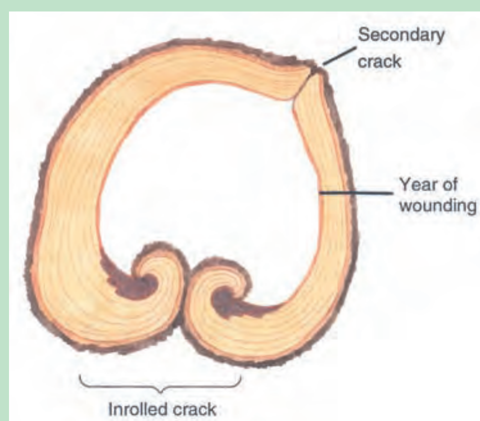


Figure 3.59. *Evaluate inrolled cracks by determining shell thickness, size of crack opening and by checking for the presence of a secondary crack.*

A tree with a ribbed crack has a raised rib of wood on its stem with a crack along the length of the rib. See Figures 3.60 and 3.61. The crack can be open or closed. See Box 9: Ribbed cracks. A ribbed crack has a high risk of failure when associated with another crack or with extensive advanced decay. Evaluate shell thickness and size of crack opening. Ribbed cracks may also form at the base of weak unions or on large branches.

Figure 3.60. *A ribbed crack creates a ridge-like protruberance from the main stem.*

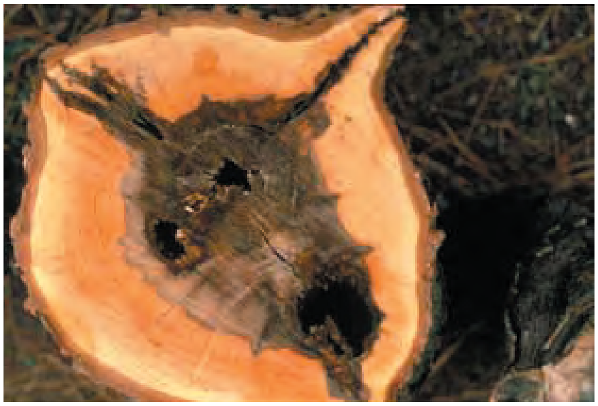


Figure 3.61. *A ribbed crack can fail when associated with extensive advanced decay or another crack.*

BOX 9

Ribbed cracks

Ribbed cracks are created as the tree attempts to seal over a wound. Margins of the crack meet and mesh but are reopened due to tree movement or extremely cold temperatures. Thicker annual rings are created in order to stabilize the developing crack at the location of the crack. This forms the ribbed appearance over a period of many years. See Figure 3.62.

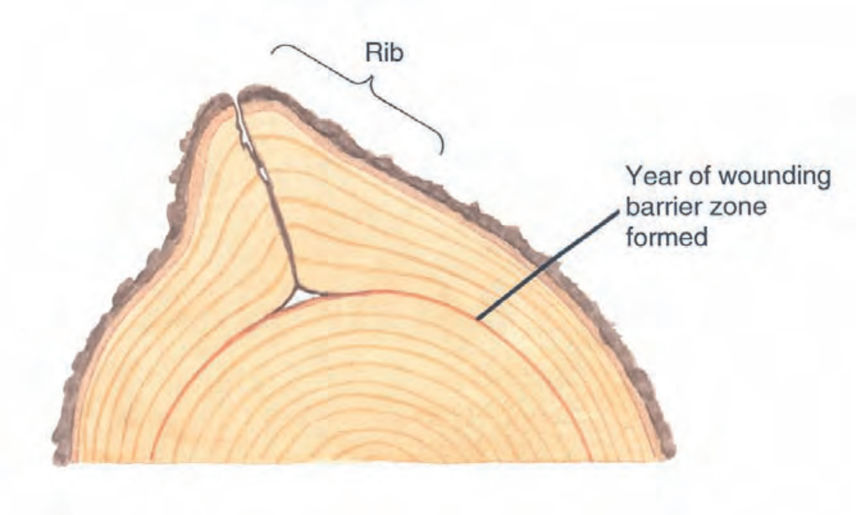


Figure 3.62. *Thicker annual rings are formed every year over the site of an old wound which creates a ridge (rib) of wood.*

Horizontal cracks run across the grain of the wood. See Figures 3.63 and 3.64. Horizontal cracks are rarely found because they develop just before the trees fail. See Box 10: Horizontal cracks. Horizontal cracks are a sign of imminent failure in leaning trees (see the section on Poor Architecture in this chapter for details).

Figure 3.63. *Horizontal cracks form across the wood grain.*

BOX 10

Horizontal cracks

These cracks run across the grain of wood and are formed when loading in the tree's crown pulls wood fibers apart. Horizontal cracks are a sign of imminent tree failure.

Figure 3.64. *Horizontal cracks are rarely found because they develop just before trees fail.*

Seams are generally not hazardous, but they can be confused with cracks. A seam is a vertical line in the bark. See Figure 3.65 Generally, a seam is flush with the stem. A seam can be considered a phase in the wound sealing process. See Figure 3.66. As time passes, a solid shell of wood begins to form over the old wound which strengthens the stem and, eventually, the seam disappears. The wood inside the tree may be sound or decayed. If in doubt, evaluate the tree's shell thickness to determine its risk of failure.

Figure 3.65. *Seams are fully compartmentalized. If internal decay is present, check shell thickness.*

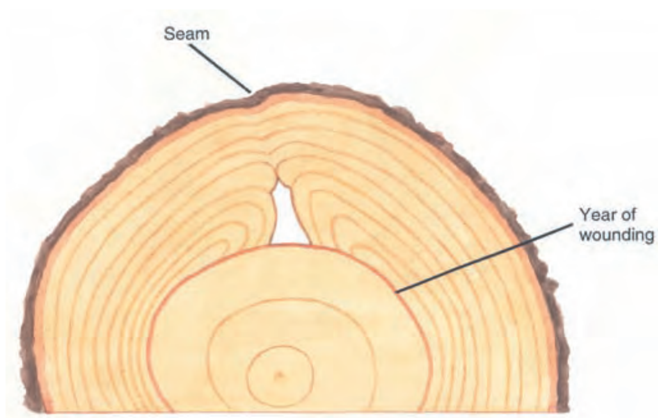


Figure 3.66. *A seam can be considered a final phase in the wound sealing process.*

Cracks are hazardous when they compromise the structure of the tree by splitting the stem in two or when another defect, such as internal decay and a crack, do not provide enough sound wood in the outer shell to support the tree. The presence of multiple cracks and decay indicates a very defective tree. Trees with an inrolled crack, advanced decay, and another crack, all in the same stem segment, have a high risk of failure.

Cracks

High risk of failure:

See Figures 3.67, 3.68, and 3.69.

- Stem is split in two by a crack.
- Stem segment has multiple cracks and decay.
- Any cracked branch.

Moderate risk of failure:

- Stem has a single crack and decay.

Figure 3.67. *High risk of failure: When stem is split in two by a crack.*

Figure 3.68. *High risk of failure: When stem segment has multiple cracks and decay.*

Figure 3.69. *High risk of failure: When any large branch is cracked.*

Root Problems

Root problems = inadequate anchoring by the root system, damaged roots, or stem-girdling roots.

When a tree has extensive root damage, the whole tree usually tips over and falls to the ground because the roots can no longer provide adequate anchoring. Roots can be lost due to excavation, trenching, soil compaction, grading, paving, fungal decay, or environmental stress, such as drought or flooding. See Figures 3.70 through 3.76.

Figure 3.70. *Failure of root system to anchor the tree.*

Figure 3.71 - 3.76. *Roots can be lost due to excavation, paving, soil compaction, regrading, trenching, and root decay.*

Common symptoms of root problems include: decline or dieback symptoms in the crown, dead roots, missing roots, broken roots, decayed roots, leaning trees, and presence of fungal fruiting bodies at the root collar. See Box 11: Crown decline.

BOX 11

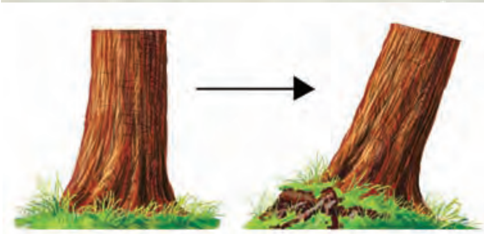
Crown decline

Trees maintain a dynamic equilibrium between their live branches and their roots. When the equilibrium is disrupted by root disease, root decay, or root loss, decline symptoms appear in the branches. The loss of essential roots is followed by the decline and dieback of twigs and branches. If too much of the root system is lost, the crown will decline and the tree will die or it will fail. See Figure 3.77.

Figure 3.77. *Crown decline is a symptom of extensive root system loss*

Serious root problems become apparent when a tree develops a new or abnormal lean. See Figure 3.78. In these cases, a portion of the root system failed and the tree started to tip over but the tree was stabilized, at least temporarily, by the remaining root system. Newly leaning trees are often accompanied by soil mounding, soil cracking, root lifting, or root breakage near the stem on the far side of the lean. See Figures 3.79 through 3.82. A tree with a new lean may indicate a high risk of failure. Trees with an established, stabilized lean are discussed further in the section on Poor Architecture.

Figure 3.78. *Root system failed to anchor tree and tree developed a "new lean." Look for soil mound, soil cracking near root collar, or broken roots sticking out of the soil.*



Figures 3.79-3.80. *A leaning tree with a soil mound at the base of the tree.*

Figure 3.81. *A leaning tree that also had advanced decay in the root collar.*

Figure 3.82. *Exposed roots on tree that failied.*

Sometimes it is obvious that trenching, paving, grading, or soil compaction occurred. See Figures 3.83,3.84, and 3.85. To determine how much damage the root system did sustain, estimate how much of the critical rooting area was damaged based on the pattern of damage. Critical rooting area is defined by the Critical Root Radius (CRR). See Box 12: Critical Root Radius. The CRR is a circular area around the stem of the tree, usually larger than the area defined by the tree's dripline. A tree is adequately anchored when the roots inside the area defined by the CRR are sound and alive. Up to 40 percent of the root system can be damaged before anchoring is seriously impaired, but some tree species are more susceptible to root loss than others. See Table 3.4: Tree characteristics. You may want to consider larger CRR's for sensitive trees.

Figures 3.83-3.84. *To estimate how much root damage was sustained, determine how much of the Critical Root Radius was disturbed.*

Figure 3.85. *Recent construction on three sides of this tree reduces anchoring ability of roots.*

BOX 12

Critical root radius

The CRR is used to define the portion of the root system nearest the stem that is critical for the stability and vitality of the tree. It is a circular area defined as CRR = DBH x 1.5 foot per inch. This area is usually beyond the dripline of the tree. The CRR can be used for narrow-canopied trees as well as open-grown trees. (Miller et al 1995, Matheny and Clark 1991) See Figure 3.86.

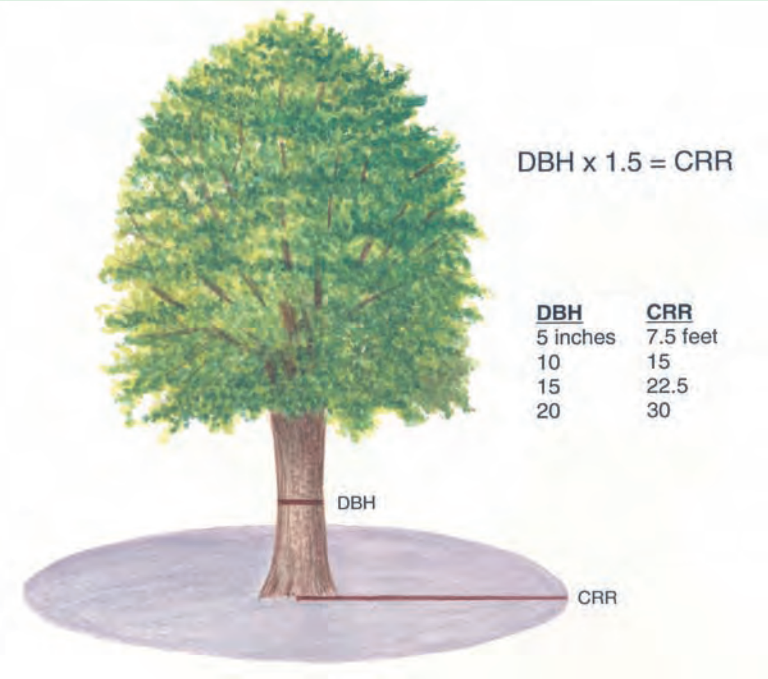


Figure 3.86. *Use the Critical Root Radius to estimate the extent of damage to a tree's root system. Up to 40 percent of the area can sustain damage before anchoring is seriously impaired.*

Table 3.4. Tree characteristics.

Species	Root severance	Soil compaction & ooding	Mature crown spread
Northern white cedar	Tolerant	Tolerant	10-20 feet
Balsam fir	Tolerant	Tolerant	20-35
White fir	Tolerant	Sensitive	10-20
Tamarack	Tolerant	Tolerant	15-25
White pine	Tolerant	Sensitive	50-80
Jack pine	Tolerant	Sensitive	20-30
Red pine	Tolerant	Sensitive	20-40
Scotch pine	(Tolerant)	(Sensitive)	30-50
Eastern redcedar	Tolerant	Sensitive	10-20
Black spruce	Tolerant	Tolerant	15-30
Colorado spruce	Intermediate	Tolerant	20-30
White spruce	Tolerant	Intermediate	20-30
Black ash	Tolerant	Tolerant	30-60
Green ash	Tolerant	Tolerant	30-50
White ash	Tolerant	Intermediate	50+
Bigtooth aspen	Tolerant	Sensitive	20-35
Quaking aspen	Tolerant	Sensitive	20-35
Blue beech	Sensitive	Sensitive	15-20
Paper birch	Intermediate	Sensitive	30-50
River birch	Tolerant	Tolerant	30-50
Yellow birch	Intermediate	Sensitive	25-50
Boxelder	Tolerant	Tolerant	35-50
Ohio buckeye	Intermediate	Intermediate	30-40
Butternut	Sensitive	Intermediate	50-60
Catalpa	Intermediate	Tolerant	30-50
Black cherry	Intermediate	Sensitive	40-50
Kentucky coffeetree	Intermediate	Intermediate	40-50
Eastern cottonwood	Tolerant	Tolerant	80-100
Red-osier dogwood	Tolerant	Intermediate	10-12
American elm	Tolerant	Intermediate	70-150
Slippery elm	(Tolerant)	(Intermediate)	40-60
Hackberry	Tolerant	Intermediate	50+
Hawthorn	Intermediate	Intermediate	20-30
Bitternut hickory	Intermediate	Intermediate	30+
Honeylocust	Tolerant	Intermediate	50-75
Ironwood	Sensitive	Sensitive	20-30
Basswood	(Intermediate)	Sensitive	50-75

Species	Root severance	Soil compaction & ooding	Mature crown spread
Black locust	Tolerant	Sensitive	20-50
Red maple	Tolerant	Tolerant	40-60
Silver maple	Tolerant	Tolerant	75-100
Sugar maple	(Intermediate)	Sensitive	60-80
Mountain ash	Tolerant	Intermediate	15-25
Black oak	Sensitive	Sensitive	50-70
Bur oak	(Tolerant)	Intermediate	40-80
Northern pin oak	Sensitive	Sensitive	30-50
Red oak	Tolerant	Sensitive	40-50
Bicolor oak	(Intermediate)	Tolerant	40-50
White oak	Sensitive	Sensitive	50-90
Wild plum	Tolerant	Sensitive	15-25
Serviceberry	Intermediate	Sensitive	6-15
Black walnut	Sensitive	Intermediate	60-100+
Black willow	Tolerant	Tolerant	20-40

In other cases, particularly for root decay, it is difficult to see the pattern of damage in the root system. Another means to assess the soundness of the main roots is to use a metal probe to locate and test them for the presence of advanced decay. See Figure 3.87. At least 60-70 percent of the buttress and main roots need to be sound in order to have the tree adequately anchored (Mattheck and Broeler, 1994).

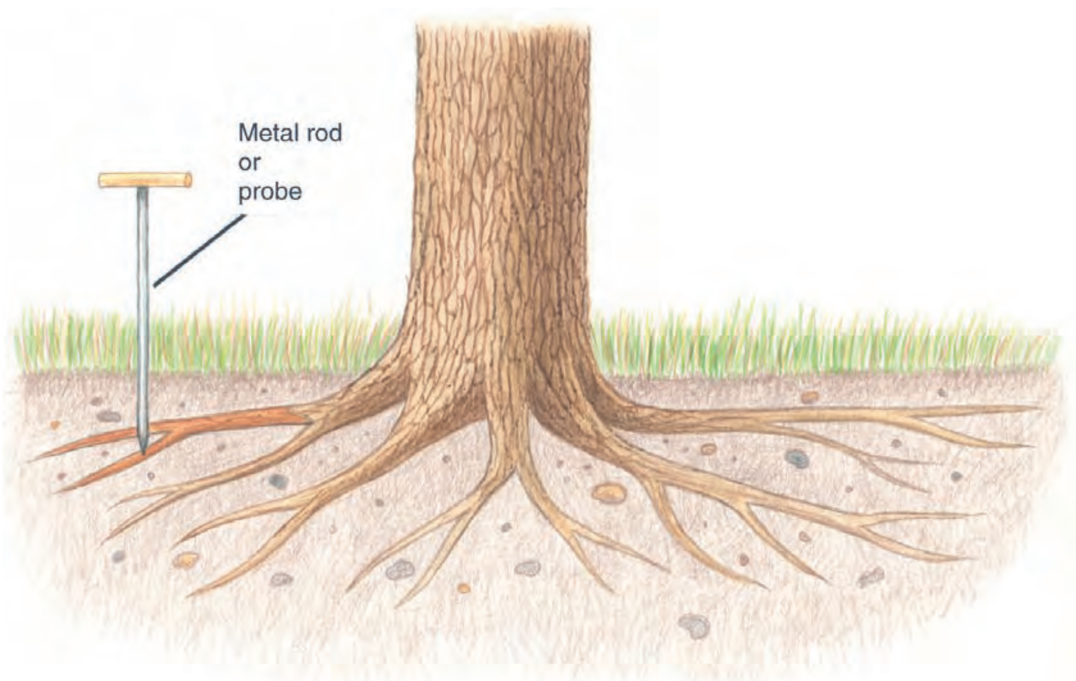
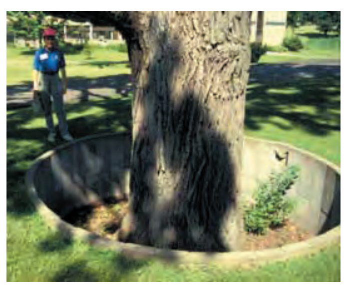
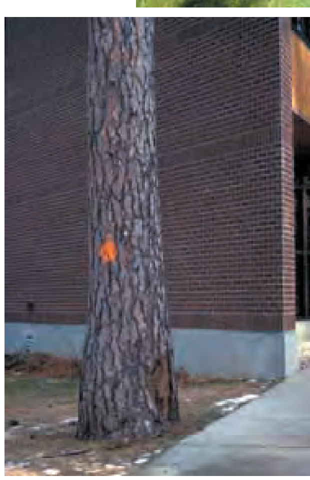


Figure 3.87. *Use a metal rod as a probe. To ensure that a tree is adequately anchored, 60-70 percent of its main roots must be sound.*

A tree may have a restricted root system which can compromise the tree's stability and vigor. Site conditions that restrict root systems are: shallow soils, compacted clay soils, saturated soils, or confined rooting areas e.g.sidewalks, buildings. See Figures 3.88 through 3.90. Due to the asymmetrical nature of restricted root systems, these trees may be at more risk than their normally-rooted counterparts. See Box 13: Restricted root systems. If new curbs or sidewalks were installed or trenches dug for utility installation, roots are more likely to be damaged or removed during the construction process. See Figures 3.91 through 3.94. Even though the trees' vitality may recover over time, the trees are highly unstable for many years due to their asymmetrical and reduced root systems. In root-restricting locations, roots are much more critical for anchoring and stability. Here, any root loss is significant. So if any of the main order roots inside the CRR are damaged or missing, the risk of tree failure is likely to be high.

Figures 3.88-3.90. *Restricted root systems will compromise the tree's stability and vitality.*





Figures 3.91-3.94. *Roots are often removed or damaged during construction.*

BOX 13

Restricted root systems

Roots of trees that have been bounded on at least two sides (e.g. by curb and sidewalk), have distinctively different growth patterns, as compared to open-grown trees. Root systems of open-grown trees are shallow (usually less than 3 feet in depth) and quite extensive (usually two to four times the height of the tree). Restricted root systems generally grow in a linear pattern, along the length of the boulevard lawn. See Figures 3.95 and 3.96. When roots grow in the direction of the sidewalks and curbs, their roots characteristically "turn" with the physical obstructions and grow parallel to them. Therefore, if a 20 inch dbh tree is growing in a boulevard site that is 5 feet wide and 60 feet long, the root system will be concentrated in that 5 foot x 60 foot rooting space.

Figures 3.95-3.96. *Root systems in restricted spaces have distinctly different growth patterns than those without barriers.*

Besides being restricted by shallow soils or concrete barriers, trees can be restricted by their own roots. See Figures 3.97 through 3.99. This condition is known as "stem girdling roots". Stem girdling roots are most commonly a human-caused problem. When a tree is planted too deeply, roots that encircle the stem can develop. Even as little as four inches of added soil can be too much. Over time, the encircling roots start compressing and killing the stem tissues below ground. Stem girdled trees most commonly break at a point just below the girdling roots. See Box 14: Stem girdling roots. Trees most commonly decline in health or suddenly fail in windstorms when stem compression reaches a point where more than 40 percent of the stem circumference is girdled. How to detect the presence of stem girdling roots is discussed later in this chapter: Tree risk inspections and use of specialized diagnostic tools.

Figures 3.97-3.98. *A tree can be restricted by its own roots when "stem girdling roots" encircle the stem.*

Figure 3.99. *Eventually trees with stem girdling roots fail due to extensive decay at the root collar.*

BOX 14

Stem girdling roots

There are probably several reasons why roots begin growing in an encircling pattern around stems: they are already present in pot-bound trees or they develop around trees planted in extremely compacted soil, trees planted too deeply or when roots hit solid obstructions in soil. See Figures 3.100. When the stem is buried, the encircling roots can survive and develop into stem girdling roots.

Figures 3.100. *Stem girdling roots develop when the tree is young and become a problem in a decade or two. If seedlings are pot-bound or planted too deeply, stem girdling roots can develop.*

Trees that are suffering from stem girdling roots exhibit some common symptoms: stunted growth, scorched foliage, abnormal leaning, lack of a characteristic trunk are, early leaf coloration and leaf fall, and vulnerability to secondary problems. See Figure 3.101. These symptoms are subtle and seemingly healthy trees can suddenly fail during windstorms. In storm damage surveys conducted in 1997-1998 by the University of Minnesota's Forest Resources Department, 30 percent of all landscape trees that failed in windstorms failed at the root collar due to stem girdling roots (Johnson 1999).

Figures 3.101. *Trees with stem girdling roots may show symptoms of crown decline, stunted growth, abnormal foliage, leaning, and lack of normal root flares.*

Root Problems

High risk of failure:

See Figures 3.102, 3.103, and 3.104.

- Leaning tree with recent evidence of root lifting, soil movement, or soil mounding.
- More than 40 percent of the roots within the CRR are damaged, decayed, severed, or dead.
- Stem girdling roots constrict more than 40 percent of the tree's circumference.

Moderate risk of failure:

- Less than 40 percent of the roots within the CRR are damaged, decayed, severed, or dead.

Figure 3.102. *High risk of failure: Leaning tree with recent evidence of root lifting, soil movement or soil mounding.*

Figure 3.103. *High risk of failure: Roots within CRR are more than 40 percent damaged, decayed, severed, or dead.*

Figure 3.104. *High risk of failure: Stem girdling roots constrict more than 40 percent of the tree's circumference.*

NOTES:

Weak Branch Unions

Weak branch union = An epicormic branch or a branch union with included bark.

Trees may suffer from naturally formed imperfections that can lead to branch failure at the union of the branch and main stem. There are two types imperfections that create weak branch unions: a branch union with included bark, and, an epicormic branch. See Figures 3.105 and 3.106.

Figures 3.105. *Weak branch union due to presence of included bark.*

Figures 3.106. *Weak branch unions due to formation of epicormic branches.*

Branch unions can be characterized as strong or weak. Strong branch unions have upturned branch bark ridges at branch junctions. See Figure 3.107 and Box 15: Strong branch unions. Annual rings of wood from the branch grow together with annual rings of wood from the stem, creating a

Figure 107. *Strong branch union.*

BOX 15

Strong branch unions

Strong branch unions have an upturned ridge of bark between the stem and branch. This is called the branch bark ridge (BBR) and can be found on the upper most part of the union. See Figures 3.108, 3.109.

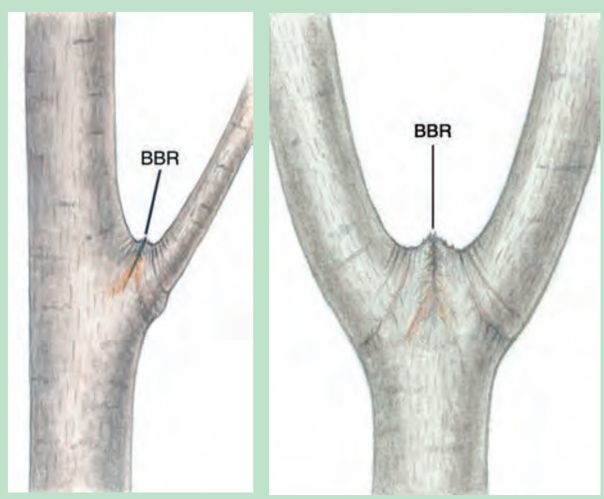


Figure 3.108 - 3.109. *Strong unions are characterized by upturned branch bark ridges (BBR).*

sound, strong union all the way into the center of the tree. One type of weak branch union occurs when a branch and stem (or two or more codominant stems) grow so closely together that bark grows between them, inside the tree. See Figure 3.110. The term for bark growing inside the tree is "included bark." See Box 16: Included bark. As more and more bark is included inside the tree, the weak union is more likely to fail. See Figures 3.112 and 3.113.

In storm damage surveys conducted in 1997-1998 by the University of Minnesota's Forest Resources Department, 21 percent of all landscape trees that failed in windstorms failed at weak branch unions of co-dominant stems. Some species are notorious for having included bark: European mountain ash, green ash, hackberry, boxelder, willow, red maple, silver maple, Amur maple, cherry and littleleaf linden (Johnson and

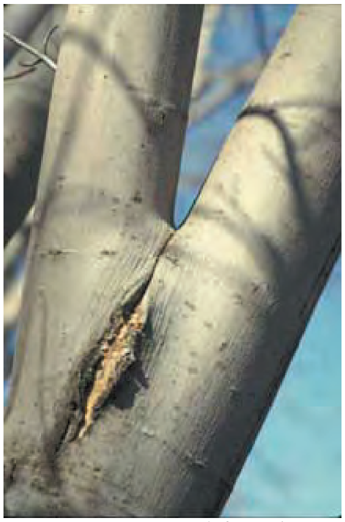


Figure 3.110. *Weak branch union because bark is growing inside the tree.*

BOX 16

Included bark

Unlike the normal wood-to-wood connections of strong branch unions, these weak unions have bark-to-wood connections. Bark does not adhere to wood, so the branch is not tightly attached to the tree. See Figure 3.111.

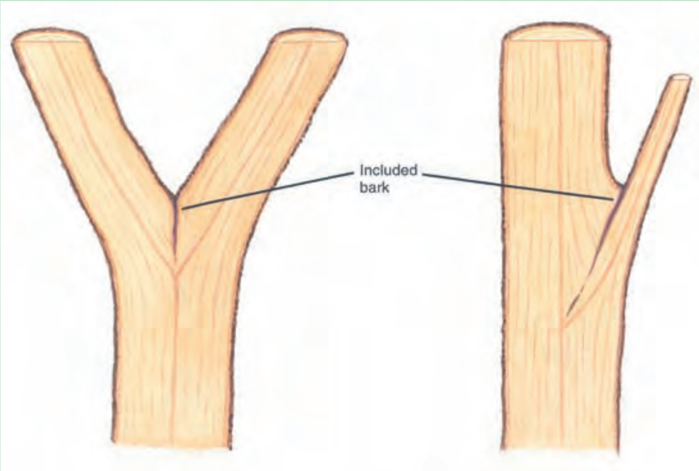


Figure 3.111. *Included bark between 2 codominant stems (left) and between the stem and a branch (right).*

Figure 3.112 - 3.113. *As more bark is included inside the branch union, the branch is more likely to fail.*

Johnson 1999).

Epicormic branches (also called water sprouts) are formed as a response to injury or environmental stress. See Figure 3.114. Epicormic branches are new branches that replaced injured, pruned, or declining branches. Commonly, epicormic branches form on the stems and branches of topped trees. When old, large epicormic branches are growing on decaying stems or branches, the epicormics are very likely to fail. See Figure 3.115 and Box 17: Failure of epicormic branch on topped stem.

Figure 3.114. *Epicormic branches are new branches that replace injured, pruned or declining branches.*

Figure 3.115. *Large old epicormic branches are likely to fail.*

BOX 17

Failure of epicormic branch on topped stem

Epicormic branches, by their very nature, form weak unions because they are shallowly attached instead of being attached all the way to the center of the stem. Epicormic branches grow very quickly so they become heavy very quickly. After a time they loose their connection to the main branch and may fall to the ground because the underlying wood cannot support their weight. See Figure 3.116.

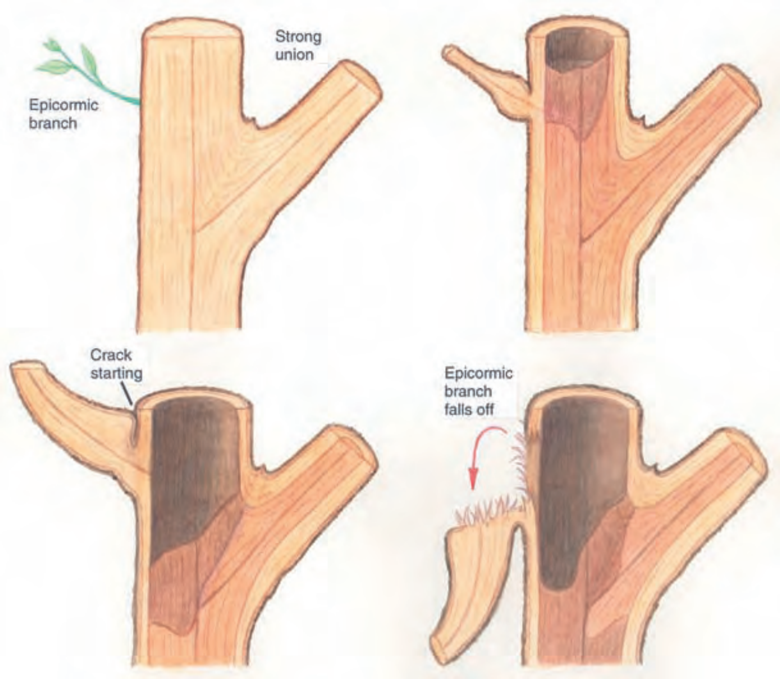


Figure 3.116. *How an epicormic branch forms, grows and eventually fails on a tree that was topped.*

If a weak union is also cracked, cankered or decayed, the union is likely to fail, causing the branch to fall off the tree. Sometimes, ridges of bark and wood will form on one or both sides of a weakened branch union in order to stabilize the union. The branch is very likely to fail when a crack forms between the ridges. See Figure 3.117.

Weak Branch Unions

High risk of failure:

See Figures 3.118 through 3.120.

- Weak union is also cracked, cankered or decayed.
- Large epicormic branch on decaying stem.

Moderate risk of failure:

- When a branch or codominant stem has included bark.

Figure 3.117. *If a weak union is also cracked it is very likely to fail.*

Figure 3.118. *High risk of failure: A weak union that is also cracked.*

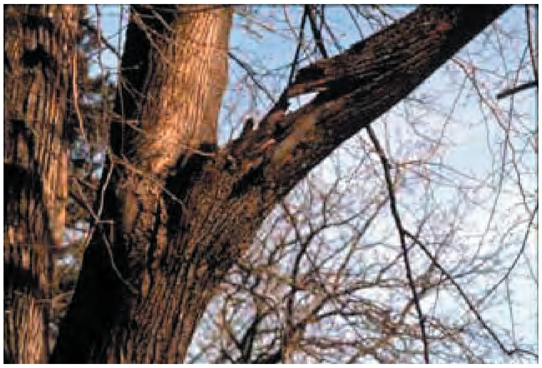


Figure 3.119. *High risk of failure: A weak union that is also cankered or decayed. Note that branch is also cracked.*

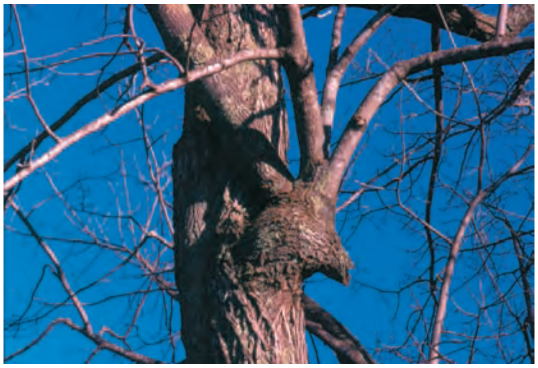


Figure 3.120. *High risk of failure: Large epicormic branches on a decaying stem.*

Cankers

Canker = an area where bark and/ or cambium are dead.

A canker is an area on a branch, stem, or root where the bark and/or cambium are dead. As the tree adds a new annual ring of wood each year, the cankered area will not be able to do so. Large cankers or a number of small cankers in close proximity can predispose a tree to fail because there is not enough wood to support the tree at the location of the canker(s). See Figures 3.121 through 3.123. Stems and branches often fracture on or near their cankers.

Figure 3.121. *A canker is an area where the bark and the cambium are dead. Wood below the canker is also disfigured.*

Figure 3.122, 3.123. *Two views of same canker: Cankers can predispose a tree to fail because there is not enough wood to support the tree at the*

Cankers can be caused by fungi, insects, lightning, or mechanical damage such as wounds and gouges caused by vehicles, vandalism, lawn-mowers, or string-trimmers. See Figures 3.124 through 3.130. Bark may or may not adhere to the canker face.

Fungal cankers are long-term, tree-fungus associations that prevent normal wood formation at the canker location. Sometimes fungal cankers quickly girdle the tree, killing the stem and branches above the canker.

Figure 3.124 - 3.126. *Many cankers have decaying wood below the cankered area.*




Figure 3.127 - 3.130. *Cankers can be caused by inseccts, fungi, and mechanical wounds, including vandalism.*

Regardless of origin, cankers can lead to tree failure if they affect 40 percent or more of the tree's circumference. If decay is also present, the combination of decay and canker can weaken the tree very quickly. When decay is present, evaluate shell thickness and size of opening caused by the canker.

Cankers

High risk of failure:

See Figures 3.131 and 3.132.

- Canker affects 40 percent or more of the tree's circumference.
- Canker plus decay affect 40 percent or more of the tree's circumference.

Moderate risk of failure:

- Canker or canker and decay affect 25 percent to 40 percent of the tree's circumference.

Figure 3.131. *High risk of failure: When canker affects 40 percent or more of the tree's circumference.*

Figure 3.132. *High risk of failure: When canker plus decay affect 40 percent or more of the tree's circumference.*

Poor Architecture

Poor architecture = growth pattern indicates structural imbalance and weakness in the branch, stem or tree.

Whether it's a leaning tree or a branch problem, in most cases poor architecture is a product of past changes in the tree's environment or growth pattern, or damage to the tree. Leaning trees are the most common example of poor architecture. See Figure 3.133.

Figure 3.133. *Strucural imbalance causes this tree to have poor architecture.*

All trees lean to some extent. In some cases, tree lean is a new or recent condition and is due to partial windthrow. See the previous section on Root Problems for this situation. In other cases, the tree has leaned for a long time and is well anchored and balanced for its load. Some situations warrant treatment, however. If an established tree leans excessively, 40 degrees or more, and hangs directly over a target, then either the target should be moved or the tree should be removed. See Figure 3.134.

Figure 3.134. *When an established tree leans excessively (40 degrees or more), then target or the tree should be removed.*

A leaning tree with a serious defect in the lower stem or root collar is very likely to fail because it has both a structural imbalance and a weakness in the stem and roots. A leaning tree is likely to fail when the lower stem or root collar is even moderately decayed or cankered. See Figures 3.135 and 3.136. Because of the unbalanced load that the tree carries, there is always a high risk of failure.

A leaning tree with a shear or inrolled crack is in imminent danger of failing because it has already fractured. See Figure 3.137.

Figure 3.135. *Note fungal fruiting bodies. Advanced decay in base of a leaning tree.*

Figure 3.136. *Canker and decay in lower stem of a leaning tree.*

Figure 3.137. *A leaning tree with a crack is in imminent danger of failing.*

Leaning trees may also fail with only subtle warning signs. A leaning tree displaying *tension and buckle* symptoms has a high risk of failure (Mattheck 1998). See Box 18: Leaning tree with tension and buckle symptoms. A leaning tree with tension and buckle symptoms has a high risk of failure because it has already partially failed. See Figures 3.139 and 3.140.

BOX 18

Leaning tree with tension and buckle sypmtoms

Tension symptoms are horizontal cracks on the upper side of a leaning tree. Horizontal cracks are formed as wood fibers are torn apart. See Figure 3.138.

Buckle symptoms are bulges in the bark and wood on the lower side of a leaning tree. The buckles are formed as the wood is compressed by the weight of the leaning tree. Bark may appear loose or compressed.

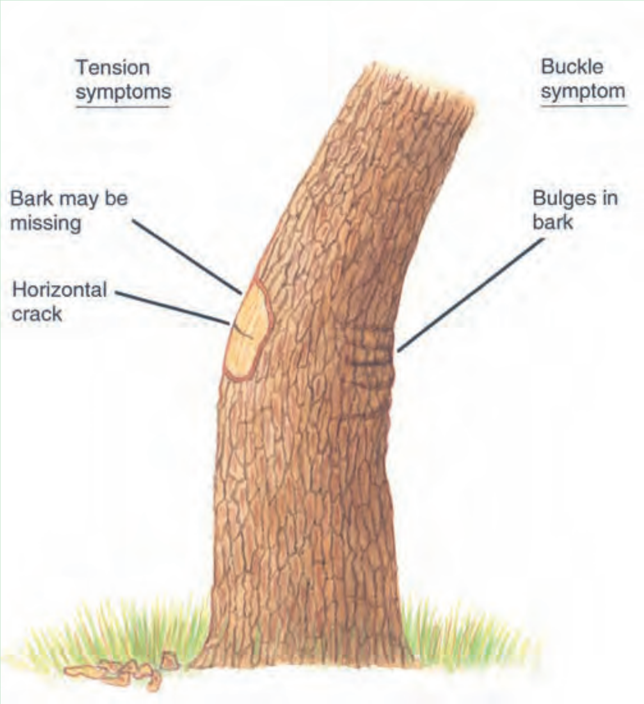


Figure 3.138. *Tension and buckle symptoms on a leaning tree.*

Figure 3.139. *Tension symptom: Horizontal crack in wood of leaning tree.*

Figure 3.140. *Buckle symptom: Bulges in bark on lower side of leaning tree.*

A *harp tree* (also called *trees on trees*) can be recognized as a tree with a large horizontal branch that supports several, smaller vertical branches. See Fgure 3.141 and Box 19: Harp trees. After many years, it is common to find cracks in the union of the horizontal branch and the main stem due to the increasing weight and movement of the horizontal branch. Branches on harp trees are especially vulnerable to winds pushing them from the side (Mattheck 1998).

Figures 3.141. *Harp tree created as epicormic branches grow vertically off a topped tree with tipped branches.*

BOX 19

Harp trees

Harp tree architecture is usually produced in response to the loss of a main branch. When a tree loses a main branch in the upper crown, the tree rebuilds the crown on its lower branches. See Figure 3.142. In doing so, epicormic branches form along the top side of the branch creating the *strings* of the harp.

Figures 3.142. *The horizontal branch supports many heavy and fast-growing vertical branches. Inspect the branch union for evidence of cracks, decay or cankers.*

Branch failure can be caused by poor architecture. In most cases, poor branch architecture is a product of past changes in the tree's environment, abnormal growth pattern, or damage to the tree. See Figure 3.143.

Branch and tree failures caused by poor architecture is usually a product of past changes in the tree's environment or growth pattern, or damage to the tree. See Table 3.5: Branch and tree failures caused by poor architecture.

Figure 3.143. *Bends, twists, and crooks can indicate poor architecture in branches.*

Table 3.5. *Branch and tree failures caused by poor architecture.*

Cause / event	Change in the tree	Worst-case Outcome
Nearby trees removed or tree is pruned heavily.	Branch grows into the new space and crown becomes imbalanced. Epicormic branches form on the stem	Tree is prone to windthrow. Branch failure
Storm damage to branch or branch tipping	Branch develops a sharp twist or bend, branch becomes decayed.	Branch failure
Partial loss of tree crown	Multiple branches, epicormic branches, or codominant stems arising from one area of the stem	Branch failures
Tree was topped	Epicormic branches form and stem decay develops quickly from stub downward	Epicormic branch failure and stem failure in the upper crown
Loss of a main branch	Harp tree architecture and epicormic branches form	Failure of epicormic branches and horizontal branch failure
Two branches rub together	Canker and decay develop at point of contact	Branch failures

Poor Architecture

High risk of failure:

See Figures 3.144 through 3.147.

- Tree with excessive lean (greater than 40 degree angle).
- Leaning tree has a crack in stem.
- Leaning tree has canker or decay on the lower stem.
- Leaning tree has a horizontal crack on the upper side of the lean or buckling bark and wood on the lower side.

High risk of failure:

- Branch has a sharp bend or twist.
- Large, horizontal branch with several vertical branches on it.

Figure 3.144. *High risk of failure: A tree with excessive lean (greater than 40 degrees).*

Figure 3.145. *High risk of failure: When a leaning tree has a crack in stem. Note crack started in branch union.*

Figure 3.146. *High risk of failure: When leaning tree has canker or decay on the lower stem.*

Figure 3.147. *High risk of failure: Leaning tree has horizontal crack.*

NOTES:

Dead Tree, Top or Branch

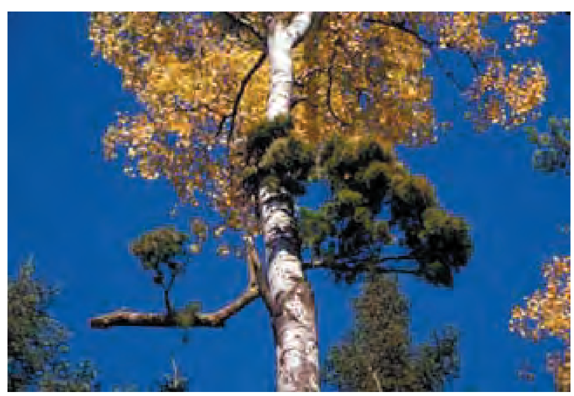
Dead = a dead tree, top or branch is structurally unsound because of pre-existing defects or rapid decomposition of the wood. Failed branches that are lodged in the crown may fall at any time.

Figure 3.148. *A dead tree always has a high risk of failure.*

Live trees most often fail first at their defects. Dead trees, however, can fracture anywhere: at the ground line, just above the stump, just below the lowest branch, or anywhere in the crown. See Figure 3.148. They can also fail where there is a pre-existing defect. As time passes, the probability of failure increases. Dead tops or branches may remain attached to live trees for several years or may fall off suddenly. Dead branches usually break off near or at the live stem. See Figure 3.149. Dead tops frequently break off just above the live stem. See Figure 3.150. Branches on dead trees usually decay and fall first, leaving a slowly decaying main stem that may stand for many years.

Figures 3.149, 3.150. *Dead branches or dead tree tops also pose a high risk of failure because they can break off at any time.*

A broken branch that is caught up in the tree's crown by other branches is called a "lodged branch." See Figures 3.151 and 3.152. A lodged branch is hazardous because it has already failed and only waits to be dislodged by the wind or by the failure of the supporting branch.



Figures 3.151-3.152. *Lodged branches have already failed and only wait to be dislodged and fall to the ground.*

Dead trees within striking distance of a target should always be removed as soon as possible, simply because we cannot predict how fast the tree will decompose and fail, especially near its defects. For wildlife habitat, dead trees may be left if they would not fall into target areas.

Dead Tree, Top, or Branch

High risk of failure:

See Figures 3.153 and 3.154.

- Any lodged branch.
- Any dead tree, top, or branch.

Figure 3.153. *High risk of failure: Any lodged branch.*

Figure 3.154. *High risk of failure: Any dead tree, tree top or branch.*

Tree Risk Inspections and Use of Specialized Diagnostic Tools

Tree risk inspections provide a systematic method of examining trees, assessing defects present, and estimating the degree of risk trees pose to public safety. Visual inspections of individual trees, using the 360-degree walk-by method, are sufficient for detecting most defects and assessing the probability of tree failure. Some defects, however, do not have external signs or symptoms and their detection requires in-depth inspections and the use of specialized diagnostic tools. Every tree risk management program must include regularly scheduled tree risk inspections, whether visual or in-depth.

In-depth tree assessments are warranted when a tree poses a high degree of risk to public safety and exhibits suspected defects that cannot be fully evaluated during the visual inspection process. For example, in high-use/risk areas where stem girdling roots (SGR) are a suspected defect, soil excavation near the base of the tree may be necessary to determine the presence of SGRs and the extent to which they constrict the stem. In the case of some root problems, it may be necessary to excavate soil to locate primary support roots and investigate if they have been severed or are decayed. For trees in high-use/risk areas that exhibit external signs of decay but the extent of internal decay is uncertain, it is advisable to measure the thickness of the outer ring or shell of sound wood within the tree, and to determine if safe shell limits (see Defects: decayed wood) are met. For each type of in-depth assessment, diagnostic tools are available to assist in the examination. Examples of in-depth assessment methods and diagnostic tools are discussed below.

Root Collar and Stem Girdling Roots Assessments

Root collar examinations are performed to detect damage or decay in buttress and primary support roots and the presence of stem girdling roots. A root collar examination typically takes from fewer than 20 minutes for smaller trees and less extensive examinations, to more than 2 hours for larger trees requiring more excavation (Johnson and Hauer 2000). The examination begins by probing into the soil near the root collar with a 3/8-inch-diameter probe, rod, or steel wire (coat hanger gauge) to determine the depth of primary branch roots and the presence of any encircling roots or other root damage such as decay or severing. See Figure 3.155. The root collar is defined as the base of the tree were the primary roots first begin to branch away from the stem and normally appears swollen or slightly flared. Next, the soil is excavated outward from the root collar and primary support roots are examined. For the average-sized landscape tree (9 to 15 inches d.b.h.), with roots 6 to 10 inches from the surface, soil should be excavated 12 to 18 inches outward from the trunk. If the primary branch roots are deeper, widen the examination area proportionately. Gradually loosen and remove soil until the stem/root conflict or root collar is exposed. Hand trowels, knives, stiff bushes,

Figure 3.155. *A metal probe inserted into the soil near the root collar.*

wet/dry vacuums, air compressors, and water can be used to loosen and remove soil around roots. Shallow examinations of smaller trees do not require the use of elaborate equipment. However, vacuums and portable air compressors are most effective with larger trees and examination areas. Do not use spades or shovels unless certain that no roots exist in the soil to be excavated. After the soil is excavated, look for the presence of stem girdling roots and evidence of stem compression or other root damage. In the case of root decay, a metal rod may also be used to probe the roots farther out from the trunk and to test for presence of advanced decay. If the roots are severely decayed, they will be punky in texture and easily probed by the metal rod. The risk of tree failure is considered to be high if girdling roots constrict greater than 40 percent of the stem's circumference or greater than 40 percent of roots within the CRR are damaged or decayed.

Decay Detection Assessments

Decay assessments determine the location and extent of decay present in a tree and whether the decay represents a significant risk to the structural integrity of the tree. The outer shell of sound wood is measured to ensure safe shell limits are met and the tree does not pose an unacceptable level of risk. Many devices are available to detect internal decay and other defects in standing trees. Traditional, low-tech devices include the steel rod, mallet, increment borer, and portable drill. High-tech devices include penetrometers (Resistograph, densitomat, and Sibert Decay Detecting Drill (DDD 200)), sonic and ultrasonic detectors (Mertigard Stress-wave Timer, Sound Impluse Hammer, and Arborsonic Decay Detector), electrical conductivity meter (Shigometer, Vitalometer), and the Fractometer. Harris et al. (1999) described the use, limitations, and invasiveness of many of these instruments. Nicoletti and Miglietta (1998) reviewed technical aspects of several decay detection instruments and offered opinions on the reliability of each. The following instruments are commercially available for use by tree care professionals in the United States. The information presented is current as of the date of writing; however, readers should be alert for new developments in technology.

Examples of Decay Detection Devices Commonly Used in the United States

Metal Rod

A 3/8-inch-diameter metal rod may be used to probe stem and root tissue to detect the size of cavities, depth of cracks, or the presence of advanced decay. If the stem or root tissue is severely decayed, they will be punky in texture and easily probed by the metal rod.

Rubber Mallet

A rubber mallet (Figure 3.156) can be manually struck against the bark or exposed wood surface, and, with experience, an operator can interpret whether the resulting sound indicates hollowness or severe decay. This method is highly subjective, and is dependent on the operator's experience and interpretation skills. Care should be taken not to mistake the sound emitted by striking loose bark as the presence of decay within the wood of the tree. This method is non-invasive, and the tool is cheap, easy to carry, and requires no maintenance.

Figure 3.156. *A rubber mallet.*

Increment Borer

Figure 3.157. *An increment borer.*

The increment borer (Figure 3.157) consists of a hollow tube with an external screw thread at one end. It is screwed into a tree and removes a core of wood approximately 5mm in diameter. The core can be examined for the presence of discoloration or decay along the wood cross-section, and the presence of decay can be manually mapped along the length of the core. Multiple borings around the stem circumference will provide a measurement of the thickness of the outer shell of sound wood, limited to the length of the core. Increment borers are inexpensive, easy to carry, and require limited maintenance. However, this method of assessment is invasive to the tree, and causes the largest diameter wound of the decay detecting devices commonly in use. In trees with internal decay, an increment borer can break an existing barrier zone within the tree and may allow decay to progress into healthy wood. Finally, if the coring tip becomes dull, the tool may get stuck and removal from the tree can be difficult.

Penetrometers

Penetrometers record the resistance encountered by a probe as it is impelled into the wood rotating at a high speed. The portable drill, Resistograph, and Siebert DDD 200 are the most commonly used decay detection instruments of this type in the United States. All of these devices assess changes in the mechanical resistance of wood to quantify the amount of decay present. They work on the premise that during the wood decay process, wood density decreases and, correspondingly, wood hardness and drilling resistance declines. In simplified terms, sound wood is dense, hard in texture, and has a high resistance to the drill penetrating it. In contrast, severely decayed wood is less dense, softer in texture, and has reduced drilling resistance.

Portable drills. Portable drills (Figure 3.158) have been used for many years by trees care professionals in the United States and are considered by many to be reliable decay detection tools. A cordless 3/8-inch drill, with a 1/8- by 12-inch brad point tip bit is used. As the tree is drilled, decay is indicated by reduced resistance to the drill penetrating the wood. The bit is pulled out typically at 0.5-inch intervals, and the wood shavings are evaluated for presence of discoloration, punkiness, and odor as indicators of decay. An advantage of the portable drill over other decay detecting drills is that drill shavings provide direct evidence of the presence and location of decay. By examining the wood shaving at frequent intervals, the operator can manually map discoloration, decay, and cavities with reasonable accuracy along the length of the drill path. This tool is relatively inexpensive, quite easy to carry, and requires very little maintenance. A disadvantage of the portable drill is the potential for subjective error in quantifying decay.

Figure 3.158. *A portable drill.*

Studies have shown the portable drill to be effective in detecting late-intermediate and advanced decay (greater than a 20-percent weight loss in the wood) when used by experienced operators, but far less reliable when used by inexperienced operators (Costello and Quarles 1999). In addition, even experienced operators can not reliably detect the presence of early to early-intermediate stages of decay (less than a 20-percent weight loss in the wood) with a portable drill.

Resistograph. The Resistograph (Figure 3.159) is a relatively new instrument developed in Germany. It is easy to operate and use, and weighs between 5 and 6 pounds, depending on the model. A battery-operated motor drives a specially engineered drill bit (needle) into the wood at a constant speed of 8, 16, or 24 inches per minute. Drilling depth is 12, 16, or 20 inches, depending on the model, and the drill bit diameter is 1/8 inch at the cutting tip and 1/16 inch along the shaft. The drilling resistance at the needle tip is transferred through a gearbox to a pointer that is visible at the top of the instrument and graphs the results on a waterproof wax paper printout. As the drill penetrates the wood, resistance to the pressure of the drill is measured and recorded, and the pattern of changes in resistance is used to determine decay presence or absence. For example, relatively high resistance readings indicate sound wood, while low readings suggest decay or other defects. Several models exist, with the higher end models (E Series) containing an electronic component with an optional personal computer interface for on-screen viewing, and specialized Windows® software for data analysis. A printer attachment is available for viewing and interpreting results onsite.

Figure 3.159. *The resistograph.*

An advantage of the Resistograph over the portable drill is the fact that results are quantitative, and a written record is graphed on waterproof paper for documentation. Advanced decay and cavities can be detected, and their location can be mapped along the cross-section of the drill depth. A disadvantage of the Resistograph over the portable drill is its increased weight and size that makes it more difficult to transport and use in the field. A disadvantage of the Resistograph over the Sibert Decay Detecting Drill is that the drill bit is sharp, not blunt, and becomes dull and needs regular replacement.

Sibert Decay Detecting Drill (DDD 200). The Sibert DDD 200 measures changes in the speed of penetration, at a constant forward pressure of penetration, and functions on the same principles of the portable drill and the Resistograph. The results are quantitative and can be displayed and printed for documentation purposes. The drill bit is 1.5 mm wide, blunt, and is normally 200 mm in length. The drill width is less than the Resistograph, and is reportedly less likely to snap. The drill bit is blunt (versus a sharp drill bit that becomes dull and requires regular replacement), and rotates at 7,000 rpm which supposedly eliminates the problem of wood chips filling the drill path and causing friction to develop along the length of the drill shaft. Models are available that provide an electronic output, viewable on a computer screen and printable.

Limitations of penetrometers. Studies have been conducted to evaluate the reliability of the portable drill and the Resistograph by comparing decay assessments generated from each instrument with decay assessments from laboratory measurements of wood density and visual examinations of density samples for elm and blue gum trees (Costello and Quarles 1999). Wood density values below a critical level were used to determine the presence of decay within wood samples tested, and then compared to Resistograph readings and portable drill findings. Both instruments were able to reliably detect late-intermediate and advanced decay and the presence of cavities. Neither, however, was able to reliably detect the presence of early to early-intermediate stages of decay. In cases where early to early-intermediate decay advances well in front of the advanced decay cylinder within the tree, penetrometers may produce an assessment that underestimates the amount of decay present. This may have significant safety implications because wood can suffer loss of strength in the difficult-to-detect earlier stages of decay.

Another limitation of decay detection devices is the variability of the wood resistance readings and lack of tree species profile data. The resistance patterns of sound wood in different tree species may vary significantly, and there may be substantial differences even within an individual tree. These differences depend on factors such as patterns-of-growth rate and the presence of resins, reaction wood, and heartwood. Friction between the probe shaft and the displaced wood fibers which line the drill hole can cause an increase in resistance with increasing depth. The friction can become strong enough to skew the resistance readings too high and prevent detection of decayed wood. For these reasons, familiarity with wood resistance patterns, between tree species and within tree species, is critical for an accurate interpretation of decay presence and absence. The operator should obtain reference data from anatomically comparable undecayed or sound wood for each tree species evaluated, as a standard of comparison. Profile data has been collected in Germany on many tree species (Mattheck et al. 1997); however, published data is lacking for U.S. tree species. Until this information becomes available, it will be difficult to accurately interpret test results for U.S. tree species.

Cost is another issue to consider. The Resistograph and Siebert DDD 200 are expensive to purchase and maintain. Many small communities, with limited budgets, would be prohibited from purchasing them. A possible solution to this problem would be for two or more communities to share the cost of purchasing the instrument, and then schedule its use on a rotational basis.

Electrical Conductivity Meters (Shigometer/Vitalometer)

The Shigometer was invented by A. L. Shigo in the early 1980's. The French have modified the instrument and market it as the Vitalometer. A 3-mm (3/32-inch) hole is drilled into the tree trunk to a depth of 30 cm, an electrode is inserted, and the electrical resistance (ER) is measured at 1-cm intervals with an ohmmeter. The quantity of free ions varies from one type of wood to another and the greater the number of free ions, the lower the ER. Decayed wood has more free ions than non-infected wood. As the electrodes encounter decayed wood the ER drops substantially and abruptly; a drop of 50 percent indicates the presence of decayed wood.

Several problems limit the effectiveness and use of electrical conductivity meters in the field. For example, the drill bit is fragile and often snaps when drilling. Interpreting results can be difficult when the moisture content of the wood is below the fiber saturation point, when the wood is impregnated with resin (resin acts as an insulator), and when the drill hole fills with water (as often happens with bacterial wet wood). Wood that is discolored, but not decayed, may result in reduced ER readings, and cause the operator to overestimate the amount of decay in the wood.

Sonic and Ultrasonic Detectors

Sonic devices (stress-wave timers). The Mertigard Stress-wave Timer and the Sound Impluse Hammer are acoustic devices that measure the time taken for a stress or shock wave to pass through an object, in this case a tree trunk. The stress wave is initiated by a hammer blow that is delivered to a start probe located on one side of the trunk, and the time required for it to travel to a second, sensor probe located on the opposite side of the trunk is measured. Probes are mounted on steel screws that are inserted into the outermost wood of the tree. All sonic devices work on the principle that transmissibility of sound waves through a body is determined by the body's density. Damaged wood is usually less dense because it has been decayed by fungi or tunneled by insects. If a portion of the trunk is damaged and the wood density reduced, transmission of the sound takes longer than if the tree was free of defects. Severe defects reduce the sound velocity to less than 70 percent of the characteristic values of sound wood (Bethge et al. 1996).

A major disadvantage of stress-wave timers is that although they are capable of detecting the presence or absence of internal defects such as decay, cracks, and holes, they cannot map the specific location or quantify the extent of internal defects. Another disadvantage of stress-wave timers is their inability to detect certain kinds of decay that cause embrittlement of the wood; in particular, decay caused by *Ustilina deusta* (Schwarze et al. 1993). For stress-wave timers, a reduction in wood density will result in a decrease in the sound velocity, whereas a reduction in the elasticity of the wood will increase the sound velocity. Decays that result in embrittlement cause a reduction in both wood density and elasticity, and hence produce no net change in the sound velocity.

Ultrasonic devices. Ultrasonic devices work on the same principle as the stress-wave timers, but measure the transit time of an ultrasound pulse between a transmitting sensor and a receiving sensor. The sensors (approximately 40 mm in diameter) must be in direct contact with wood to ensure a good acoustic contact with the tree, requiring two discs of bark to be removed for each measurement. The Arborsonic Decay Detector (Figure 3.160) is an example of an ultrasonic device used by tree care professionals in the United States.

Figure 3.160. *The arborsonic decay detector.*

Similar to stress-wave timers, ultrasonic devices can detect the presence or absence of defects, but the type of defect (e.g., decay, cracks, cavities) and the severity of strength loss cannot be distinguished. Use of these devices does not allow the operator to measure the thickness of the outer shell of sound wood or to map the specific location and extent of defects. As in the case of stress-wave timers, certain studies have indicated that test readings obtained with ultrasonic timers generally need to be evaluated by reference to readings from sound wood of the tree species concerned (Lonsdale 1999). Ultrasonic devices might be expected to share with stress-wave timers the inability to detect certain types of decay, particularly those that cause embrittlement of the wood, and this possible shortcoming should be investigated. Unlike stress-wave timers, ultrasonic devices cannot be used on very large diameter trees, as the signals that they emit are quite rapidly attenuated in the wood. In the case of the Arborsonic Decay Detector, the maximum path length is about one meter.

Fractometer

The Fractometer is an instrument that determines wood quality in terms of wood strength and elasticity (Mattheck et al. 1994). A 5-mm diameter core of wood is extracted with an increment borer, placed in a clamping device, and stressed to the point of failure by increasing the force pushing against it. The fracture moment and angle of failure are measured at a number of points along its length. Measurements of breaking strength allow zones of weakened wood to be mapped with the stem cross-section, and the bending angle measurements help to determine if the wood is liable to undergo brittle on non-brittle fracture. Mattheck et al. (1994) concluded that large fracture moments and small fracture angles were indicative of sound wood. A decrease in fracture moment, an increase in fracture angle, or a combination of the two is indicative of the presence of decay.

Several limitations exist with the use of the Fractometer. Sample cores from several tree species tested in the United States could not be properly tested using this instrument because core samples broke when the lever arm was initially placed against the sample, and no measurable results could be obtained (Matheny et al. 1999). The tree species tested included Monterey cypress (*Cupressus macrocarpa*), ponderosa pine (*Pinus ponderosa*), black cottonwood (*Populus trichocarpa*), Douglas fir (*Pseudotsuga menziesii*), and coast redwood (*Sequoia sempervirens*). Secondly, the operator must know the breaking strength value that should be expected for sound wood (decay-free) for a given tree species. The manufacturer provides strength data for different tree species, but this data is based on work completed in Germany, and the values should not be regarded as standards for U.S. tree species. A study assessing the fracture moment and fracture angle of 25 tree species in the United States using the Fractometer (Matheny et al. 1999) concluded that due to the variation in test results among geographic locations and within individual species, operators must compare Fractometer results with decay-free samples taken from the same tree and should not rely on tables of standardized results.

This assessment method is more invasive than many decay detection devices, and involves the use of an increment borer and the collection of 5-mm core samples. It is essential for the borer to be kept sharp and aimed at towards the center of the tree (i.e., parallel to the rays and at right angles to the axes of the stem). Any deviation form these conditions could produce misleading results.

A Final Word About Decay Detection Devices

Decay detection devices should be used with discretion because most are invasive in their mode of application and cause some degree of injury to the tree. Wounds, created when probes are drilled into the tree or when the bark is removed to attach sensors, may serve as entry points for decay organisms. Invasive methods may also allow existing decay to spread internally by interfering with the tree's ability to compartmentalize the decay. Although it is uncertain to what extent these small diameter wounds contribute to the development of decay within trees, the injury caused by most decay detection devices should not be overlooked. It is advisable to restrict the use of decay detection devices to situations when additional information about the location and extent of internal decay is critical to assessing the probability of tree failure, particularly for trees in high use areas.

When using decay detecting devices, limit the number of drill holes or sensor sites to the minimum needed to collect critical field data. When determining the number and location of sampling sites, try to visualize the width and length of the decay column based on external signs and symptoms. Make multiple borings around the circumference of the stem and at more than one height along the length stem to help determine the width and length of the of the decay column, respectively. Test areas that you suspect to have the thinnest shell of sound wood. The shell of sound wood will be thinnest between root flares, where the defect symptoms are most pronounced, or just behind the bulge on an inrolled crack (Hayes 2000).
The specific assessment device that you choose to use will depend on the field situation, your level of experience, and the size of your pocketbook. For example, a low-tech, inexpensive tool such as the portable drill has been documented to be quite effective in detecting advanced decay, and sometimes intermediate decay, when operated by a person experienced in its use. The stress-wave timers and the ultrasonic timers are capable of detecting the presence of internal defects such as decay, cracks, and holes, but cannot be used to quantify the extent or position of the defects. In most cases, more detailed mapping of the defects will be desired, and currently the penetrometer devices have more potential to measure the location and severity of defects. When measuring the thickness of sound wood surrounding cavities or decay columns, the device employed should be suited to the size of the tree. For example, drilling devices, although limited to the length of the drill-bit or probe, can be used on most large diameter trees since the acceptable safety factor (safe shell limits) depends on as little as the outermost 30 percent of the cross-section being completely sound. Currently available ultrasonic timers, however, will provide data only if the cross-section of the tree is less than or equal to one meter (39.37 inches).

Misinterpretation of results is an inherent problem associated with all of the above-mentioned decay detection devices. Problems with misinterpretation of results can be minimized by ensuring that devices are evaluated under a wide range of conditions that should include different defect types and severities, and a wide range or tree species over a large geographic area. As mentioned above, tree species profile data, from anatomically comparable undecayed sound wood for each tree species evaluated, should be developed for U.S. tree species as a standard of comparison for each device used.

In the future, what is needed ideally is a compact, non-invasive device that is affordable, quick and easy to use, and that will provide reliable information on the location, extent, and type of defect or decay. The use of radar, x-rays, x-ray tomography, thermal imaging, frequency imaging, and nuclear resonance is being explored and may one day provide the solution.

Formulating Tree Risk Ratings

The purpose of tree risk inspections is to detect defective trees in target areas, assess the severity of the defects, and recommend corrective actions before tree failure occurs. Tree risk ratings can assist communities in quantifying the level of risk posed to public safety and in prioritizing the implementation of corrective actions. Two systems of field inspection and risk rating follow, one from the Minnesota Department of Natural Resources, and one from the U.S. Forest Service. Although these systems are similar in many ways, their approach to risk rating (step 3) differs. Each is presented in its entirety to be used as a stand-alone process.

A 7-Step Process Using the Minnesota DNR System

Step 1. Locate and Identify Trees to be Inspected

Inspections can be conducted anytime of the year with the exception of times when snow cover prevents examination of the root collar area. When the inspectors arrive on the site, they must determine which trees to inspect. Only trees that could fall onto a target or into a target area need to be inspected. To determine whether a tree could fall on a target, measure or estimate tree height and the distance to the target. If the target area is within 1.5 X the tree's height, then the tree should be inspected (Figure 3.161). When in doubt, measure heights and distances. Consider tall, distant trees as well as those immediately adjacent to the target area.

Step 2. Inspect Individual Trees and Assess Their Defect(s)

Individual tree evaluations must include a close inspection of the rooting zone, root flares, main stem, branches, and branch unions. Use a pair of binoculars to visually inspect the higher branches. All sides (360 degrees) of the tree must be examined. During the inspection, judge the severity of each tree's defects with respect to defect severity levels established in this manual. A more detailed explanation of the seven defect categories and their failure thresholds can be found in the beginning of this chapter. Assign a single defect level for each tree: low-, moderate-, or high-risk of failure.

A common error made during hazard tree inspections is confusing crown vigor with structural soundness. Just because the crown is full and green, it doesn't necessarily

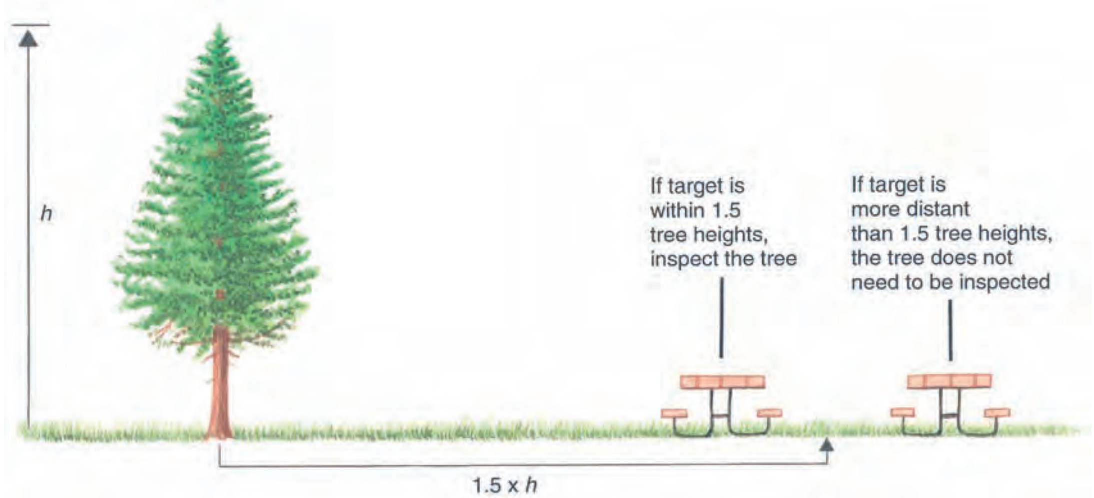


Figure 3.161. *If the target is within 1.5 times the tree's height, then the tree should be inspected.*

mean that the tree is sound. Health and vigor are related to energy supply. Energy and food-related activities occur in the thin layers of cambium and sapwood. When cambium and sapwood healthy, the crown looks good. But that doesn't mean the tree is sound. Structural soundness is related to the condition of stem wood, branch attachments, and anchoring roots.

Step 3. Estimate the Risk Rating for Each Tree

Use the severity levels found in this manual as *guidelines* when assessing trees. Remember, these are guidelines; no absolute rules can be made to cover the natural variability of trees and their defects. Although the list of defects and their combinations appears to be lengthy, it is not exhaustive. Inspectors need to use their judgment and local experience when evaluating and assessing tree defects.

All defective trees cannot be detected, corrected, or eliminated. To begin with, our knowledge of the trees is less than complete. Although we can readily recognize most defects and symptoms, there are root problems and some internal defects that are not easily discernable and may require in-depth inspections and the use of specialized diagnostic tools. Secondly, trees can survive for many years with internal defects. Defect severity can and does change with time. Whereas all defective trees cannot be detected, our aim is to find 80 percent or more of the defective trees with each inspection. By doing inspections and acting on them, we can successfully manage the risk of tree failure.

There are three categories of tree risk ratings:

Low-risk rating : At the current time, the defects do not meet the threshold of failure. No corrective action is necessary.

Moderate-risk rating: At the current time, the defects do not meet the threshold for failure. The defects may or may not result in eventual tree failure. Corrective action is discretionary.

High-risk rating : Currently, these defects indicate that the tree is failing, is in imminent danger of failing, or has already partially failed. Corrective action should be taken as soon as possible.

Step 4. Prioritize Highly Defective Trees for Treatment

In some communities, the defective tree population may be very low or may be manageable with existing resources. In this case, the community may opt for assigning the risk rating equal to the defect rating. The risk rating for each inspected tree can be estimated by simply rating its defects.

Low probability of failure = Low-risk rating
Moderate probability of failure = Moderate-risk rating.
High probability of failure = High-risk rating.

Larger communities, or those with a high proportion of defective trees, may want to rank their highly defective trees in order to prioritize treatments and removals. In this case, target area usage is used to augment the ranking. Target area usage is simply an estimation of the occupancy and duration of occupancy of an area by people and their vehicles, buildings or equipment. Inspectors must assess each tree's target area for its human occupancy during the data gathering phase of tree inspections.

Community policy usually dictates how the frequency of target area use is estimated. The following is an example of what your community could choose to do.

Frequent use areas would generally be located along downtown streets, along congested streets, near schools, in public playgrounds and picnic areas, near bus stops, near public buildings, in parking lot interiors. Intermediate use areas would include parking lot peripheries, and along secondary streets. Low use areas would be in industrial areas, in public wooded areas, and along trails.
Assign a point value for each inspected tree as follows:

1 = Frequent use.
2 = Intermediate use
3 = Low or occasional use

Only rank trees that have a "high" defect rating. Use the following formula (see Table 3.6):

Trees with high defect rating + Target area use rating = Treatment ranking

Table 3.6. Ranking highly defective trees for treatment priority.

Defect rating	Target area use rating	Treatment priority
High	Frequent use = 1	1 (Highest)
	Intermediate use = 2	2
	Low or occasional use = 3	3

Based on your community's policy, remove or treat trees starting with those ranked as 1 and move on down the list as financial resources allow.

Step 5. Conduct a Public Review Before Implementing Corrective Actions

Communication with community members and landowners is recommended before corrective actions are taken. If people are informed of the need for the corrective actions before the time they begin to see trees being removed or pruned, there will be clearer understanding and better community acceptance of why the actions are being taken.

Step 6. Take Corrective Action as Soon as Possible on the Highest Risk Trees

Once high risk trees are identified, action must be taken as soon as possible. Negligence may be assumed if a community identifies high risk and then takes no action. See Chapter 5 for more information about treating and correcting high-risk trees.

Step 7. Document the Process: Inspection Results, Actions Recommended, and Actions Taken

Documentation should include recording the inspection dates, individual tree ratings and corrective actions recommended and then carried out. These are absolutely critical to keep on file. Document all ratings, including the low ratings, on the field sheets. Data may be taken during street tree inventories, hazard tree inventories, as reported by community personnel, etc. Use the form supplied in this manual or create one that suits your needs. See Form 2. Maps are helpful and can be reused in subsequent years.

Form 3.2: Hazard tree inspection form
(*See Forms Section for a full-size copy of the form*)

HAZARD TREE INSPECTION FORM

MAP

Unit ______________________

Subunit ______________________

Inspectors ______________________

____

____

Date ______________________

Remarks ______________________

____

____

____

Tree location or map number	Tree species	Defect(s)	Hazard potential H or M	Remarks	Recommended action	Action taken/date

Local Manager ______________________ Date ______________________

Source: MN DNR

A 7-Step Process Using the USDA Forest Service Community Tree Risk Rating System

Step 1. Locate and Identify Trees to be Inspected

Inspections can be conducted anytime of the year with the exception of times when snow cover prevents examination of the root collar area. When the inspectors arrive on the site, they must determine which trees to inspect. Only trees that could fall into a target area need to be inspected. To determine whether a tree could fall on a target, measure or estimate tree height and the distance to the target area. If the target area is within 1.5 X the tree's height, then the tree should be inspected (Fig 3.179). When in doubt, measure heights and distances. Consider tall, distant trees as well as those immediately adjacent to the target area.

Step 2. Inspect Individual Trees and Assess Their Defect(s)

Individual tree evaluations must include a close inspection of the rooting zone, root flares, main stem, branches, and branch unions. Use a pair of binoculars to visually inspect the higher branches. All sides of the tree must be examined. During the inspection, the severity of each tree's defects is judged with respect to defect severity levels established in this manual. A more detailed explanation of the seven defect categories and their failure thresholds can be found in the beginning of this chapter.

A common error made during hazard tree inspections is confusing crown vigor with structural soundness. Just because the crown is full and green, it doesn't necessarily mean that the tree is sound. Health and vigor are related to energy supply. Energy and food-related activities occur in the thin layers of cambium and sapwood. When they're healthy, the crown looks good. But that doesn't mean the tree is sound. Structural soundness is related to the condition of stem wood, branch attachments and anchoring roots.

Step 3. Estimate the Risk Rating for Each Tree

Use the severity levels found in this manual as *guidelines* when assessing trees. Remember, these are guidelines, no absolute rules can be made to cover the natural variability of trees and their defects. Although the list of defects and their combinations appears to be lengthy, it is not exhaustive. Inspectors need to use their judgment and local experience when evaluating and assessing tree defects.

All defective trees cannot be detected, corrected, or eliminated. To begin with, our knowledge of the trees is less than complete. Although we can readily recognize most defects and symptoms, there are root problems and some internal defects that are not easily discernable and may require in-depth inspections and the use of specialized diagnostic tools. Secondly, trees are masters at covering up problems and surviving. Defect severity can and does change with time. Whereas all defective trees cannot be detected, our aim is to find 80 percent or more of the defective trees with each inspection. By doing inspections and acting on them, we can successfully manage the risk of tree failure.

The U.S. Forest Service uses a 10-point numeric system to rate the risk of damage or injury posed by a defective tree or tree part. This numeric system provides communities with a management tool to help prioritize corrective treatments. Trees with the highest numeric risk ratings receive corrective treatment first. The total risk rating is equal to the numeric sum of three primary components, and under certain situations, an optional fourth component. See the formula below:

Risk Rating (3-10 points) = probability of failure (1-4 points) + size of defective part (1-3 points) + probability of target impact (1-3 points) + optional subjective risk rating (0-2 points)

The optional subjective risk rating is used if professional judgment suggests the need to increase the total risk rating and invoke immediate corrective action. For example, trees with a numeric risk rating of 9 or 10 would be identified as high priority trees to receive corrective treatments first. An inspector may wish to increase a tree's risk rating from 8 to 9 as a means of ensuring the tree will receive immediate corrective treatment. The total risk rating should not exceed 10 points.

Below is a discussion of the four components contained in the 10-point risk rating system:

Probability of failure: 1-4 points

1. Low: some minor defects present:
   - Minor branch/ crown dieback
   - Minor defects or wounds
2. Moderate: several moderate defects present:
   - Stem decay or cavity within safe shell limits: shell thickness > 1 inch of sound wood for each 6 inches of stem diameter
   - Crack(s) without extensive decay
   - Defect(s) affecting 30 to 40 percent of the tree's circumference
   - Crown damage/breakage: hardwoods up to 50 percent; pines up to 30 percent
   - Weak branch union: major branch or codominant stem has included bark
   - Stem girdling roots: <40 percent tree's circumference with compressed wood
   - Root damage: < 40 percent of roots damaged within the CRR
3. High: multiple or significant defects present:
   - Stem decay or cavity at or exceeding shell safety limits: shell thickness < 1 inch of sound wood for each 6 inches of stem diameter
   - Cracks, particularly those in contact with the soil or associated with other defects
   - Defect(s) affecting > 40 percent of the tree's circumference
   - Crown damage/breakage: hardwoods >50 percent; pines >30 percent

- Weak branch union with crack or decay
- Girdling roots with > 40 percent of tree's circumference with compressed wood
- Root damage: > 40 percent of roots damaged within the CRR
- Leaning tree with recent root breakage or soil mounding, crack or extensive decay
- Dead tree: standing dead without other significant defects

4. Extremely High: multiple and significant defects present; visual obstruction of traffic signs/lights or intersections:
    - Stem decay or cavity exceeding shell safety limits and severe crack
    - Cracks: when a stem or branch is split in half
    - Defect(s) affecting > 40 percent of the tree's circumference or CRR and extensive decay or crack(s)
    - Weak branch union with crack and decay
    - Leaning tree with recent root breakage or soil mounding and a crack or extensive decay
    - Dead branches: broken (hangers) or with a crack
    - Dead trees: standing dead with other defects such as cracks, hangers, extensive decay, or major root damage
    - Visual obstruction of traffic signs/lights or intersections
    - Physical obstruction of pedestrian or vehicular traffic

Size of defective part(s): 1-3 points

1. Parts less than 4 inches in diameter
2. Parts from 4 to 20 inches in diameter
3. Parts greater than 20 inches in diameter

Probability of target impact: 1-3 points

1. Occasional Use: Low use trails and roadways; parking lots adjacent to low use areas; natural or wilderness areas; transition or buffer areas with limited public use; industrial areas.

2. Intermediate Use: Moderate to low use school playgrounds, parks, and picnic areas; parking lots adjacent to moderate use areas; secondary roads and inter sections,(neighborhoods) and park trails within moderate to high use areas; and dispersed campgrounds.

3. Frequent Use: Emergency access routes, medical and emergency facilities and shelters, and handicap access areas; high use school playgrounds, parks, and picnic areas; bus stops; visitor centers, shelters, and park administrative buildings and residences; main thoroughfares and congested intersections in high use areas; parking lots adjacent to high use areas; interpretive signs, kiosks; scenic vistas; and campsites (particularly drive-in).

Other risk factors: 0-2 points

This category is to be used if professional judgment suggests the need to increase the risk rating and invoke immediate corrective actions. Total risk rating typically should not exceed 10 points. It is especially helpful to use when tree species growth characteristics become a factor in risk rating. For example, some tree species have growth patterns that make them more vulnerable to certain defects such as weak branch unions (silver maple) and branching shedding (beech species, *Fagus*).

Step 4. Prioritize Defective Trees for Treatment

The removal or immediate corrective treatment of high-risk trees must be a top priority within any tree risk management program. Trees with the highest numeric risk rating (10) should be treated first. Based on your community's policy, remove or treat defective trees starting with those rated as 10 and move down the list as financial and human resources allow.

Step 5. Conduct a Public Review Before Implementing Corrective Actions

Communication with community members and landowners is recommended before corrective actions are taken. If people are informed of the need for the corrective actions before the time they begin to see trees being removed or pruned, there will be clearer understanding and better community acceptance of why the actions are being taken.

Step 6. Take Corrective Action as Soon as Possible on the Highest Risk Trees

Once high risk trees are identified, action must be taken as soon as possible. Negligence may be assumed if a community identifies high risk and then takes no action. See Chapter 5 for more information about treating and correcting high-risk trees.

Step 7. Document the Process: Inspection Results, Actions Recommended and Actions Taken

Documentation should include recording the inspection dates, individual tree ratings and corrective actions recommended and then carried out. These are absolutely critical to keep on file. Document all ratings, including the low ratings, on the field sheets. Data may be taken during street tree inventories, hazard tree inventories, as reported by community personnel, etc. Use the forms supplied in this manual or create one that suits your needs. See Form 3: USDA community tree risk evaluation form and Form 4: Guide to risk rating codes. Maps are helpful and can be reused in subsequent years.

Form 3.3: USDA community tree risk evaluation form (*See Forms Section for full size form)*

USDA COMMUNITY TREE RISK EVALUATION FORM
Example Form *

Location:___________________ Date:________________ Inspector(s):_______________________

Tree #	Species	DBH	Location (Street Address)	Defect Code(s)	1 Probability of Failure	2 Size of Defective Part(s)	3 Probability of Target	4 Other Risk Factors (Optional)	Description of Other Risk Factors	Risk Rating (Sum of Columns 1-4)	Corrective Action Code(s)	Action Completed	
					1-4 pts	1-3 pts	1-3 pts	0-2 pts		3-12 pts		Date	Initials

* This is an *example* form adapted from various sources by the US Forest Service, Northeastern Area Hazard Tree Training Team. The US Forest Service assumes no responsibility for conclusions derived from the use of this form. Managers should construct their own forms, based on need and experience. Revised: 4/03

Form 3.4: Guide to codes for USDA community tree risk evaluation form

(See Forms Section for full size form)

Guide to Risk Rating Codes

(companion guide to the Community Tree Risk Evaluation Form)

PROBABILITY OF FAILURE: **1-4 points**

1. **Low:** some minor defects present:
   - minor branch/ crown dieback
   - minor defects or wounds
2. **Moderate:** several moderate defects present
   - stem decay or cavity within safe shell limits: shell thickness > 1 inch of sound wood for each 6 inches of stem diameter
   - crack(s) without extensive decay
   - defect(s) affecting 30-40% of the tree's circumference
   - crown damage/breakage: hardwoods up to 50%; pines up to 30%
   - weak branch union: major branch or codominant stem has included bark
   - stem girdling roots: <40% tree's circumference with compressed wood
   - root damage: < 40% of roots damaged within the CRR
3. **High:** multiple or significant defects present:
   - stem decay or cavity at or exceeding shell safety limits: shell thickness < 1 inch of sound wood for each 6 inches of stem diameter
   - cracks, particularly those in contact with the soil or associated with other defects
   - defect(s) affecting > 40% of the tree's circumference
   - crown damage/breakage: hardwoods >50%; pines >30%
   - weak branch union with crack or decay
   - girdling roots with > 40% of tree's circumference with compressed wood
   - root damage: > 40% of roots damaged within the CRR.
   - leaning tree with recent root breakage or soil mounding, crack or extensive decay
   - dead tree: standing dead **without** other significant defects
4. **Extremely High:** multiple **and** significant defects present; visual obstruction of traffic signs/lights or intersections:
   - stem decay or cavity exceeding shell safety limits **and** severe crack
   - cracks: when a stem or branch is split in half
   - defect(s) affecting > 40% of the tree's circumference or CRR **and** extensive decay or crack(s)
   - weak branch union with crack **and** decay
   - leaning tree with recent root breakage or soil mounding **and** a crack or extensive decay
   - dead branches: broken (hangers) or with a crack
   - dead trees: standing dead **with** other defects such as cracks, hangers, extensive decay, or major root damage
   - visual obstruction of traffic signs/lights or intersections
   - physical obstruction of pedestrian or vehicular traffic

SIZE OF DEFECTIVE PART(S): **1-3 points**

1. Parts less than **4** inches in diameter
2. Parts from **4 to 20** inches in diameter
3. Parts **greater than 20** inches in diameter

PROBABILITY OF TARGET IMPACT: **1-3 points**

1. **Occasional Use:**
   - low use roads and park trails; parking lots adjacent to low use areas; natural areas such as woods or riparian zones; transition areas with limited public use; industrial areas.
2. **Intermediate Use:**
   - moderate to low use school playgrounds, parks, and picnic areas; parking lots adjacent to moderate use areas; secondary roads (neighborhoods) and park trails within moderate to high use areas; and dispersed campgrounds.
3. **Frequent Use:**
   - emergency access routes, medical and emergency facilities and shelters, and handicap access areas; high use school playgrounds, parks, and picnic areas; bus stops; visitor centers, shelters, and park administrative buildings and residences; main thoroughfares and congested intersections in high use areas; parking lots adjacent to high use areas; interpretive signs, kiosks; scenic vistas; and campsites (particularly drive-in).

OTHER RISK FACTORS: **0-2 points**

- This category can be used if professional judgment suggests the need to increase the risk rating.
- It is especially helpful to use when tree species growth characteristics become a factor in risk rating. For example, some tree species have growth patterns that make them more vulnerable to certain defects such as weak branch unions (silver maple) and branching shedding (beech).
- It can also be used if the tree is likely to fail before the next scheduled risk inspection.

Table 1. Defect Codes

Code	Defect
D	Decay
CR	CRack
Root	Root Problems
RSG	Stem Girdling
RS	Severed
RPD	Planting Depth (too deep)
RGC	Grade Change
RSB	Sidewalk Buckling
WBU	Weak Branch Union
CA	CAnker
PTA	Poor Tree Architecture
PTA:LT	Leaning Tree
PTA:TT	Topped Tree
EE	Excessive Epicormics
DEAD	DEAD tree, tops or branches
VO	Visible Obstruction
PO	Physical Obstruction

Table 2. Corrective Action(s) Codes

Prune	
PD	Deadwood
PW	Weakwood (defective part(s))
PC	for Clearance
PT	to Thin crown or reduce crown weight
PR	to Reduce crown height
Target	
TM	Move
TEV	Exclude Visitors from Target Area
CB	Cable/Bracing
CWT	Convert to Wildlife Tree
RT	Remove Tree
Monitor	Monitor regularly
NA	No Action Required

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Forms Section

This section contains the following full-size versions of the forms that were discussed in this chapter.

Form 3.1 - Defective Trees Risk Management Guidelines
Form 3.2 - Hazard Tree Inspection Form
Form 3.3 - USDA Community Tree Risk Evaluation Form
Form 3.4 - Guide Codes for the USDA Community Trees Evaluation Form

Defective trees: Risk assessment guidelines

Tree defects	Moderate risk of failure	High risk of failure
Decay = Wood that has rotted or is missing. Indicators of advanced decay are rotten wood, fungal fruiting bodies, cavities, holes, open cracks or bulges in the wood.	• Indicators of advanced decay are found on 25% to 40% of the circumference of any stem, branch or root collar. • Shell thickness is >1 and < 2 inches of sound wood for each 6 inches of stem diameter and stem has opening < 30% of stem circumference.	• Indicators of advanced decay are found on ≥ 40% of the circumference of any stem, branch or root collar. *Note: In order to verify the extent of decay, you may want to use probes or drills to determine shell thickness.* • Stem has advanced decay and the shell thickness meets the following criteria: • Shell thickness < 1 inch of sound wood for each 6 inches of stem diameter, or, • Stem has an opening ≥ 30% of the stem circumference and shell thickness is ≤ 2 inches of sound wood for each 6 inches of stem diameter. • Any large branch with decay.
Crack = crack is a separation of the wood ; a split through the bark into the wood.	• Stem has a single crack and decay.	• Stem is split in two by a crack. • Stem segment has multiple cracks and decay. • Branch has a crack.
Root problems = inadequate anchoring by the root system, damaged roots or stem girdling roots.	• Roots within the area defined by the Critical Root Radius are ≤ 40% damaged, decayed, severed, or dead.	• Leaning tree with recent evidence of root lifting, soil movement or soil mounding. • Roots within the Critical Root Radius are ≥ 40% damaged, decayed, severed, or dead. • Girdling roots constrict ≥ 40% of the root collar.
Weak branch union = An epicormic branch or a branch union with included bark.	• Branch union has included bark.	• Weak union is also cracked, cankered or decayed. • Large epicormic branch on decaying stem.
Canker = An area where bark and cambium are dead.	• Canker or canker plus decay affect 25% to 40% of the tree's circumference.	• Canker affects ≥ 40% of the tree's circumference. • Canker plus decay affect ≥ 40% of the tree's circumference.
Poor architecture = growth pattern indicates structural imbalance or weakness in the branch, stem or tree.	• Branch has a sharp bend or twist. • Large, horizontal branch with several vertical branches on it.	• Tree with excessive lean (> 40°). • Leaning tree has a crack in stem. • Leaning tree has canker or decay on the lower stem. • Leaning tree has a horizontal crack on the upper side of the lean and/ or buckling bark and wood on the lower side.
Dead wood = A dead tree or dead branches.		• Any lodged branch. • Any dead tree, tree top or branch.

Defects : Defects are visible signs that a tree is failing or has the potential to fail. Defects predispose a tree to fail at the location of the defects.

Defective tree : A tree with one or more defects.

Risk of failure : Risk of tree or branch failure can be predicted because defects indicate which part of the tree is structurally the weakest. Since defect severity can change, the tree's risk of failure can change over time.

Moderate risk of failure : Currently, the tree's defects do not meet the threshold for failure. The defects may or may not result in eventual tree failure. "Moderate risk" trees need to be closely monitored to determine if the defects have changed since the last inspection.

High risk of failure : Currently, these defects indicate that the tree is in imminent danger of failing or has already partially failed. Corrective action should be taken as soon as possible.

Risk management : These guidelines are intended to provide the information needed to evaluate the failure potential of inspected trees. They are only guidelines. Absolute rules can not be made because of the natural variability of trees and their defects. ***All of the defective trees can not be detected, corrected or eliminated.*** However, by doing inspections and acting on them, we can successfully manage the risk of tree failure.

Inspections : Be systematic and complete. Inspect annually, except where policy indicates otherwise. Additional inspections should be done after severe storm events. Common sense, experience and professional judgment are required of the trained tree inspector.

Tree species, age, size and condition : These all play a role in the type, extent and severity of defects. Certain species are consistently prone to certain defects. Old trees tend to have more defects. Trees in good condition have the capacity to create more wood which can reduce the severity of some defects over a period of years.

Exposure and crown size : Open-grown trees with full crowns have a higher exposure to winds than trees growing in groups or stands. Recent change in wind exposure or crown size can affect the severity of defects.

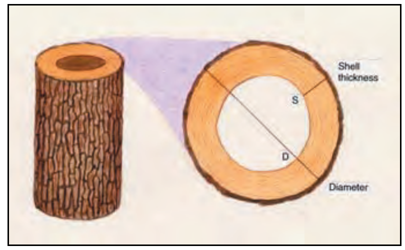
Documentation : ALWAYS document inspections and actions. Use a form that records inspection date, tree species, tree location, defects and their severity, recommended actions, action taken and date. It's helpful to map the area. Remember to document the "Low Risk" trees.

Treatment : Correcting defective trees can be as creative as your imagination and resources allow. Treatments include: moving the target, rerouting traffic, closing off or fencing off the site, pruning the defective branches, reducing the crown weight/ exposure and, ultimately, removing the tree.

Epicormic branch : Epicormic branches are new, younger branches that replaced injured, pruned or declining branches. They form weak unions because they are not attached all the way to the center of the stem.

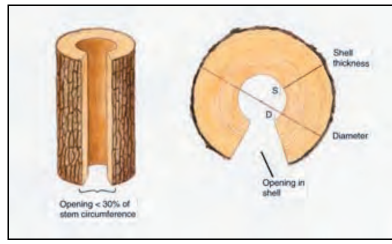
Decay : Decay is generally limited to the column of wood present at the time of wounding. Measure shell thickness to determine if enough sound wood remains to support the tree. The risk of failure increases when decay columns expand into the new wood because there is no sound shell of wood near those defects. Continuously expanding columns of decay are the result of inrolled cracks (rams-horning), girdling roots and canker-rot infections.

Minimum amount of sound wood in shell needed:



Need 1" of sound shell for each 6" of diameter	
Stem Diameter	Shell thickness
6"	1"
12	2
18	3
24	4

For stem without openings or cracks.

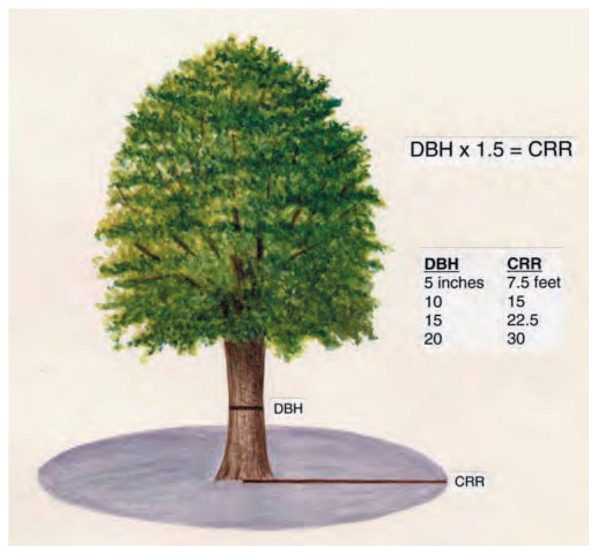


Need 2"of sound shell for each 6" of diameter	
Stem Diameter	Shell thickness
6"	2"
12	4
16	6
24	8

For stem with openings < 30% of stem circumference.

Critical root radius : The CRR is used to define the portion of the root system nearest the stem that is critical for stability and vitality of the tree. This area is usually <u>beyond</u> the dripline of the tree. The radius of this circular area is defined as

CRR (in feet) = DBH x 1.5.



MINNESOTA
Department of
Natural
Resources

HAZARD TREE INSPECTION FORM

MAP

Unit ____________________

Subunit ____________________

Inspectors ____________________

____

____

Date ____________________

Remarks ____________________

____

____

____

Tree location or map number	Tree species	Defect(s)	Hazard potential H or M	Remarks	Recommended action	Action taken/date

Local Manager ____________________ Date ____________________

Source: MN DNR

USDA COMMUNITY TREE RISK EVALUATION FORM

Example Form *

Location:____________________ Date:_________________ Inspector(s):_________________________

Tree #	Species	DBH	Location (Street Address)	Defect Code(s)	1 Probability of Failure	2 Size of Defective Part(s)	3 Probability of Target	4 Other Risk Factors (Optional)	Description of Other Risk Factors	Risk Rating (Sum of Columns 1-4)	Corrective Action Code(s)	Action Completed	
					1-4 pts	1-3 pts	1-3 pts	0-2 pts		3-12 pts		Date	Initials

* This is an *example* form adapted from various sources by the US Forest Service, Northeastern Area Hazard Tree Training Team. The US Forest Service assumes no responsibility for conclusions derived from the use of this form. Managers should construct their own forms, based on need and experience.

Revised: 4/03

Guide to Risk Rating Codes

(companion guide to the Community Tree Risk Evaluation Form)

PROBABILITY OF FAILURE: **1-4 points**

1. **Low:** some minor defects present:
   - minor branch/ crown dieback
   - minor defects or wounds

2. **Moderate:** several moderate defects present
   - stem decay or cavity within safe shell limits: shell thickness > 1 inch of sound wood for each 6 inches of stem diameter
   - crack(s) without extensive decay
   - defect(s) affecting 30-40% of the tree's circumference
   - crown damage/breakage: hardwoods up to 50%; pines up to 30%
   - weak branch union: major branch or codominant stem has included bark
   - stem girdling roots: <40% tree's circumference with compressed wood
   - root damage: < 40% of roots damaged within the CRR

3. **High:** multiple or significant defects present:
   - stem decay or cavity at or exceeding shell safety limits: shell thickness < 1 inch of sound wood for each 6 inches of stem diameter
   - cracks, particularly those in contact with the soil or associated with other defects
   - defect(s) affecting > 40% of the tree's circumference
   - crown damage/breakage: hardwoods >50%; pines >30%
   - weak branch union with crack or decay
   - girdling roots with > 40% of tree's circumference with compressed wood
   - root damage: > 40% of roots damaged within the CRR.
   - leaning tree with recent root breakage or soil mounding, crack or extensive decay
   - dead tree: standing dead **without** other significant defects

4. **Extremely High:** multiple **and** significant defects present; visual obstruction of traffic signs/lights or intersections:

   - stem decay or cavity exceeding shell safety limits **and** severe crack
   - cracks: when a stem or branch is split in half
   - defect(s) affecting > 40% of the tree's circumference or CRR **and** extensive decay or crack(s)
   - weak branch union with crack **and** decay
   - leaning tree with recent root breakage or soil mounding **and** a crack or extensive decay
   - dead branches: broken (hangers) or with a crack
   - dead trees: standing dead **with** other defects such as cracks, hangers, extensive decay, or major root damage
   - visual obstruction of traffic signs/lights or intersections
   - physical obstruction of pedestrian or vehicular traffic

SIZE OF DEFECTIVE PART(S): **1-3 points**

1. Parts less than **4** inches in diameter
2. Parts from **4 to 20** inches in diameter
3. Parts **greater than 20** inches in diameter

PROBABILITY OF TARGET IMPACT: **1-3 points**

1. **Occasional Use:**
   - low use roads and park trails; parking lots adjacent to low use areas; natural areas such as woods or riparian zones; transition areas with limited public use; industrial areas.

2. **Intermediate Use:**
   - moderate to low use school playgrounds, parks, and picnic areas; parking lots adjacent to moderate use areas; secondary roads (neighborhoods) and park trails within moderate to high use areas; and dispersed campgrounds.

3. **Frequent Use:**
   - emergency access routes, medical and emergency facilities and shelters, and handicap access areas; high use school playgrounds, parks, and picnic areas; bus stops; visitor centers, shelters, and park administrative buildings and residences; main thoroughfares and congested intersections in high use areas; parking lots adjacent to high use areas; interpretive signs, kiosks; scenic vistas; and campsites (particularly drive-in).

OTHER RISK FACTORS: **0-2 points**

- This category can be used if professional judgment suggests the need to increase the risk rating.

- It is especially helpful to use when tree species growth characteristics become a factor in risk rating. For example, some tree species have growth patterns that make them more vulnerable to certain defects such as weak branch unions (silver maple) and branching shedding (beech).

- It can also be used if the tree is likely to fail before the next scheduled risk inspection.

Table 1. Defect Codes

Code	*Defect*
D	**D**ecay
CR	**CR**ack
Root	**R**oot **P**roblems
RSG	**S**tem **G**irdling
RS	**S**evered
RPD	**P**lanting **D**epth (too deep)
RGC	**G**rade **C**hange
RSB	**S**idewalk **B**uckling
WBU	**W**eak **B**ranch **U**nion
CA	**CA**nker
PTA	**P**oor **T**ree **A**rchitecture
PTA:LT	**L**eaning **T**ree
PTA:TT	**T**opped **T**ree
EE	**E**xcessive **E**picormics
DEAD	**DEAD** tree, tops or branches
VO	**V**isible **O**bstruction
PO	**P**hysical **O**bstruction

Table 2. Corrective Action(s) Codes

Code	Action
Prune	
PD	**D**eadwood
PW	**W**eakwood (defective part(s))
PC	for **C**learance
PT	to **T**hin crown or reduce crown weight
PR	to **R**educe crown height
Target	
TM	**M**ove
TEV	**E**xclude **V**isitors from Target Area
CB	**C**able/**B**racing
CWT	**C**onvert to **W**ildlife **T**ree
RT	**R**emove **T**ree
Monitor	**M**onitor regularly
NA	**N**o **A**ction Required

Prevention of Hazardous Tree Defects

By Gary R. Johnson, Richard J. Hauer, and Jill D. Pokorny

Introduction

The fundamental goal of tree risk management is to prevent development of hazardous tree defects and reduce the risks hazardous trees pose to public safety. Development of many hazardous defects in trees can be prevented through effective planning, and the implementation of sound arboricultural practices. Post-storm tree damage surveys document that appropriate species composition, and proper planting and maintenance practices can help prevent the formation of many structural defects that predispose trees to branch and stem failures. (Dempsey 1994, Johnson 1999). This chapter discusses how communities can prevent development of many hazardous tree defects through effective streetscape planning and design. Designing a species-diverse, uneven-aged forest, matching tree species to site conditions, purchasing high quality nursery stock, implementing proper planting and pruning techniques, and protecting trees from construction damage help to promote healthy trees and reduce development of hazardous tree defects.

Designing a Species-Diverse, Uneven-Aged Urban Forest

When many of our older cities were established, there were initially few large trees present. Tree planting programs lined the streets of many communities with avenues of even-aged trees all of the same species. While these planting programs eventually resulted in aesthetically beautiful tree-lined boulevards, this practice led to problems that eventually convinced arborists that this practice should be avoided. The vulnerability of an urban forest to insect and disease outbreaks is much higher where a single species of tree dominates the landscape. This problem was dramatically illustrated during the Dutch elm disease epidemic that altered forever the character of so many eastern city streets.

As many of the avenue trees planted in the early 20th century are rapidly approaching the end of their normal lifespan in an urban setting, urban forest managers have an opportunity to develop a well-designed, species-diverse, uneven-aged management system. In such a system, replacement trees are of varying species with different life expectancies. While this system will not recreate the avenues of majestic single-species canopies of eras past, it will help to provide sustainable tree cover over a large part of the urban landscape. Even in those communities where trees are somewhat haphazardly replanted as they die, the result will be an unavoidable shift from an even-aged management system towards a more sustainable species-diverse, uneven-aged management system.

Matching Tree Species to Site Conditions

Tree species vary in their nutritional, water, and light requirements, and in their resistance to environmental and chemical extremes. Match tree species to each site by considering both the silvical characteristics (requirements) of the tree, and the conditions of the site. The Silvics Manual of North America, volumes 1 (conifers) and 2 (hardwoods) are excellent sources of information on plant/site requirements (Burns and Honkala 1990). Both publications are available through the publications link on the following website: http://www.na.fs.fed.us/spfo.

Site Characteristics that Affect Tree Species Selection

When choosing a species to fit a site, consider soil and light conditions; exposure to sun, wind, ice, snow, and de-icing salt; space limitations (both above and below ground); and human use of the site. Soil conditions, especially in urban areas, often drive tree species selection. In addition to the site factors listed above, trees in areas that are converted from woodland to urban through new construction require specific consideration. Each site characteristic is described below in more detail.

Soil pH

Apply soil and percolation tests to all potential planting sites. Soil texture and pH test results will provide the most valuable information for tree selection. Trees that require loose and organic soil should not be planted on sites that are primarily compacted, heavy clay soils. Always plant trees that perform best on neutral to alkaline soils on sites with soil pH levels greater than 7.2. Trees that perform better than others on neutral to alkaline soils include hackberry (*Celtis*), basswood (*Tilia*), ginkgo (*Ginkgo biloba*), and most crabapple species (*Malus*).

Soil Compaction

Compaction can be measured with a penetrometer, a field instrument that measures the pressure required to push a probe through the soil to various depths. Compaction can also be approximated with a digging spade. If a shovel can easily penetrate the soil to a depth of two spade blade lengths, compaction is not limiting. If the shovel requires a person to jump on it and provide weight to penetrate the soil, compaction may limit certain species. If a pick-axe is required to break the ground and dig the planting hole, compaction will be severely limiting to all but a few (mostly undesirable) tree species.

Soil compaction problems can be minimized by site preparation and plant selection. Often, trees that perform well in wet areas do better than others in compacted, clayey soils since potential oxygen limitation is similar in both environments. Chisel tooth plowing or otherwise fracturing the soil prior to planting creates loosened avenues for tree roots to expand. This advantage may be relatively short-lived and limited in relationship to the entire compacted site, but it does allow the tree to recover from transplant shock and become adjusted to the harsh site.

Soil Drainage

Percolation rates are likewise relatively easy to determine. Dig a hole in the planting area to a depth of 24 inches. Fill the hole with water and allow it to completely drain. Fill the hole with water a second time. If the hole drains within a couple of minutes, choose trees that survive in drier sites, such as coffeetree (*Gymnocladus dioicus*), corktree (*Phellodendron*), and elm (*Ulmus*), or surface mulch the area to build up an organic layer and conserve moisture. If the hole drains completely within 24 hours, the soil is suitable for most tree species. If the hole takes several days to completely drain (or never drains), plant only trees that survive in waterlogged conditions. Alder (*Alnus*), willow (*Salix*), tamarack (*Larix laricina*), and black ash (*Fraxinus nigra*) are all suitable for wet sites.

Urbanized soils are often altered significantly from their native condition.

The chemical, physical, and biological changes listed below all affect tree species selection.

Chemical Changes

- Increased soil pH
- Reduced nutrient recycling
- Increased soil pollutants (heavy metals, de-icing salts)

Physical Changes

- More shallow soil profile
- Reduced organic matter content
- Increased concentration of buried debris (asphalt, concrete, etc.)
- Reduced percolation rate (soil drainage)
- Reduced oxygen concentration due to soil compaction

Biological Changes

- Increased competition by turf grasses, such as Kentucky bluegrass
- Reduced numbers of symbiotic microorganisms (mycorrhizal fungi, bacteria, and actinomycetes)
- Increased numbers of opportunistic pathogens and insect pests

Low Light Situations

Canyons are commonly found in urban areas, most commonly in larger cities with tall buildings. Trees planted in these areas must be able to thrive in low-light situations. Often, trees that naturally occur as understory trees are better choices for these sites. For example, redbud (*Ceris spp.*), ironwood (*Ostrya virginiana*), hemlock (*Tsuga*), and bladdernut (*Staphylea*) thrive in low-light situations.

Exposure to Sun and Wind

Exposure to sun and wind can limit tree selection choices and tree health. Sites that are fully exposed tend to dry out faster, heat up faster, and make it harder for trees to establish and thrive. Sites that are fully exposed to wind can further compound these problems. Trees that are native to prairies, exposed outcroppings, or savannas, such as honeylocust (*Gleditsia*), hawthorn (*Crataegus*), spruce (*Picea*), and bur oak (*Quercus macrocarpa*), would be better choices than trees that are native to shaded, organic-rich forest situations.

Susceptibility to Ice, Snow, and Wind Damage

Trees vary in their susceptibility to ice, snow, and wind storms (Table 4.1). In general, trees fail when their ability to withstand loading events from storms is surpassed. Wood strength has been suggested as a primary determinant of tree susceptibility to storms. While wood strength is important, other factors, including leaf morphology, canopy density, tree architecture, decay susceptibility, included bark, and rooting patterns, also determine storm resistance in trees.

Table 4.1 *The ice storm susceptibility of tree species commonly planted in urban areas.*

Susceptible	Intermediate	Resistant
American elm	Bur oak	American Sweetgum
American linden	Eastern white pine	Arborvitae
Black cherry	Northern red oak	Baldcypress
Black locust	Red maple	Black walnut
Bradford pear	Sugar maple	Blue beech
Common hackberry	Sycamore	Catalpa
Green ash	Tuliptree	Eastern hemlock
Honeylocust	White ash	Ginkgo
Pin oak		Ironwood
Siberian elm		Kentucky coffeetree
Silver maple		Littleleaf linden

partially adapted from Hauer et al (1993)

De-icing Salt Damage

In many areas of the northern tier states, de-icing salt spray drift is a major limiting site factor. Trees that are located within 60 feet of an arterial street or highway that support 10,000 or more vehicles per day are particularly vulnerable to de-icing salt spray damage (Johnson and Sucoff 1995). De-icing salt spray places significant stress on trees, even if it does not always kill the tree. Typically, trees within the spray zone area become disfigured and generally unhealthy (e.g., poor growth rate, scorched, or lost foliage) and are more vulnerable to secondary problems and decay. De-icing salts can accumulate in the soil, and cause trees to exhibit foliar symptoms induced by excess sodium and chlorine levels, and leaf scorch due to reduced uptake and translocation of water within the tree. If trees are to be planted in areas where de-icing salts are a limiting site factor, only use tree species that are tolerant to salt injury. Black alder (*Alnus glutinosa*), white ash (*Fraxinus americana*), Japanese tree lilac (*Syringa reticulata*), and Norway maple (*Acer platanoides*) would be suitable for these sites (Johnson and Sucoff 1995).

Human Use of the Area

No matter where the planting site is (e.g., residential, park, tree lawn, sidewalk, or plaza), consider how the area will be used. Human activities have long-term effects on tree condition and health. Unintentional wounding and landscape management practices are the most notable causes of damage.

Trees in tree lawns, plazas, and parks are particularly susceptible to wounding by unintentional vandalism. Car doors and bumpers wound stems, signs are nailed or stapled to public trees, and branches are broken when children climb trees. Locate trees far enough away from curbs, sidewalks, and intersections (i.e., areas where traffic is concentrated) to reduce chances of wounding. Do not use species that are notoriously poor compartmentalizers (e.g., beech (*Fagus*), red maple (*Acer rubrum*), silver maple (*Acer saccharinum)*, hackberry (*Celtis*), red oak (*Quercus rubra*), and many poplars (*Populus*) in areas where wounding is likely. Avoid the use of low-branched species where climbing and subsequent wounding is likely. Although low-branched species can be pruned to raise their canopies, the frequent pruning required to remove lower branches only adds to the amount of wounding and the maintenance care such trees receive.

Figure 4.1. *Lawn mower and string trimmer damage caused by mechanical injury and subsequent decay at the base of the tree.*

All trees are vulnerable to wounding where turf grass is allowed to grow up to the stems. Invariably, lawn mowers and string trimmers will wound the base of these trees repeatedly (Figure 4.1). If for no other reason, all trees should have a mulched area around their stems to prevent the need for trimming grass away.

Sites that are characterized by clay soils can become particularly vulnerable to foot traffic compaction if the activities in the area are frequent and well attended. State parks, picnic areas, fairgrounds, school-yards all have the potential of many feet compacting clay soils. Although this does not normally result in direct damage to trees, it indirectly weakens trees by adversely changing soil moisture and oxygen availability, and reduces the ability of trees to recover from wounds and other site stresses or attacks from insects and diseases.

Planting trees in groupings rather than as specimens can reduce the site stresses that weaken individual trees. Especially where groupings are mulched or understory planted, the trees are much less susceptible to unintentional vandalism, soil, and exposure stresses. The beauty of the planting becomes more important than the beauty of the individual trees.

Space Limitations

The most common space-limiting sites are the areas that occur between street curbs and sidewalks (e.g., tree lawns, boulevards, parkways, or medians), sidewalk planting pits, and plazas. Tree lawns usually offer the most confining situations for trees: limited root volumes, limited canopy width, greatest minimum height to the first set of branches (if over hanging an arterial street), and limits to height (if above-ground utilities are present). Other variables that further limit the success of a tree in a tree lawn include de-icing salt spray or deposits in the soil, buried utility lines within the rooting area, and highly altered soils.

Tree lawns must be at least 10 feet in width to support a large tree through maturity at an accepted level of risk to public safety. Large trees (>60 feet in height) are more prone to windthrow during wind loading events. This becomes more of a problem when the inevitable root cutting takes place during installation or repair of streets, sidewalks, curbs, and buried utilities (Figure 4.2). The problem is further compounded if the trees in question have dense canopies, which offer significant resistance to wind and make the already unstable trees even more likely to fail.

Plant small- and medium-sized trees in tree lawns that are less than 10 feet wide. The rooting volume afforded by tree lawns less than 10 feet in width is more in scale with supporting the growth of small- to medium-sized trees. In these narrow planting spaces, tree species with smaller crowns and root systems are the best planting choices. Examples of trees suitable for these sites include crabapple (*Malus*), hawthorn (*Crataegus)*, ironwood (*Ostrya virginiana)*, silverbell (*Halesia*), and water-ash (*Ptelea*). These trees are more likely to be healthier in these root-limited environments, and therefore better able to recover from both above and below ground wounding. They will also compartmentalize wounds more effectively and limit the amount of potential wood decay.

Figure 4.2. *Tree with excessive root severing caused by curb and sidewalk reconstruction damage. Root severing can compromise the structure of a sound, healthy tree and increase its susceptibility to windthrow during wind loading events.*

Small- to medium-sized trees also create fewer problems with above ground utility line conflicts. For example, tree species that do not exceed 30 feet in height at maturity are the best choices for locations with overhead wires.

Trees planted in tree lawns should also have a growth form that allows them to be pruned up to a height that allows pedestrian and vehicular traffic to safely pass under their branches. Further, species that do not require excessive amounts of pruning to maintain a safe height of the lowest branches are the best choices. Trees that require excessive pruning are likely to be poorly maintained. Even if the trees are regularly maintained, the frequent pruning operations will create excessive amounts of pruning wounds and increase the potential for wood decay problems to develop.

Do not plant trees where conditions exist that prevent the use of smaller trees (e.g., deicing salt spray, truck traffic that limits the height of the lowest branches to 12 to 14 feet above ground). If trees must be planted in these areas, they should be planted on the property-side of the public sidewalk. Planting on the property-side of the sidewalk may require that the community pass a “green easement” ordinance, and develop a memorandum of understanding regarding tree maintenance with the property owner. Alternatively, tree lawns can be designed so that they are greater than 10 feet in width. This design approach will greatly reduce the incidence of tree roots causing sidewalk buckling or curb damage. Reciprocally, if sidewalk or curb repair is needed, damage to tree roots will be reduced in larger sized tree lawns, and tree mortality or growth rates should not be adversely affected.

Sidewalk and plaza planting pits may present the same limitations on tree selection that tree lawns do, but normally they are most restrictive in terms of rooting volume. Generous planting pits are 5 feet square by 3 feet deep, providing only 75 cubic feet of rooting volume. A healthy small- to medium-sized tree requires 300 to 1,000 cubic feet of rooting volume to reach maturity (Urban, 1992). Planting pits must provide adequate soil drainage to sustain tree health. If larger planting pits cannot be incorporated into current streetscape planning and design, consider fewer but larger planting islands. These islands would have a larger volume of soil that could successfully support a group (copse) of trees that would share the larger rooting volume. Structural soils are also an option to increase soil rooting volume in downtown and parking lot situations. Structural soils are a combination of crushed stone, clay loam, and hydrogel (a copolymer that helps hold the stone and loam together) that can be used under pavement such as sidewalks (Bassuk et al. 1997). These soils allow for suitable compaction under sidewalks while still providing a root-friendly environment.

Sidewalk or plaza trees also need to be tall enough that the lowest branches can be removed to allow pedestrians safe passage under them, usually a minimum of 8 feet above ground. Island plantings, especially if the planting is slightly elevated, reduce the need for pruning all trees in the group. Only the edge trees would require elevation pruning (pruning for clearance).

As discussed, the presence of overhead utility wires and limited space for planting sites are two common factors that restrict the choices of tree species that are suitable for use in community tree planting programs. A publication entitled Compatible Tree Factsheets for Electric Lines and Restricted Spaces compiles information that will aid communities in the selection of trees for planting sites under electric wires, in narrow tree lawns, and other places where small crowns and root systems are advantageous (Gerhold et al. 2001). This publication focuses on tree species suitable for planting in USDA Hardiness Zones 3-6. It is available from the Municipal Tree Restoration Program at 109 Ferguson Building, The Pennsylvania State University, University Park, PA 16802.

Park trees generally experience fewer pressures resulting from space restrictions. Parks are the best location for large trees since the rooting volumes are not limited and utility lines are rare. The most common space restriction in parks is the distance from the ground to the first set of branches. Trees selected for planting in parks should be species that mature to a height that proportionately allows the lower branches to be pruned up to provide human traffic clearance (minimum of 8 feet), or unrestricted light diffusion from street/park security lights (usually, at least 12 feet above ground).

Urbanization of Woodlands

Forest trees that have been in relatively protected and undisturbed environments for all of their lives become very vulnerable to exposure when these forests are urbanized, that is, when residential or commercial subdivisions are built in or around the forests. Suddenly, the trees that were once protected from wind and sun are exposed, in particular those that have now become edge species. Typically, these trees are tall and slender, with very high canopies and very shallow root systems, and are more prone to windthrow.

Roots of the new edge species are commonly lost during development of wooded areas, either directly through cutting, or indirectly through exposure, loss of soil moisture, and subsequent death of the shallow network of supportive, fine roots. As a result, they become less stable and more vulnerable to winds and windthrow. In addition, they produce more dead wood in the canopies as a result of defensive dieback in reaction to the root loss and death. So even if they are able to remain vertical despite the increasing wind loads, they often produce a significant amount of deadwood high in the canopies that presents a threat to people and structures below.

Root loss can be prevented during the design stages of woodland development by avoiding injury to the critical root area of the edge trees, or at the very least, by not cutting any roots within the dripline. Construction activities should be avoided within the CRR (Figure 4.3) to ensure the tree's root zone is adequately protected.

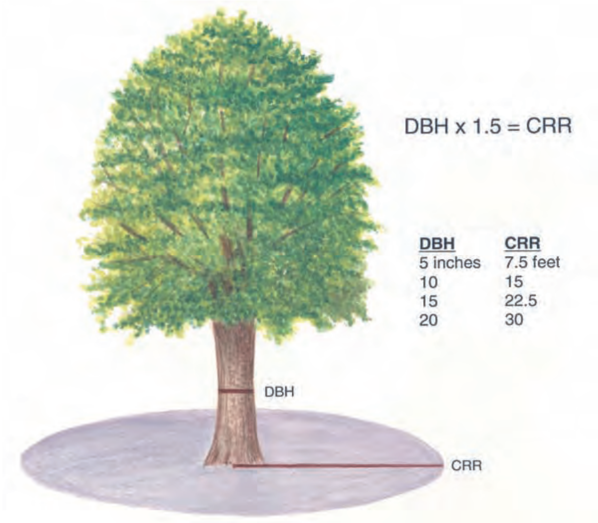


Figure 4.3. *Critical Root Radius (CCR) and critical rooting area.*

Indirect root death as a result of forest floor exposure to wind and sun can be minimized by keeping the area mulched with an organic mulch, irrigating during and after construction activities, and underplanting the areas where sun and wind are more pervasive. Understory shrubs and small trees will help reduce the amount of drying wind and sunlight that reach the forest floor, that area where the shallow, fine roots proliferate. Under no circumstances should the forest floor be "cleaned up" and converted to a competitive, turf grass groundcover.

Purchasing High Quality Nursery Stock

Just as it is important to select the right trees for the right places, it is equally as important that the trees selected for planting are of high quality. Planting unthrifty planting stock is money wasted, and sets the stage for future tree health problems and unsuccessful streetscape designs. Communities that invest in high quality trees and proper planting and maintenance practices will enjoy the benefits of a tree resource that increases in aesthetic and economic value, possesses fewer hazardous defects, and lives longer.

What Determines Tree Quality?

Industry standards for nursery stock have been established by the American Association of Nurserymen and are published in the American Standard for Nursery Stock, ANSI Z60.1 (ANSI 1996). These standards cite height/caliper relationships for shade trees, and a recommended minimum root ball size based on tree caliper. These standards were established to help ensure that nursery stock would have enough sound roots present to support healthy tree growth. Community program managers responsible for community tree planting should be familiar with these industry standards. Implementation of these standards is voluntary, and communities may opt to establish their own set of standards. A copy of The ANSI Z60.1 standards can be purchased from the American Nursery & Landscape Association, 1250 I Street NW, Suite 500, Washington D.C. 20005-3922 or through their publications/general business link at http://www.anla.org.

When communities purchase trees for planting along streets or sidewalks, quality specifications are different than those for trees used in other landscape situations. For example, street trees should have a single, straight trunk that is free of branches to a height where limbs will not obstruct pedestrian or vehicle traffic or block the line of sight to traffic signs and lights. Municipal buyers should ensure that bidding specifications state the height to which the tree should be free of branching, at the time of planting. Specifications will vary according to individual community bidding guidelines, however, a height of 6 to 8 feet is commonly cited. If the community is able to perform frequent pruning (every 3 years), pruning up at the time of planting can be delayed. If low-branched trees are planted, tree establishment and growth is improved, stem taper is increased, and trees require staking less frequently, however, the community must have in place a follow-up pruning schedule to raise the crown over time.

Here are some tree quality characteristics that communities should look for when purchasing nursery stock for tree planting operations:

Figure 4.4. *Avoid purchasing nursery stock with codominant leaders (more than one leader), or select stock that can be successfully pruned back to a single leader. Even though these branch attachments are not weak, this codominance began 3 feet above ground, far too low for a tree that will mature to 40 to 50 feet in height.*

- Single, straight trunk that is free of branches below 6 to 8 feet (for trees to be planted within a few feet of a sidewalk or street)
- A strong form with well-spaced, firmly attached branches
- A trunk free of stem defects such as mechanical wounds, flush cut pruning wounds, cankers, insect injuries, or cracks
- Adequate root ball/container/root spread size in relation to tree caliper see American Standard for Nursery Stock, ANSI Z60.1)

Inspect Nursery Stock to Verify Quality

Retain the right to inspect trees at the time of delivery and reject those that fail to meet stated specifications. Consider rejecting trees with the following problems:

Figure 4.5. *Branch with included bark that failed and caused extensive damage to the stem.*

- **Trees with double or multiple leaders:** Trees with double or multiple leaders and included bark in the attachments have an increased likelihood of stem failure, and often suffer the greatest damage during and after storm events (Figure 4.4).
- **Trees with weak branch unions (e.g., narrow, V-shaped) and included bark in branch unions:** Branches with included bark in their attachments are always weak and are one of the primary causes of branch failure. If they are not pruned out when the branches are small, even minor thunderstorm loading events can

cause premature failure of branches with included bark and extensive damage to the stem (Figure 4.5). Two types of branch attachments are shown in Figure 4.6: The branch attachment to the left is strong and the branch attachment to the right is weak, with included bark.

Figure 4.6. *The branch attachment to the left is strong, with the branch bark ridge pushing up. The attachment to the right is weak, with extensive included bark. This attachment (to the right) targets the branch that should be removed.*

- **Trees with defects on the main stem:** Common stem defects include mechanical injuries, flush cut pruning wounds, cankers, insect injuries, or cracks (Figure 4.7). Tree wraps can conceal stem defects, so remove tree wraps to inspect the trunk.

Figure 4.7. *Don't buy this plant! That wound on the stem is extensive and decay has already entered the wood. Even if the wound is sealed by new wood, the stem wood can continue to discolor and decay.*

- **Trees with serious root related problems:** Such problems may predispose trees to opportunistic root pathogens or the development of stem girdling roots. Examples include:

    - Balled-and-burlapped and tree-spaded trees with root collars that are deeply buried within the root ball (> than 4 inches). With balled and burlapped plants that are buried too deeply in the soil ball, there are two problems: 1) the risk that they will be planted too deeply in the landscape which may lead to development of stem girdling roots, and 2) the limited amount of roots that may be in the soil ball (Figure 4.8).

Figure 4.8. *This hackberry was buried by 12 inches of soil in the soil ball, and had very few roots to support the tree after the excess soil was removed.*

The location of the root collar can be determined by inserting a steel wire (coat hanger gauge) or metal probe into the root ball (at several points) and measuring the depth at which the first primary root(s) attach to the stem (Figure 4.9).

Figure 4.9. *The location of the root collar can be determined by inserting a metal probe into the root ball (at several locations) and measuring the depth at which the first primary root(s) attaches to the stem.*

- Bare-root trees with moderate to severe amounts of "J" roots or encircling roots (Figure 4.10).

Figure 4.10. *Avoid purchasing bare-rooted nursery stock that has extensive J-root problems. If left untreated, these root systems will continue to develop as dysfunctional root systems.*

- Container grown trees that are root bound and have moderate to severe amounts of encircling roots (Figure 4. 11). If only a few non-woody roots are encircling, cut them away with a sharp tool.

Figure 4.11. *Encircling roots from pot-bound, containerized trees do not self-straighten. If correction of the root system is not made at planting time, the dysfunctional root system will remain and only worsen with time.*

- Container grown trees that have root collars that are deeply planted in the container or within plastic or fabric bags (> than 4 inches deep) or have incomplete or poorly developed root systems.

- Trees with moderate to severe amounts of crushed or torn roots. If only a few roots are crushed or torn, use a sharp tool to prune them to remove the injured tissues. Make the cuts immediately before planting and watering.

Proper Tree Planting Techniques

Trees can be purchased as bare root, containerized, or balled-and-burlapped specimens. Basic planting methods are the same for all specimen types, but handling and special considerations apply, depending on the size and type of tree. A checklist of basic planting guidelines for all tree types, and planting guidelines for special situations is provided below. These guidelines are provided as a handy reference for communities to use as they implement their tree planting programs and develop contract and bidding specifications for tree planting projects.

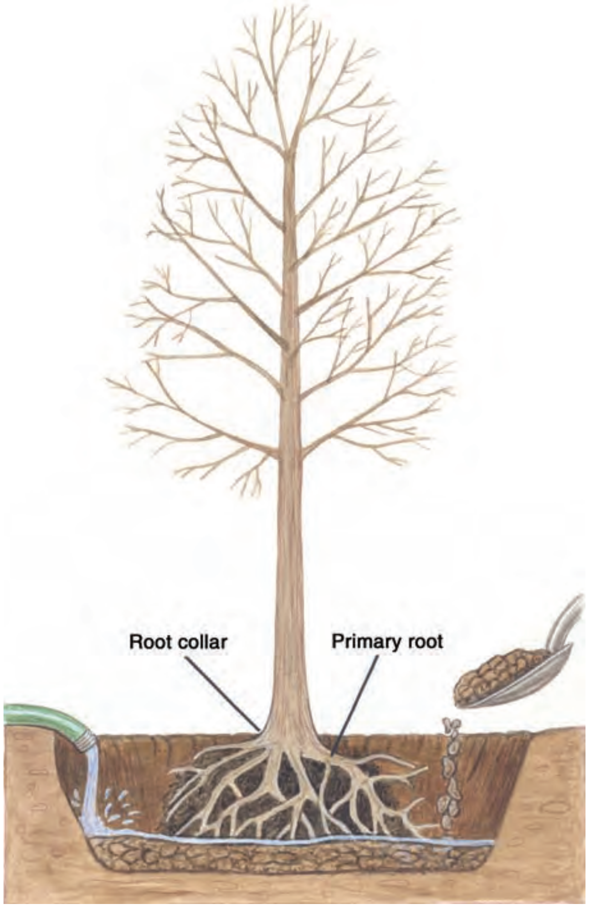


Figure 4.12. *Make sure the root collar (arrow) is at the soil surface or slightly above (e.g., 1-2 inches) when the tree is planted.*

Basic Planting Guidelines for All Tree Types

Match the tree species to site conditions. Base this on the soil type, soil pH, surface and sub-soil drainage, growing space, exposure factors (e.g., sun, wind, ice and snow, and de-icing salts), and the tree's cold hardiness.

Prepare the site by removing the sod. Loosen the soil by tilling or spading an area three- to five-times wider in diameter than the width of the root system, and only to the depth of the root system.

Figure 4.13. *Back fill the planting hole half way with the original soil that was removed and water.*

Dig a hole in the center of this circle that is 1 to 2 feet larger in diameter than the root ball and deep enough so the root collar is at the soil surface when the tree is planted. The root collar is the base of the stem where the primary roots first begin to branch away from the stem (Figure 4.12) The root collar may be buried in balled and burlapped, container grown, or tree spade dug trees. If you find the root collar is buried 3 inches deep in the root ball, dig the planting hole 3 inches shallower than the depth of the root ball.

Maintain undisturbed (not loosened) soil beneath the root ball to prevent the tree from settling.

Carefully place the tree in the center of the hole and gently remove any excess soil to expose the root collar flare. Double-check that the root collar (base of the stem where the primary roots first begin to branch away from the stem) is at the soil surface or slightly above (e.g., 1 to 2 inches). Planting trees at the proper depth, and not too deeply, is a critical step that can help to prevent the development of stem girdling roots and premature tree failure. Stem girdling roots can compress and kill trunk tissue, and cause trees to decline 10 to 20 years after planting or suddenly fail during storms by snapping off at the stem/root compression area.

Backfill around the roots with the soil that was removed. Lightly pack or water the soil during this process to eliminate air pockets (Figure 4.13). Backfill the planting hole to the height of the root collar, but no higher.

Mulch with 4 to 6 inches of coarse wood chips or shredded bark. Pull the mulch back from the trunk to prevent direct contact with the root collar and trunk. Be sure to avoid creating a mulch volcano by applying the mulch too deeply and placing it right up to the stem (Figure 4.14).

Figure 4.14. *Avoid mulch volcanoes. Mulch heaped too deeply and too close to the base of the stem can lead to stem girdling roots and decay.*

Water is very important to a newly planted tree. Newly transplanted trees will benefit from daily watering for the first 1 to 2 weeks, applying approximately 1 to 3 gallons-per-caliper-inch at each watering.

Thereafter, water trees every 2 to 3 days for the next 2 to 3 months and then weekly until established. Newly transplanted trees are absorbing water from a diminished root area. Apply water directly to the root ball at first. Roots must generate and grow into surrounding soils before a larger soil volume can be tapped for moisture. This watering regime should provide the new roots with sufficient moisture without drowning them. Roots need oxygen, too! Adjust the watering schedule accordingly for rain or very dry conditions.

Don't Forget To:
Inspect containerized and container-grown trees prior to planting to see if the roots are pot-bound or encircling. (Avoid the purchase of moderately- to severely-pot-bound plants). If the roots are slightly pot bound, remove the pot and make a vertical slice up each quarter of the root ball to a depth of about 1 inch. Cut an X across the bottom of the soil ball to a depth of about 1 inch. Gently loosen some of the roots, then plant (Figure 4.15). If encircling roots are flexible, it may be possible

Figure 4. 15. *If the tree is pot bound, score the root ball with a knife to a depth of 1 inch, as shown.*

to straighten and orient them in a radiating direction outward from the trunk, rather than cutting them.

Inspect bare root trees for broken or encircling roots, and all trees for broken or damaged branches prior to planting. Remove any broken or encircling roots and broken or damaged branches with a sharp hand pruner. Also, remove crossing or rubbing branches.

Keep all types of root systems moist prior to planting. For bare root trees, placing moist straw or sawdust around the roots works well.

Soak bare root trees in water 1 hour prior to planting.

Sweat bare root trees in a shaded place such as a garage and keep them moist until the buds open. Sweating is a process that creates favorable conditions necessary for bud break and development on certain tree species, such as oaks and hackberries.

Remove all containers prior to planting, including biodegradable, papier-mâché pots. If the roots and soil are loose in the container, then place the container in the planting hole and carefully cut away the container as you backfill with soil.

Be sure all roots extend away from the trunk to prevent future problems with encircling and stem girdling roots.

Remove at least the upper two rungs on wire baskets before completely backfilling. Typically it is best not to remove any portion of the wire basket before the tree is safely placed in the planting hole and is partially backfilled.

Remove the nails holding the burlap together, then cut away as much of the burlap as possible after the plant has been partially backfilled. Never allow any burlap to remain above the soil surface.

Cut and remove all twine and rope from around the soil ball and tree trunk.

Prevent animal damage to young trees, if needed, by placing a 12- to 24-inch-tall cylinder of 1/4-inch mesh hardware cloth around the trunk, leaving 2 to 3 inches between the wire and the trunk.

Provide follow-up care during the establishment period to ensure tree survival and success. Recent research suggests watering frequency is very important to facilitate rapid and successful establishment. See the suggested watering schedule mentioned above. Successful establishment and tree survival rates will decrease total costs of a tree planting project when tree removal and replacement costs are factored into the total budget.

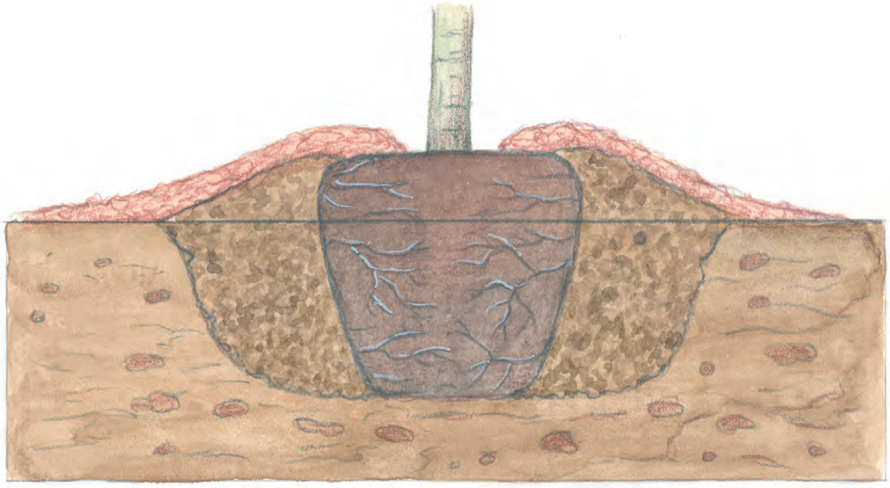


Figure 4.16. *For heavy or poorly drained soils, plant the root collar slightly higher than the soil surface (e.g., 1 to 2 inches), and mound the soil to cover the root ball.*

Planting Guidelines For Special Situations:

For heavy and/or poorly drained soils, plant slightly higher than normal and mound the soil up to cover the root ball (Figure 4.16).

Do not add peat to poorly drained, heavy clay soils, as it can act as a sump and draw water into the root zone.

Do not add rocks or gravel to the bottom of a planting hole to improve drainage unless drain tiles are installed.

When using tree spades, water the trees thoroughly before moving them. Rough up the sides of the planting holes with a shovel or rake, then place the trees slightly higher than the original grade to allow for settling.

If using a weed control barrier, use a porous landscape fabric. Do not use plastic around trees.

Staking is generally not necessary unless the tree is unstable. Stakes and strapping should be applied to support the tree, yet allow the tree to move and sway. Stakes and strapping should be REMOVED within one year. Connect the tree to the stakes with wide (two inches or wider), flexible materials, such as strips of canvas, mesh or burlap or old bicycle inner tubes (Figure 4.17). Avoid ropes, strings or wires in garden hose sections since these materials can compress and girdle stem tissue.

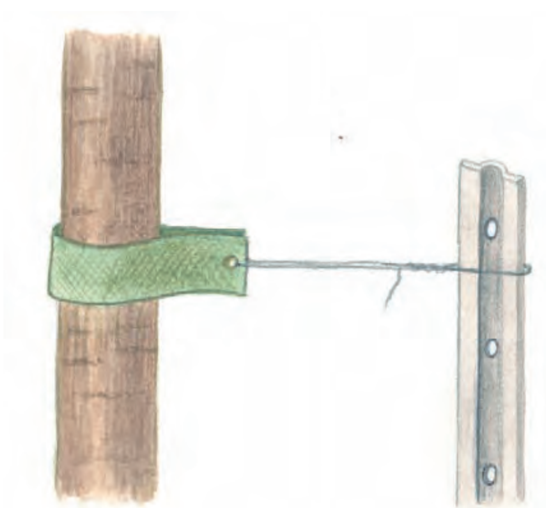


Figure 4.17. *Stake if necessary, for no more than 1 year.*

Proper Tree Pruning Techniques

Sound arboricultural practices will prevent development of many hazardous tree defects. Investing community resources in proper tree pruning techniques is one of the most effective tree risk management strategies. Early formative pruning and ongoing maintenance pruning will prevent the development or eliminate many tree defects that are leading causes of tree failure. Early and regular tree pruning will also reduce the costs of subsequent pruning, tree removal, and replanting.

Industry standards for pruning trees are published by the American National Standards Institute in *The American National Standard for Tree Care Operations - Trees, Shrubs and other Woody Plant Maintenance- Standard Practices: ANSI A300 – 1995* (ANSI 1995). The A300 (Part 1) standards currently address tree pruning practices only, and provide guidelines for young tree, mature tree, and utility pruning operations. The American National Standards Institute has also published a standard reference for safety requirements for workers and the public who are engaged in tree care operations entitled *The American National Standard for Tree Care Operations - Pruning, Trimming, Repairing, Maintenance, and Removing Trees, and Cutting Brush - Safety Requirements: ANSI Z1331.1-2001* (ANSI 2001). The purpose of this standard is to provide safety criteria for workers and the public, and to serve as a guide to federal, state, and municipal authorities in the drafting of their regulations.

These industry standards can help communities develop pruning specifications and safety regulations. Community tree care managers who write contracts and bidding specifications for tree maintenance work projects should be familiar with them. Both publications are available from the American National Standards Institute, National Arborist Association, and the International Society of Arboriculture at their respective websites as follows:

http://www.ansi.org http://www.natlarb.com http://www.isa-arbor.com

Pruning Schedules

Trees should be pruned regularly during their early formative years to improve tree structure and promote tree health. Good structure of primary, scaffold branches should be established while the tree is young. The scaffold branches provide the framework of the mature tree, and properly trained young trees will develop a strong structure and require less corrective pruning as they mature. Early formative pruning is “good preventive medicine” that will help to avoid the development of many tree defects, or eliminate them before they become hazardous to public safety. For example, early formative pruning that removes weakly attached branches will improve tree structure, and can prevent major branch failures in subsequent years. The elimination of codominant stems, early in the tree’s life, will prevent the development of defects that could lead to stem failure such as included bark and/or cracks at the stem union.

Many pruning schedules have been published, and the recommended interval between pruning activities varies. The ANSI A300 pruning standards provide guidelines for pruning young trees at the time of planting, 1 to 3 years after planting, and 4 to 6 years after planting. Here are some tips to remember when pruning young trees. These tips incorporate the ANSI A300 pruning standards and recent research findings:

Pruning Young Trees

At Planting

Little, if any, pruning should be needed at the time of planting. This is especially true if high quality nursery stock has been selected for planting. Any pruning performed on newly planted trees should be limited to corrective pruning. Several studies have shown that pruning the crown at planting to achieve a better balance between roots and foliage does not enhance establishment and can actually increase the time required for establishment. This phenomenon occurs because the food manufacturing capacity of the foliage is needed to produce new roots and shoots.

Corrective pruning to be done at planting

- Remove diseased, dead, or broken branches
- Eliminate double leaders (The top of a tree should never be pruned except to remove a double leader)
- Remove branches with included bark in their attachments
- Do not remove lower branches or thin the crown at planting

1-3 Years After Planting

- Never remove more than one quarter of the foliage or live branches of a tree per year
- Remove branches that are dead, broken, or rubbing
- Select primary scaffold branches that are well spaced along the tree trunk as follows:
  - 18 inches apart for tree species that will reach >40 feet at maturity
  - 6-8 inches for tree species that will reach < 40 feet at maturity
- Remove branches with included bark in their attachments

4-6 Years after Planting

- Never remove more than one quarter of the foliage or live branches of a tree per year
- Remove branches that are dead, broken, rubbing
- Selectively thin to promote a structurally sound scaffold branch system and strong branch unions
  - Eliminate codominant stems. Codominant stems are a leading cause of tree failure
  - Remove branches that interfere with proper spacing of scaffold branches
  - Remove branches with weak branch attachments and included bark
  - Retain branches with strong U-shaped angles of attachment
- Prune lower branches to prevent interference with site lines, pedestrian traffic, and other clearance issues

Basic Pruning Methods

Pruning cuts should always follow the guidelines provided in Appendix 3: How to Prune Trees. Proper training and experience is needed, particularly for large limb removal and the removal of highly hazardous trees. Communities should hire experienced and insured arborists, if the public works staff are not trained or experienced in these procedures.

Wound Dressings

Wound dressings are not necessary or recommended for most pruning cuts. Research has shown that dressings do not hasten wound closure or reduce wood decay. The application of dressings can effectively reduce sap flow from wounds, and in this capacity can help prevent the transmission of certain diseases such as oak wilt and Dutch elm disease. If oaks or elms are wounded or must be pruned during active disease transmission periods, use a latex rather than oil-based or asphalt-based paint.

Timing of Pruning

Try to schedule pruning activities during the late dormant season. Pruning in late winter, just before spring growth starts, leaves fresh wounds exposed for only a short length of time before new growth begins the wound sealing process. Pruning trees during the dormant season can help to avoid certain diseases such as oak wilt, Dutch elm disease, and fireblight. Another advantage of dormant pruning is that it is easier to make pruning decisions without leaves obscuring branch structure.

Ideally, it is best to avoid pruning trees when leaves are forming and until they are fully mature. This is true because much of the tree's energy reserves are being used to support leaf expansion and growth, and only limited energy reserves are available for defensive activities like wound sealing and compartmentalization.

Protection of Trees From Construction Damage

Construction activities impact trees and can create or exacerbate hazardous situations. Protecting tree health and mitigating high-risk situations on a construction site is a matter of recognizing the potential impacts of construction activities, and identifying hazardous trees or defects that exist on the site. Avoiding or minimizing construction damage is a critical step in preventing the development of many hazardous tree defects, and eliminates the costs of treating construction damaged trees. Advanced planning and simple mitigation steps can minimize the risks associated with trees during and after construction. These include:

- **Protecting healthy, structurally sound trees**
- **Protecting trees from direct injury**
- **Protecting the structural integrity of trees**
- **Protecting the overall health of trees throughout construction**

Although they are not discussed here, there are significant tree risk management issues that should be considered along with the risk of structural tree failure during and after construction (Johnson 1999). These issues include creating a structure and site that are defensible against wildfire, providing adequate visibility at roadway intersections, and providing visibility for security and surveillance.

Protect Healthy, Structurally Sound Trees – "Save the Best – Chip the Rest"

In areas where trees will impact people and structures, trees should be assessed to ensure that they are healthy and structurally sound. Trees that are unhealthy and/or structurally weak will only get worse following construction activities. No efforts

Steps for a successful tree protection plan:

- Mark construction zone boundaries
- Inventory trees on the site
- Train contractors and sub contractor crews
- Design the site to accommodate construction activities:
  - Vehicle movement and parking
  - Material storage
  - Vehicle cleaning
- Select the trees to be saved
- Protect the trees you plan to save
- Prepare the trees for construction disturbance
- Protect and preserve the soil for future tree planting
- Monitor the construction process and hold periodic meetings with contractors
- Enforce penalties for non-compliance
- Make a final inspection of the site
- Commit to long-term maintenance

should be made to save these trees. A tree specialist can inventory and inspect trees and provide a report of potential problems. The specialist should review construction plans to see if the proposed construction or subsequent landscaping activities will create new target areas. Eliminate or correct hazardous situations, or exclude people from hazardous areas.

Protect Trees From Direct Injury

Trees can be damaged or killed by a wide variety of construction activities. Construction practices can result in obvious damage such as torn bark and less obvious damage to roots. Any injury to the wood or bark of a tree is a potential long-term problem. Open wounds deplete a tree's energy resources and provide entry points for insects, diseases, and decay. Decay is the leading indicator of potential tree failure and is always the result of wounds. The worst damage, however, often remains hidden underground. Roots that lie within the path of construction must be protected because they are so important for anchoring the tree.

Approximately 90 to 95 percent of a tree's root system is located in the top 3 feet of soil, and more than half is in the top 1 foot. Avoid construction activities within the CRR to ensure the tree's root zone is adequately protected.

When you remove a large number of trees, you change the site conditions for the remaining trees. Sudden increases in amounts of sunlight and wind may shock trees. It is not uncommon to find scorched leaves, broken branches, and uprooted trees after a site is cleared. Although some of these problems are temporary, they may compromise tree health when coupled with additional construction damage.

Protect the Structural Integrity of Trees

Trees acclimate to the conditions of the site where they grow. Mature trees have less ability to adapt to changes in the environment than younger trees. Construction activities can change soil moisture, wind exposure, and sunlight, requiring trees to acclimate to new conditions. The shape of a tree's trunk and root system reflect the tree's adaptation to environmental conditions that existed prior to construction. For example, forest or plantation trees have trunks with less taper and few lower branches than open grown and exposed trees. Collectively, they protect each other from most wind damage. Once exposed along the edges of openings created by construction activities, individual trees may not have the strength to withstand increased wind. This problem can be mitigated by selectively thinning the woodland or plantation several years prior to construction activities. You can avoid sun and wind stress and improve tree survival by preserving trees in groups rather than as individuals.

Root loss not only affects the health of trees but also their condition and stability. Any tree that experiences significant root loss will have a different center of gravity as a result. This shift in balance often results in less stable trees especially the large, mature trees and leaves them more vulnerable to toppling over, especially during high wind. Construction activities that sever more than 40 percent of roots located within the CRR will result in a tree that is in imminent danger of falling over, with or without the help of wind. Trees growing in tree lawns or near streets typically have an unbalanced and restricted root distribution. Therefore, any root removal or damage during construction is a more significant loss to trees growing in tree lawns as compared to trees growing in more open areas.

Protect the Overall Health of Trees Throughout Construction

In addition to protecting the CRR, there are other ways in which you can reduce the impact of construction activities on your trees. Some of these are relatively simple; others are complex and expensive. Carefully consider the importance of each tree to the future appearance of the site and consult a tree specialist before deciding whether protective measures are worth the cost.

Soil compaction is the single largest killer of trees in construction areas. Tree roots need loose soil to grow, obtain oxygen, and absorb water and nutrients. Stockpiled building materials, heavy machinery, and excessive foot traffic all damage soil structure. Lacking good soil aeration, roots suffocate and tree health declines. Prevent soil compaction by establishing storage areas and traffic routes safely away from the CRR of trees, and installing protective fences and signs. If traffic cannot be rerouted, apply several inches of protective mulch (6 inches or more) within the CRR of affected trees to reduce soil compaction. Mitigating existing soil compaction problems is rarely effective, so careful planning will help avoid the expense and labor of corrective treatments or removal of damaged trees.

Improper handling or disposal of materials used during construction also can harm roots. Fill gas tanks, clean paintbrushes and tools, and repair mechanical equipment well outside the CRR of trees to prevent chemical spill damage. Finally, avoid changes to native soil pH by not cleaning out concrete mixers or mortar boxes on site or burying concrete materials within the CCR of existing trees or in areas where future plantings are planned. Alkaline clays or limestone should not be used for fill or paving.

Grade changes within the CRR usually kill a tree. This happens either directly, or by changing soil moisture and oxygen availability within the root zone. Except where absolutely necessary, avoid disruptions to the natural contour of the site or shift them well outside the CRR. Mitigate disruption to the CRR with techniques such as use of porous fill, mulch and non-turf groundcover, and constructing retaining walls at or beyond the CRR.

As much as 40 percent of a tree's root system can be cut during the installation of a nearby utility line. This reduces water and nutrient uptake and may compromise the stability of the tree. If it is not possible to relocate the utility line outside the tree's CRR, you can reduce root damage by tunneling under the tree's root system (Figure 4.18).

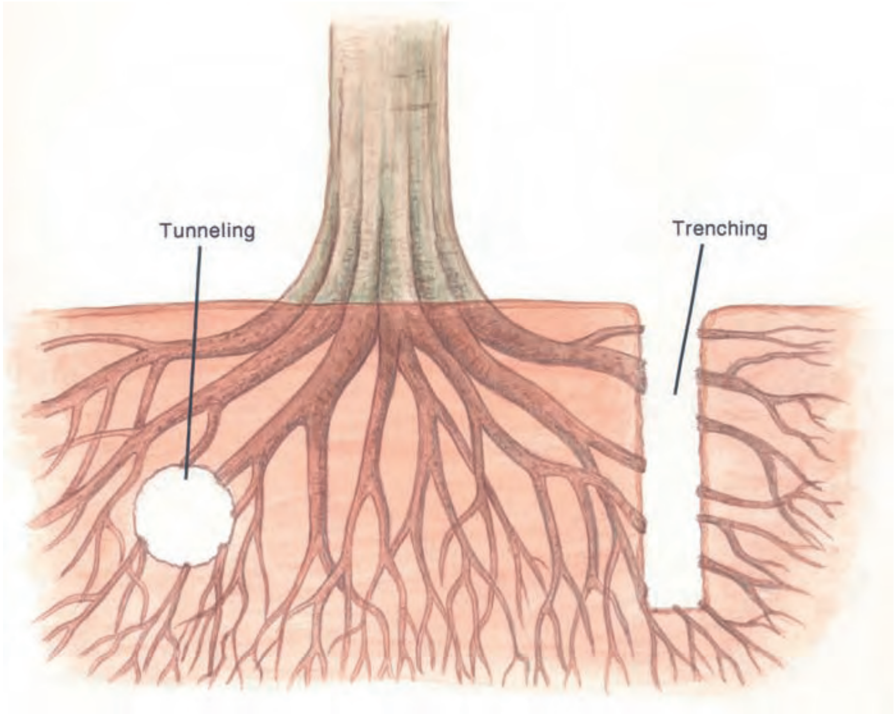


Figure 4.18. *Underground utilities installed via a tunneling system cause less root damage than convention trenching operations.*

Avoid soil tunneling (augering) too close to the tree's stem in order to minimize injury to tree roots. The diameter of the tree can be used as a guide to determine the minimum distance from the tree where tunneling should occur (Table 4.2).

Table 4.2 Minimum distance (feet) from the tree's stem that soil augering/tunneling should occur, based on tree diameter.

Tree diameter (dbh, inches)	Auger distance from tree stem (radius, feet)
0-2	1
3-4	2
5-9	5
10-14	10
15-19	12
> 19	15

Source: Morell 1984

Trenching for building foundations also poses a danger to nearby trees. Posts, pillars, or I-beams sometimes can be substituted for foundation walls and footers on homes. Drilling single holes as opposed to cutting deep trenches saves critical roots.

Street Trees and Construction Damage

Established street trees are subjected to damage from construction activities more frequently than forest trees. The infrastructure of any community (e.g., streets, sidewalks, curbs, and buried utilities) is continually updated, repaired, or expanded, and trees growing in tree lawns (e.g., tree lawns) or close to these public services are vulnerable to construction activities. A community can minimize construction damage to public trees by adopting a tree preservation policy that establishes tree preservation guidelines.

Root loss is the most common type of construction damage that street trees suffer. This is particularly harmful because these trees already are growing in root-limited spaces, and are often less healthy than other landscape trees due to other environmental stresses posed by tree lawns. Stresses include reduced soil volume, poor quality soil, accumulation of de-icing salts, and characteristically drier conditions than other landscape sites.

Minimize root loss to minimize construction damage to street trees. Most healthy trees can tolerate one-sided root cutting and recover from the loss with long-term after care (Johnson 1999). Trees that have roots cut on two sides usually suffer much more damage and are less stable. It is questionable whether to save trees that suffer root loss on three or more sides.

Damage to sidewalks, curbs, and gutters near trees is costly and the damage is frequently listed as a tree problem. In California over $70 million dollars in damage to these grey infrastructure components has been reported (McPherson 2000). Nationally, it is likely then that billions are spent annually repairing damage to curbs, gutters, and sidewalks. But is the tree 100 percent of the problem? Some evidence suggests that defects in sidewalks and natural expansion and contraction of soils account for sidewalk damage. In other cases attempting to grow a tree too close to infrastructure is the problem.

Damage to sidewalks, curbs and gutters becomes less frequent the farther away tree stems are form the edge of these structures. Damage becomes infrequent in tree lawns that are approximately 8- to 10-feet wide or greater. Also, in the cases where damage does occur, the repair process and subsequent damage to tree roots systems on average does not cause any greater tree mortality than normally occurring nor a detectible reduction in tree condition (Hauer et al. 1994).

The amount of root cutting near street trees may be reduced by a variety of methods and compromises:

- Plant smaller stature trees (Remember, doing so will also reduce the ecological benefits that larger stature trees can produce).
- Move the sidewalk away from the tree.
- Plant trees on the sidewalk side opposite of the tree lawn (If this area is private property a green easement could be developed to allow tree planting on private property and future care by a municipality).
- Ramp the sidewalk to minimize trip and fall events.
- Grind down the raised sidewalk to increase the time period before infrastructure replacement is needed and the subsequent root damage will occur.
- Evaluate soil texture when designing sidewalk projects.
- Avoid widening streets or sidewalks when they are replaced.
- Narrow the width of the street when possible to lessen the amount of root damage and provide more area for future root growth.
- Use air or water tools to expose main structural roots to facilitate clean cutting of roots rather than ripping them from soil excavation with a backhoe.
- If curbs are need to be replaced, hand form the curbs adjacent to tree roots, rather than excavating with machinery. Excavation with machinery destroys major branch roots, even if the new curb remains in the same position as the old curb.
- Consolidate utilities into common trenches whenever possible, and tunnel under tree root systems. Laying several utilities in a common trench minimizes the number of trenches and root cuts.
- Avoid regrading the surface of the tree lawn. Although it is not trenching, it still cuts and removes roots, usually the fine roots that absorb most of the water and nutrients for the tree. If regrading must be done and creates a mowing/maintenance problem, consider the installation of retaining walls at the curb line, or remove the turfgrass from the tree lawn and replace it with mulch and landscape plantings.

When tree lawns are greater than 10 feet wide, take steps to plant trees to avoid future damage. Placement of trees in the center of the tree lawn rather near the sidewalk or curb side is important. Simple centering of the tree in the tree lawn in wide tree lawns will help prevent future tree and infrastructure conflicts.

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Correction of Hazardous Defects in Trees

By Martin MacKenzie, Tom T. Dunlap, Barbara J. Spears, and Joseph G. O'Brien

Introduction

Every tree in the urban landscape will eventually fail regardless of care. While many trees in an urban environment remain sound and present low risks to public safety until they die from other causes, some trees break apart from accumulated defects and diseases while they are still alive (Fig 5.1). If a target is present near where a tree is growing, there is always a risk that falling limbs or a catastrophic failure of the stem or roots may result in harm to people or damage to property. When any tree in a community accumulates defects that exceed a certain level, the tree becomes an unacceptable risk, and must be corrected or removed. Of course, dead trees and branches present an especially imminent hazard, and should be removed as soon as practical after they are discovered. Pruning or cabling and bracing can correct many defects that make a tree a hazard. This chapter outlines the strategies that communities can adopt to correct trees that develop hazardous defects, along with some ideas for converting dead or dying trees into desirable wildlife habitat.

Figure 5.1. *This tree was previously topped, and extensive wood decay has developed as a result. Two major branches have already failed. This tree will continue to decline at a rapid rate and should be removed.*

While the bulk of this manual deals with the recognition of hazard trees and the development of a community tree risk management program, one of the most important aspects of such a program is the implementation of effective corrective actions in a timely manner. Although the goal of risk management is preventing injury and damage, avoiding litigation is also important to communities, because of the potential costs involved. Evidence that a community has exercised "reasonable care" in regard to maintaining its trees lies in its ability to produce documentation that proves that not only are trees inspected, but that hazardous trees are corrected in a timely manner.

Strategies for Corrective Action

Procedures to correct hazardous defects in trees range from simply pruning out defective branches, to applying simple or complex cabling and bracing systems, to taking the ultimate step of removal and replacement of the tree. The use of cabling and bracing to correct

There are many ways to reduce the risk to the public posed by a hazardous tree, and many times more than one solution is possible.

Corrective action strategies to manage hazardous trees include :

- Moving the target
- Correcting the tree
  - Pruning
  - Cabling and bracing
- Converting the tree to a wildlife tree
- Closing the area to the public
- Removing the tree

Figure 5.2. *Hazard Tree: Structurally defective tree with a target within striking range.*

defective trees is such an important, controversial, and technical subject that it was decided to devote a major portion of this chapter to this subject alone. See the cabling and bracing section below. The rest of this chapter focuses on the other means of correcting hazardous trees: pruning, conversion to non-hazardous wildlife habitat, or removal. Strive for the treatment that results in the least impact on the site while eliminating the immediate hazard.

Moving the Target

As defined in Chapter 1, a "hazard tree" is a structurally defective tree that has a target within range (Fig 5.2). If the target is moved out of range of the defective tree, then the tree is no longer a hazard, but is still a defective tree. Because it is difficult to predict the direction of fall of a defective tree or tree part, and because most people are poor judges of the actual heights of trees, it is recommended that a "target" be defined as any object within a specified distance (1.5 times the estimated tree height) of the defective tree.

Moving the target away from a defective tree can also be an important way of "buying time." If a hazardous tree is identified but corrective action cannot be taken immediately, consider moving the target first. For example, if a picnic table or bench is the target beneath a highly defective tree, but corrective actions cannot be taken for several days or more, move the table or bench away from the tree. Moving the target in most urban situations is probably a temporary measure; in most cases it reduces risk, but does not eliminate it entirely.

Wherever people congregate or spend significant amounts of time in one place, the potential for a hazardous situation exists. For example, one of the categories of users of urban parks is the homeless. Many homeless people will seek shelter for the night under a tree in a park, even if the tree is dangerously defective. Other users of urban parks seek solitude, and go to great lengths to get away from their fellow visitors. For this reason, it should be assumed that if a tree within an urban park is surrounded by mown grass it should be considered as having potential targets. An area of mown grass without nearby picnic tables, benches, or paved paths (i.e., "targets") can probably be considered a low-risk area, but the trees in such an area should still receive periodic inspections, even if the intensity and frequency is less rigorous than that afforded other, more intensively used areas. However, if it is known that people regularly sleep or congregate under a tree or group of trees in a park, even if such use is technically illegal, increased vigilance is required.

Correcting the Tree

Pruning

Pruning out the defective parts of a tree is by far the most common means of correcting defects and minimizing the chance of tree failure. Pruning is described fully in Chapter 4 (Prevention of Hazardous Tree Defects). Always follow industry standards for pruning (ANSI 300 – 1995 and ANSI Z1331.1 – 2000) as described in Chapter 4. Guidelines are also provided in Appendix 2: How to Prune Trees.

Examples of tree defects that often can be corrected using proper pruning techniques include:

Cracks: For a large branch with a major crack, removal of the entire branch back to its junction with the main stem is usually the most effective remedy (Fig 5.3). However, cabling and bracing is an option that should be considered in some circumstances.

Figure 5.3. *Remove the entire branch back to its junction for large branches that are cracked.*

Figure 5.4. *Remove large branches that are broken or lodged in the crown.*

Dead Branches: Remove large branches (> 4 inches) that are broken or lodged in the crown. At the same time, remove the remaining stub, using good pruning techniques (Fig 5.4).

Weak Branch Unions with included bark: Where a tree has a weak branch union with included bark, remove the affected branch (Fig 5.5). As with most corrective

Figure 5.5. *Remove branches with weak branch unions and included bark.*

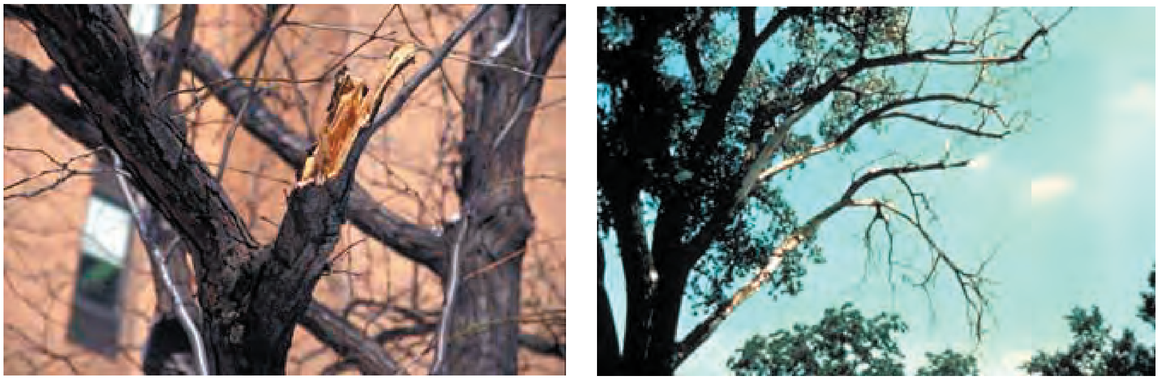


Figure 5.6. *Remove all large branches that are decayed (A) or dead (B).*

actions, they are more likely to be effective if implemented while the tree is young. See the cabling and bracing section for other options.

Figure 5.7. *Remove all branches that have highly abnormal branching habits such as sharp bends or twists.*

Decayed branches: Remove all large branches (> 4 inches) with evidence of decay, and all large dead branches (Fig 5.6 A and B). The pruning procedure must remove the branch back to live, sound wood, but should not necessarily cut into live wood. Proper pruning cuts, even for large branches, are made just outside the branch-bark ridge, without injuring the branch collar.

Unsound Architecture: Prune branches that have a sharp angle, bend, or twist (unless such growth is characteristic of the tree species) (Fig 5.7). These are "architecturally unsound trees." As with weak unions early intervention is always better than removing large branches later in the tree's life.

Figure 5.8. *Remove all branches that obstruct street signs, signals, street or security lighting or that limit visibility of approaching traffic.*

Visual Obstructions: Remove branches that obstruct street signs, signals, street or security lighting, or branches that limit visibility of approaching traffic (Fig 5.8).

Physical Obstructions: Remove branches that impair pedestrian or vehicular traffic.

Interference with Utility Lines: Prune trees that interfere with overhead utility lines to eliminate the interference. Topping trees for utility clearance is no longer considered an acceptable pruning practice (Fig 5.9). Maintenance of such trees is usually the responsibility of the utility company that owns the lines. Special training and certification for maintenance workers who do this work is mandated by the federal Occupational Safety and Health Act (OSHA), and should be required by all communities.

Figure 5.9. *Trees that interfere with overhead utility lines should be pruned. But not this way! Tree topping is not an acceptable pruning practice.*

Cabling and Bracing

We do not recommend cabling and bracing as a treatment for hazardous trees unless the tree has significant historic or landscape value. The decision to apply cabling and bracing procedures to trees should not be made lightly. Because it is critically important that such procedures be done correctly, the following section provides information that communities can use to make informed decisions regarding when and how to use these tools in their tree risk management programs.

Industry Standards. Industry standards for installing support systems in trees are published by the National Standards Institute in *The American National Standard for Tree Care Operations- Tree, Shrub, and Other Woody Plant Maintenance-Standard Practices - Part 3 - Tree Support Systems* (ANSI 2000). This publication includes sections on hardware selection and requirements, installation practices, cabling and bracing requirements, and guying techniques. The ISA has published a companion publication, *Best Management Practices: Tree Support Systems,"* to serve as a "how to" guide for defining cabling, bracing, and guying procedures and methods (Smiley et al. 2001). Community tree care managers who write contracts and bidding specifications for tree maintenance work projects should be familiar with these standards and best management practices. Communities should hire arborists who are experienced and will agree in writing to perform all cabling and bracing operations in accordance the ANSI A300 - Part 3 - Standards.

History of Cabling and Bracing. Cabling and bracing of trees has been practiced for many years. There are obscure references to bracing done in the early 1800s, but bracing trees, as we know the practice today, can be traced back to the early twentieth century. Some of the first bracing systems used chains and other rigid materials such as rods, flat straps, and tubing. Cable and eyebolts came into use after 1910 and have been widely accepted, with some modifications, as new materials were developed. During the 1930's the National Park Service published guidelines for material sizes and strengths that have been followed since that time. Modern materials used in cabling and bracing systems include rigid material such as threaded rod or bolts or flexible material such as metal or synthetic fiber cable.

Cabling and bracing systems are very similar to the standing rigging on sailing ships. The use of flexible and rigid braces between masts and spars onboard sailing ships to support huge loads is very similar to the goals of bracing trees to themselves (Fig 5.10). Proper selection, sizing, and placing of support materials can be expected to add to the life expectancy of trees.

Figure 5.10. *H.M.S. Victory, the flag ship of Vice-Admiral Lord Nelson at the Battle of Trafalgar, illustrating the use of flexible and rigid braces between masts and spars.*

Cabling and bracing has extended the life of many trees and reduced the risk from failure to an acceptable level. But the design and installation of a proper system of cabling and bracing requires professional judgment and experience. When hiring an arborist to install a cabling and bracing system, look for an experienced arborist who has observed tree failures and worked in trees that have been saved by proper cabling and bracing systems.

Cabling and Bracing Defined

Cabling and bracing is the practice of adding a support system to a tree to reduce the stress on weak branch unions. Many trees have acute, V-shaped branch unions that form included bark. Included bark acts as a wedge that weakens and separates branch unions that join at too sharp an angle. A similar situation occurs when two equal-sized stems form off the main bole of a tree after the loss of the main leader. The bark of the two stems push against each other and the two leaders do not have a strong connection to the main bole (Fig 5.11). As the tree grows, these structural defects can lead to failure of one of the two stems. Adding properly installed cabling and bracing will reduce the strain on the branch union, and extend the life of the tree.

Figure 5.11. *The through bolt was installed to add support to a weakened codominant branch.*

Cabling and bracing can also be used to correct trees with poor architecture. Typically, as trees grow, the trunks and limbs taper toward the ends. This tapering reduces the strain on the higher and outer limbs in the tree. If limbs and trunks do not taper, a large amount of leverage acts on the point of attachment where the branch meets the stem, which can lead to failure. Improper pruning can also place strain on branch unions. The inner branches of some trees have been removed because of the mistaken belief that such hyper-thinning eliminates the possibility of wind failure. Actually, by removing these inner branches, the tree will put on more length and less bulk in its limbs. This leads to the condition referred to as "lion's tailing." Because the limbs are long and thin, but still maintain a full complement of foliage, the limbs will whip severely and possibly fail, instead of swaying naturally.

Analysis of Tree Condition. There are many considerations that must be addressed before a cabling and bracing system is installed in a tree. The tree may have a high value in a particular landscape, or it might be a historic or unique specimen. Before investing in a cabling and bracing system, the cost of installation and future maintenance must be balanced against the risk of failure and possible loss of aesthetic value during the tree's extended life.

Carefully assess the tree to determine if it is a reasonable candidate for the investment in cabling and bracing. Consider the whole tree during this assessment. The roots must be strong enough to support the tree. If there is decay in the main trunk or branches, factor that information into the decision to remove or save the tree. If the tree has cracked already, the arborist must know how well the tree species in question is able to compartmentalize decay. Some trees can isolate decay better than others. The outcome of a decision to apply a cabling and bracing procedure to a white oak (*Quercus alba*) may be completely different than if the tree in question is a basswood. Remember that cabling and bracing does not repair a tree. Cabling will add a level of security and risk reduction, and can help to affect the direction of failure if a branch should fail. When designed properly and installed by a trained arborist, proper use of cabling and bracing will extend the life of a tree and reduce the risk to an acceptable level.

If the decision is made to use cabling and bracing to extend the life of a tree, it must be understood that such treatments are temporary. Give consideration to planting a younger tree or trees to be used as replacements if the cabled and braced tree is removed.

Some trees will benefit from having weight removed from the branches before the installation of cabling and bracing hardware. Therefore, do all necessary pruning before the tree is cabled. Remember, removing major lateral limbs creates large wounds that can lead to extensive decay on the main bole of the tree. If weight reduction is determined to be necessary, a slight crown reduction by using proper thinning cuts in the crown is the safest course of action. The possible harm from over-pruning a tree to remove a significant amount of weight must also be recognized. Most trees will need only routine pruning to remove dead limbs and other material in accordance with accepted pruning standards as discussed in Chapter 4.

Inspection Schedule. Once a tree has been cabled and braced it is necessary to inspect the tree on a routine schedule. The size, age, site, and risk potential of the tree will determine the inspection schedule. However, no cabling or bracing installation should ever go more than two years without inspection, and annual inspections are a good idea. Some inspections can be done from the ground. Binoculars can be used to make a more thorough inspection of the tree without having to climb it, or use an aerial lift to inspect the crown. As time passes, it will be necessary to have an arborist inspect the anchor points and any changes in the tree's growth from within the tree. There may come a time when a new cabling and bracing system will be necessary. Again, this assessment will need to be done by an experienced arborist following the same procedures as in the first installation.

As the tree grows taller, the time will come when a new system should be added, higher in the tree. Do not remove the old, lower system before the new system is completed. Do not attempt to remove old hardware imbedded in the tree. That will unacceptably damage the tree. Cut such hardware flush and leave it in place.

The Wye Oak:

A case study of corrective actions including cabling and bracing

The Wye Oak was recognized as America's largest white oak for more than 60 years. Located in the village of Wye Mills on the Eastern Shore of Maryland, the Wye Oak was 96 feet tall with a crown spread of 119 feet and a bole circumference, at 4.5 feet above ground, of more than 31 feet (Fig 5.12). It has been estimated that the acorn that gave rise to this tree germinated around the year 1540. The Wye Oak was one of only two National Champion trees that remained on the American Forestry Association's list of champions since the list's inception in 1940. What enabled this tree to survive for more than 460 years, despite injuries and defects, was a conscientious effort on the part of managers to preserve the tree with corrective treatments, including application of fertilizer and insecticides, pruning, and cabling and bracing.

Figure 5.12. *The Wye Oak, formerly known as the largest white oak in the United States. It was located in the village of Wye Mills, MD and was estimated to be 460 years old. Deeded to the state of Maryland on September 20,1939 and made into a State Park. The end for this urban monarch came when a thunderstorm on June 6, 2002 felled the tree.*

The Wye Oak was the focal point for the four-acre Wye Oak State Park, established in 1939. At the time the park was established, the tree had marked buttressing at its base (Fig 5.13). The most common theory is that in the past, riders tied their horses to the tree while visiting nearby stores or taverns, and that damage caused by these actions resulted in the malformations. Also, the inner portion of the lower trunk had been severely decayed to a height of eight feet. While today's arborists would never recommend filling a tree cavity with concrete or any other rigid material, filling cavities was an accepted practice in the past, and at some time, the bole cavity in the Wye Oak was partially filled with concrete. The lowermost piece of the concrete filler can be seen in Figure 5.14. Cavity filling treatments like this one do not delay the decay process in the tree, do not make the tree less likely to fail, and can considerably complicate the removal

Figure 5.13. *Buttressing knees were present on the Wye Oak. The most likely theory of their origin is that horses tied to it while their riders visited a nearby store or tavern, damaged the tree, and initiated the malformations.*

process. The tree has been fertilized annually, and treated with insecticide if gypsy moth or other insect damage was predicted.

By the 1980s, the tree was in the declining phase of its life. In 1984, a large limb, weighing more than 35 tons, fell from the tree. Many more equally massive limbs were losing the mechanical exibility needed to withstand the stress loading placed upon them by wind. For this reason, the tree received frequent pruning to remove dead limbs and excessive new growth that would produce wind resistance. In the 1950's the State Park began using cabling and bracing to support the old tree. More than 100 load-sharing cables intertwined throughout the crown. The cables had a combined length of more than 3,500 feet (Fig 5.15). As can be seen in Figure 5.16, in a leaf-off setting, the cables had some slack in them. Once the tree came into full leaf, these cables would be taut. Each cable was equipped with an adjustable turnbuckle that was checked every two years.

Figure 5.14. *Cavity treatments do not delay the decay process in the tree, do not make the tree less likely to fail, and can considerably complicate the removal process when it is finally time to take the tree down.*

Figure 5. 15. *Looking up into the crown of the Wye Oak, some of the over 100 load-sharing cables could be seen. The cables have a combined length of over 3,500 feet.*

The addition of this amount of metal cable into the crown of the tree increased the risk of a lightning strike. For this reason, four highly conductive, braided copper leads were grounded on each of four sides of the tree. Every cable in the tree was joined to every other cable by short braided copper jumper cables. Despite being an open grown tree and having a significant amount of metal in its crown the tree was never been damaged by lightning.

In addition to the actions described above, the state of Maryland worked to mitigate the increased liability this large old tree and the addition of hardware in the tree created. A fence was erected around the tree (Fig 5.17). This fence effectively moved the target (the public) away from the tree, eliminating the risk of damage caused by a falling 35-ton (or heavier) limb. While people could not walk under the dripline of the tree, they could still use the area outside the fence for viewing the tree close up. All major limbs had been trimmed back to the fence line.

While the cables might not have held up a limb if it failed, they would in uence the direction the limb fell in, swinging the failing limb inside the fence line. As an added benefit, the fence protected the roots of the tree from being trampled.

Figure 5. 16. *In this leaf-off view, some slack can be seen in the cables due to the reduced weight of the branches.*

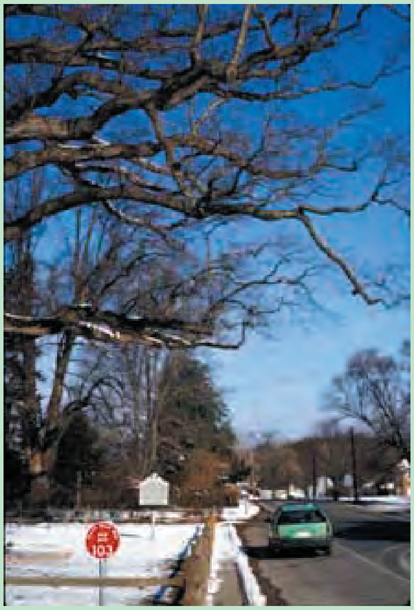


Figure 5.17. *All major limbs of the Wye Oak were trimmed back to the fence line. Should a limb fail, the cables might not hold it up; they would, however, influence the direction of its fall and swing the failing limb inside the fence line.*

What eventually felled this giant tree was fungal decay. For decades, possibly centuries, fungi had been recycling the heartwood of the Wye Oak. For several years, it was known that brown cubical butt rot fungus (Laetiporus sulphureus, previously known as Polyporus sulpureus) was attacking the root crown of the tree. What was not fully appreciated was the extent to which the sapwood had decayed. On June 6, 2002, a thunderstorm felled the giant tree. After the Wye Oak fell, park employees discovered the tree was hollowed to about 10 feet and the cavity was about eight feet across. In addition, there was a shell thickness of only 2 to 4 inches on a radius of more than 15 feet. As described in Chapter 3, the shell thickness guidelines for this tree would have required a 60-inch shell thickness. What is even more amazing than the fact that the tree was standing at all, is the fact that when it died, it was bearing a maturing crop of acorns. Thus, a 2- to 4-inch shell of functional sapwood was sufficient to maintain but not structurally support its crown.

When the thunderstorm of June 6, 2002 felled the tree it imploded upon its butt shell, the main stem falling straight down into the void above the partial concrete filling, and then toppled over into the street. That the tree was standing at all is a testimony to how well it had been cabled and braced. The judicious use of pruning and heavy application of cabling and bracing extended the useable life of this historic and culturally significant urban tree to more than 460 years. However, urban trees are not immortal and even the largest of them eventually succumb to wood decay fungi if not to an accident or to the accumulation of a lifetime of injuries.

Liabilities. Cabling and bracing is a practice that, when properly applied, can extend the life of a tree. In addition, cabling and bracing can reduce the potential for failure to an acceptable level. Once a tree comes under an arborist's care, the arborist is obligated to follow accepted trade practices. During the inspection, the arborist may determine that the removal of part of the tree is a better option than cabling and bracing. Care must be exercised in this case since the removal of large portions of the tree can lead to conditions that could lead to tree failure. If the risk of failure is too high, then removal of the tree may be the best option.

Since cabling and bracing has a long history of use and is an accepted, standard practice, the concern for additional liability should be little different than if the tree were being pruned. However, correction of defects by cabling and bracing requires additional inspection and maintenance that must be performed regularly to ensure the integrity of the procedure. Failure to perform regular inspections, and to correct any problems that may arise, may indicate negligence. Choosing not to install a cabling and bracing system because of a fear of liability is not a good decision. The best procedure is to follow a plan that reduces the risk of failure to an acceptable level.

Converting Hazardous Trees Into Wildlife Trees

Although tree risk management often involves the complete removal of dead or dying trees, some defective trees can be treated to reduce the threat to human life and property to an acceptable level, while leaving a portion of the tree intact to provide wildlife habitat. This approach has been coined *converting board feet into bird feet* (Ostry and Nicholls 1998). Several techniques exist for converting hazardous trees into good wildlife habitat in a safe and environmentally responsible fashion. These techniques ensure that if a tree falls (or when it falls) there are no targets within striking range.

Not all defective trees are good candidates for providing wildlife habitat, nor can all good candidates be safely converted to wildlife trees. For example, converting hazardous trees into wildlife trees is not recommended for street trees, and should be reserved for use in parks and natural areas. We will describe the *wildlife cycle* of a tree, and discuss criteria to determine if a tree can be safely converted into a wildlife tree. We will introduce a decision-modeling tool that provides a logical approach to deciding whether to convert a defective tree into a wildlife habitat tree.

Communities often overlook the environmental benefits that a tree risk management program can provide, especially as it relates to creating wildlife habitat. A community tree risk management program that helps to create wildlife habitat will nurture public interest in the program. People value a variety of wildlife in and around the places where they live and work, from inner city to rural communities. The 1996 National Survey of Fishing, Hunting and Wildlife-Associated Recreation reports that 62.9 million people intentionally fed, observed, or photographed wildlife around their homes and on trips away from home (USDI 1996). Other studies have shown that in urban areas 93 percent of residents want to know how to attract wildlife and support habitat components.

Wildlife in cities and rural communities may offer greater opportunities for environmental education and non-consumptive recreation than remote locations because of the proximity to large numbers of people (Shaw et al. 1985). Demonstrations sites, located in parks, nature areas and on school properties, can be very effective teaching tools and serve as *living laboratories* to display and interpret the wonders of nature. Demonstration sites, showcasing wildlife habitat areas as a managed component of the community forest, can also encourage the observer to think beyond the individual tree and gain a greater understanding of natural systems.

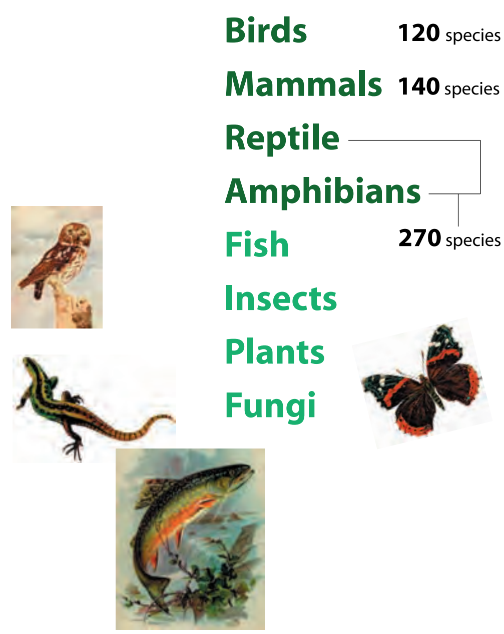


Figure 5.18. *Over 120 species of birds, 140 species of mammals, and 270 species of reptiles and amphibians depend on standing dead and dying tree of all sizes*

How Trees Benefit Wildlife

Standing dead trees and dead or dying parts of live trees are beneficial to wildlife for foraging and food storage, nesting and den sites, shelter and cover, bridges, perches, and roost sites. Over 120 species of birds, 140 species of mammals, and 270 species of reptiles and amphibians depend on standing dead and dying trees of all sizes (Ackerman 1993) (Fig 5.18). In addition, many species of insects, spiders, mites, millipedes, centipedes, slugs, and fungi use these trees for the completion of their life cycle and in turn provide a food source for many other species. For example, the white-breasted nuthatch, common in urban forests, is a cavity nester that prefers mature stands with large decaying trees, and feeds its young an animal-based diet consisting of many of the arthropod species listed above.

Wildlife Cycle of a Tree

A tree's capacity to provide wildlife habitat changes over time. As a tree matures and begins to decline (due to insects, diseases, injury or old age), the tree enters into a "wildlife cycle" and plays a vital role in providing habitat and promoting ecosystem biodiversity. Even when a tree dies, its usefulness does not end; it continues to provide valuable habitat for many species of wildlife. When evaluating a tree as a possible wildlife tree, certain characteristics make them suitable for different types of wildlife habitat, depending on what phase of the "wildlife cycle" they are in. The "wildlife cycle" can be simplified into three identifiable phases, each phase being unique and adapted for different types of wildlife:

Phase 1: The first phase in the "wildlife cycle" of a tree involves standing dead or dying trees that initially attract non-cavity nesting species and primary cavity excavators (e.g., woodpeckers). These trees contain sound wood and the branches are intact (Fig 5.19). Trees in this initial phase provide foraging sites and perches for insect-feeding birds and raptors, singing perches for many songbirds, nest sites for species such as great blue herons, osprey, hawks and eagles, and nesting sites for primary cavity excavators such as woodpeckers, nuthatches, chickadees, and others.

Phase 2: The second phase in the "wildlife cycle" of a tree involves increased decay. The tree is still standing, but the wood is no longer sound. The branches and bark are shed and the top and larger portions of the stem break off. During this phase, the tree becomes attractive to secondary cavity users that colonize existing cavities, excavated and abandoned by primary cavity nesting species or formed when branches are shed or when tops are broken off. (Fig 5.20). Secondary cavity users include owls, some species of ducks, birds (e.g., bluebirds, swallows, wrens and flycatchers), raccoons, flying squirrels, bats, and some amphibians. These species use the tree for nesting, foraging, roosting, and perching.

Figure 5.19. *Example of a Phase 1 Wildlife Tree: a standing dead tree that initially attracts non-cavity nesting species. Here, it serves as a nesting site for a bald eagle.*

Phase 3: In this third and final phase of a tree's "wildlife cycle," decay has reduced the tree to a stump and debris pile (Fig 5.21). Woody debris is important habitat for many wildlife species such as salamanders, toads, mice, grouse, and woodpeckers. It is used for nesting and shelter, as a source of and place to store food, as a lookout site, for drumming, sunning, and preening sites, and as a natural bridge or highway across streams. Decaying logs also serve as nurse-trees for seedlings and contribute to nutrient cycling.

Figure 5. 20. *Example of a Phase 2 Wildlife Tree: a tree with existing cavities that is attractive to secondary cavity dwellers. Here, a boreal owl has discovered a cavity and established a nesting site.*

Criteria for Selecting Wildlife Trees

Within community parks and other natural areas, a variety of wildlife trees should be selected for use, ranging from trees suited for long-term management to trees suited for short-term management. Phase 1 trees will be the most valuable trees for providing long-term wildlife habitat since they will remain standing for an extended period and will likely develop a large number of cavities over time. Trees greater than 15 inches in diameter, and more than 50 feet tall, are considered the most valuable to wildlife. These trees should be slow decaying tree species such as oak and pine. Phase 2 trees provide immediate habitat for secondary cavity users and serve as foraging, roosting, and perching sites. To identify Phase 2 trees, look for existing cavities, dens or foraging holes; existing nesting or roosting sites; and/or the presence of fresh scats or bird droppings. Phase 3 trees provide immediate habitat for wildlife and contribute to nutrient recycling. Selecting trees that are currently inhabited or used by wildlife has the obvious advantage for educational purposes and demonstration projects.

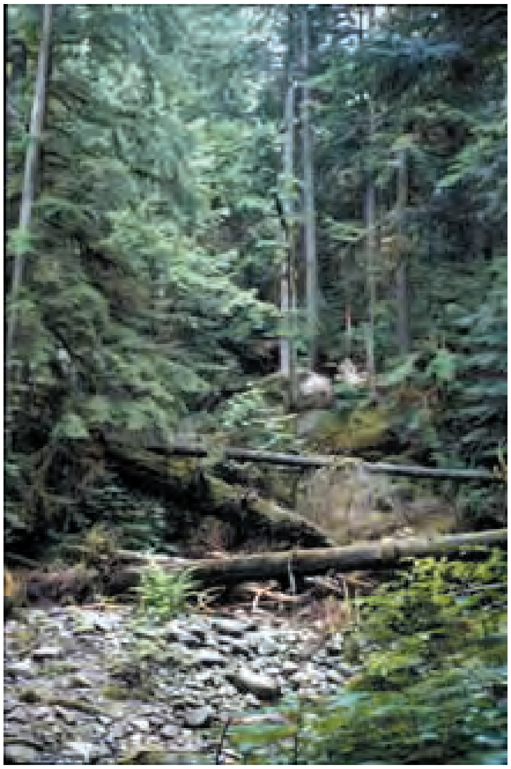


Figure 5.21. *Fallen, decayed logs provide nesting and shelter, a source and a place to store food, lookout sites, drumming, sunning and preening sites, and as a natural bridge or highway across streams.*

When to Consider Converting a Defective Tree into a Wildlife Tree

Only consider establishing wildlife trees when human safety will not be compromised or damage to property is not imminent, and when the defective tree is a good candidate for wildlife habitation. For these reasons, it is not a recommended corrective action for street trees, and the establishment of wildlife trees should be reserved for parks and natural areas.

Reduction of risk may be as simple as moving targets such as picnic tables, benches, or kiosks out of striking distance of the defective tree. If the target can be moved, risk to public safety is mitigated, and the tree can be preserved for wildlife habitat. If it is not feasible to move the target, other corrective actions such as pruning to remove defective branches or to reduce tree height should be considered. For example, wildlife trees that are located along high-use urban trails and in parks will often require corrective pruning to reduce tree height to a level where the tree will no longer strike a target, should it fail. Placing a nesting box near the location where a cavity has been lost through tree or limb removal may be a successful habitat replacement. If it is not feasible to perform corrective actions that will reduce risks to public safety with minimal impact to wildlife, closing the area to pedestrian traffic is a final option. Closing the site temporarily (such as during the breeding season) is often a possibility. With proper fencing and interpretive signing, a site closed to pedestrian traffic may still be valuable as an educational/demonstration area.

The Wildlife Habitat/Defective Tree Decision Model, developed by the U.S. Forest Service, provides a logical approach to deciding whether to convert a defective tree into a wildlife tree (Fig 5.22). The model operates under two assumptions: 1) a defective tree exists and various corrective actions can be performed to reduce the public safety risks to an acceptable level, and 2) wildlife is using or could potentially use the tree. This simple tool poses basic questions to help determine what corrective action(s) could be implemented that will reduce risk to public safety and preserve as much of the tree as possible for wildlife habitation. Corrective management strategies include: 1) removing targets within striking distance of a wildlife tree, 2) performing corrective pruning, 3) closing off the site, with fencing or signs, to restrict pedestrian traffic within striking distance of a wildlife tree and, 4) removing the tree and leaving the felled tree on site.

Closing the Area

Closing an area and denying the public access to a portion of the urban forest is an extreme action that should be considered only in the direst situations. However, there are times when closing an area, either temporarily or permanently, is the only option available (Fig 5.23). One example of the effective use of temporary closures is a situation where an adverse weather event such as an ice storm or tornado has left so many hazardous trees in an area that it is impossible to guarantee public safety. Closing a public area temporarily until the needed tree maintenance is done should be an option that is available to tree maintenance workers in communities.

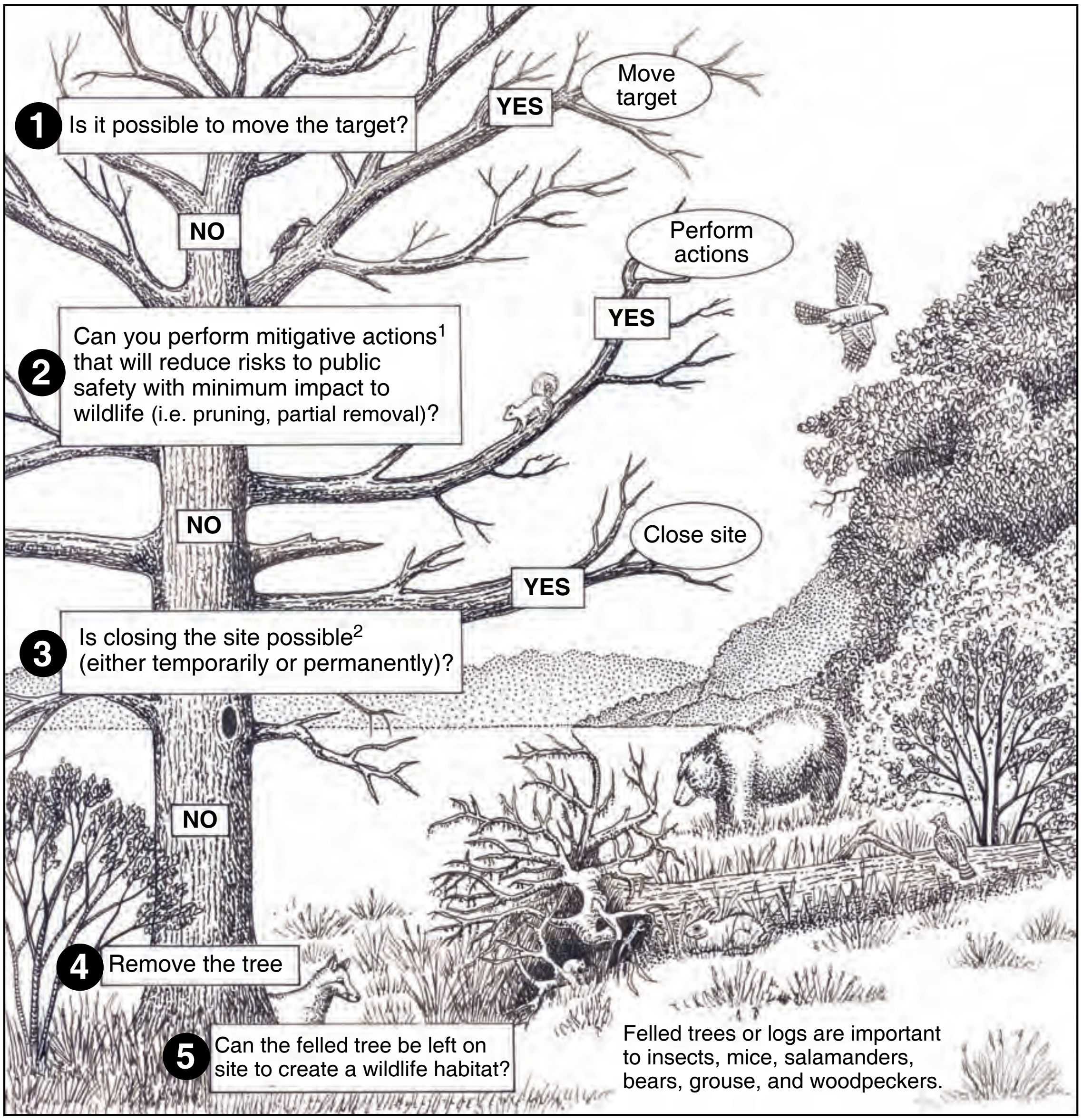
Figure 5.23. *Place a Do Not Enter sign to close the site to visitors.*

In more permanent or sensitive situations, judicious use of a "close the area" approach can also be an effective tool for managing risk. As an example, placing a fence around a large tree to keep the public from compacting

Wildlife Habitat/Hazardous Tree Decision Model

This decision model provides a logical approach to deciding whether to convert a hazardous tree into a wildlife habitat tree. The model's function is to help maintain and create wildlife habitat and reduce public safety risks associated with trees with hazardous defects. Assumptions of the model are:

1. A hazardous tree exists and various mitigation actions can be performed to reduce public safety risks to an acceptable level.
2. Wildlife is using or could potentially use the tree.



[1] *Placing a nesting box (Screech Owl, Northern Flicker, squirrel) on a site can be a successful replacement for cavities that are lost through tree or limb removal.*

[2] *If it is not possible to move a target, prune the tree or conduct a partial removal, consider closing the site. This mitigative action can prevent disturbance to wildlife during the most critical (breeding) time. Remember, risk and values must be balanced with common sense when making decisions about hazard trees.*

Text prepared by: Mary Torsello and Toni McLellan, USDA Forest Service. Illustration by Julie Martinez

Figure 5.22. *Wildlife Habitat/Hazardous Tree Decision Model.*

the soil over tree roots, or from being at risk from falling branches is in many ways equivalent to closing the area. For large trees of significant cultural heritage, placing a fence around them is often the only acceptable way to mitigate a hazard. Alternatively, planting wide, fenced, or densely continuous beds of flowers around an architecturally unsound tree may be an acceptable way of retaining an otherwise hazardous tree in the urban landscape. This will keep the public at a safe distance, and will also prevent the trampling of roots and soil compaction around the hallowed monarchs of the urban forest. But at the same time the hazardous situation is being resolved, consider eventual replacement of the defective tree. Wise management can extend the lifetime of a tree by only so long. Communities need long-term strategies for tree removal and replacement to achieve sustained development of the urban forest.

Removing the Tree

Removing a hazardous tree is the option of last resort. Implement this action only when other corrective actions cannot reduce the level of risk to an acceptable level. Before removing the tree, consider and balance all options, including the possibility of cabling and bracing, against the opportunity that removing a tree provides in the development of the overall community tree risk management plan. The effects of removing a tree, including visual impact on the site, and emotional impacts to people who value a particular tree, can be substantial. While removing a tree is not an option to be considered lightly, it is sometimes an unavoidable cost to abate a hazard. Always couple the removal of a tree with a community tree planting program that includes strategies to reestablish trees that are best suited for the urban landscape and the site on which they will grow. For example, plant small-stature trees under utility lines, and consider trees with smaller crowns and root systems for narrow lawn extensions and other places with restricted root space. Make educating the public about the benefits of matching trees to specific sites a goal of every tree risk management plan. See Chapter 4 (Prevention of Hazardous Tree Defects) for more information on proper species selection.

Following are some examples of high-risk tree defects that warrant tree removal. Refer to Chapter 3 (How to Detect and Assess Hazardous Tree Defects) for additional photographic examples of all the tree defects listed below.

Bole Decay: Trees that do not meet the minimum sound shell thickness guidelines described in Chapter 3 must be removed (Fig 5.24). There is no other remedy for a tree that lacks the necessary amount of sound wood. Filling cavities or other methods for bracing or cabling such trees are not effective.

Leaning Trees: Trees with an excessive lean, as described in Chapter 3, must be removed. Trees that have evidence of soil mounding on the side away from the lean are particularly dangerous. Such mounding indicates that the roots on that side of the tree are failing, and usually mean that the tree has recently begun to lean. A tree that has grown for a long time with a lean less than 45 degrees may not be a significant hazard, but should be monitored closely for evidence of an increase in the lean angle.

Dead Trees: Dead trees are at great risk of failure, and should be considered highly hazardous in all situations. These trees should receive priority attention by the maintenance crew, and should be removed as soon as they are found.

Cankers on the Main Stem: Trees with cankers that affect 40 percent or more of the tree's circumference or are associated with decay or other defects should be considered hazardous and removed (Fig 5.25).

Figure 5.24. *This tree has a large cavity with extensive wood decay that affects >40 percent of the tree's circumference. This tree does not meet safe shell requirements and should be removed.*

Figure 5.25. *This tree has a canker and associated decay that affects >40 percent of the tree's circumference. This tree does not meet safe shell requirements and should be removed.*

Unsound Architecture: Some trees with a tendency to form multiple upright branches can become dangerously defective if timely pruning is not provided over the life of the tree (Fig 5.26). Other trees, particularly conifers, can develop "twin stems" if the leader is killed and two branches assume dominance. The branch unions of these trees tend to form "included bark" as described in Chapter 3, which acts as a wedge to force such branches apart. If it is feasible to remove one branch in such a tree to correct the problem or to buy time while other nearby trees grow larger, the trees might be pruned.

Severe Root Injury: Trees where root damage such as root decay or root severing affect more than 40 percent of its critical rooting area (Fig 5.27).

Figure 5.26. *This tree has experienced major crown failure. The remaining branches are declining as evidenced by poor leaf development, and the overall health of the tree is very poor. This tree should be removed.*

Figure 5. 27. *This tree has experienced damage to two sides of the root system and surface root loss due to re-construction activities. An older sidewalk restricts the roots on a third side of the root system, making this tree a prime candidate for failure.*

Implementing Corrective Actions

Just as it may take several decades for trees in an urban setting to accumulate the injuries and structural defects that make them hazardous, it may take decades of careful maintenance and planning to develop an urban tree population into the ultimately desired condition. However, individual corrective actions must be completed in a timely manner. When a community first establishes a tree risk management program, the number of maintenance activities that seem necessary can be overwhelming. Aside from the removal or corrective treatment of very high-risk trees, which must be a top priority, a community has many options available to deal with correctible trees that pose a low or moderate hazard.

One strategy available to communities to help control the initial costs and visual impacts of mitigating hazardous trees lies in spreading corrective maintenance and planting over several years. This strategy requires ranking the corrective maintenance needs of all defective trees, and identifying those trees that require immediate attention as well as those with problems that can safely be put off for future correction. Be prepared to explain the rationale used for assigning or delaying treatments for all trees with identified defects, preferably with guidelines that are consistently used by tree inspectors and maintenance workers. Carefully consider benefits, risks, costs, and visual impacts when making decisions regarding tree risks.

Consider the tree shown in Figure 5.28. It is clear from the photo that a large and presumably defective limb was removed some years ago. The photograph clearly shows that there was a target within range. At the time the photo was taken the tree does not appear to create an imminent hazard, yet as an urban tree it is not in the desired condition. The storm-damaged tree had a defective limb that was removed, eliminating the immediate hazard. However, the resulting wound is so large that there is a high probability that it will become invaded by decay fungi before the tree has time to seal over the branch stub. There is also a high probability that the decay process will result in a cavity developing in the main stem that will one day violate the minimum "shell thickness guidelines" discussed in Chapter 3. Prudent hazard tree management dictated that the storm-damaged limb be removed; however the corrective action resulted in the creation of a tree that was not in its ultimately desired condition, which is a tree with only small wounds, or no wounds at all. Although the immediate hazard was corrected, the action itself has likely contributed to the development of a future hazard. In this case, the usable lifespan of this tree in the urban setting has been extended, and the community has bought some time in which to defer removal costs and plan for the replacement of this wounded tree.

Figure 5.28. *This tree has a very large wound that was created when a large branch was previously removed.*

Always include tree risk inspections and maintenance as part of the overall vegetation management strategy of a community, including plans for replacing trees that will be removed. For example, trees with large defective branches can be pruned, but preparations should be made to replace trees that require drastic corrective actions with young, defect-free trees. Cabling and bracing a defective tree can also extend its lifetime in an urban setting, but a tree that requires such treatment most often is a prime candidate for replacement. Young trees can be planted near older ones that will require removal in the near future, and the removal and planting schedules can be coordinated so that marginal trees can be replaced over time with younger, vigorous trees.

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APPENDIX1. Summary of survey responses, as provided by the authors of urban tree risk rating manuals or systems, published in the U.S.

Survey Questions	Producers of public tree risk rating systems/manuals designed for use in urban areas, published in the United States				
	Bartlett Tree Research Laboratories	**Colorado Tree Coalition**	**ISA**	**Minnesota Department of Natural Resources**	**Safetrees.com**
What is the target audience(s) of your tree risk assessment system?	Commercial arborists	Professionals in the tree care industry including city foresters/arborists, commercial arborists, utility arborists; government agencies, and homeowners.	Arborists of all types.	Public and private recreation site managers, hazard tree trainers, municipal parks, zoos, and campgrounds, state departments of transportation, federal agencies and private tree services.	Arborists, tree care companies, community foresters, resource managers, recreation site managers and owners, highway departments, utility arborists, and educators.
What assessment methodology do you use?	Individual tree examinations (360°)	Combination of 360 ° individual tree examination and drive-by surveys. This allows an inventory or crew person to take notes during daily routine activities, and report info to a more qualified individual to conduct an in-depth exam.	Individual tree examinations (360°), using decay detection methods (drill, resistograph), root crown examinations, and aerial inspections as required.	Only individual tree examinations (360°)	Individual tree examinations (360°) VTA (Visual Tree Assessment), sounding for tree decay, and probing for decay if needed with drill, increment borer, or Resistograph,
Is your assessment system numeric or non-numeric?	Non-numeric: ranging from low to severe	Numeric: Rating is based on tree species, target, defect and size of defect. System also allows for field notes and photos.	For multi-tree surveys, we use the ISA's 12 point numeric system. For 1-few trees, we use a non-numeric system of describing defects.	Non-numeric. Trees are simply rated as low, moderate or high with no attempt to rate the target importance, size of failing tree part, etc. We feel that the inspected trees need to be rated based on their symptoms and defects. That way, managers know what the hazard tree population looks like and hazard trees can still be prioritized for management work based on recorded location, type of defect, etc., depending on the data recorded for each tree.	Non-numeric. This is a definitive guide on how to evaluate all categories of tree defects

APPENDIX1. Summary of survey responses, as provided by the authors of urban tree risk rating manuals or systems, published in the U.S. - *continued*

Appendix 1. Summary of survey responses, as provided by the authors of urban tree risk rating manuals or systems, published in the U.S.

On a per tree basis, how long does it take to conduct a risk assessment using your methodology?	5 minutes to hours, depending on the tree.	Less than 5 minutes to 30 minutes, depending on what is needed to conduct the assessment.	It all depends on the nature of the assessments.	1-15 minutes, per tree: longer if invasive tests (increment coring or drilling) are needed or if the upper crown needs to be inspected from above by machinery.	It depends on the extent of tree defects present. If invasive techniques are necessary, the assessment time increases.
How much training is needed to prepare field staff to conduct assessments?	Our usual training session is one 6-hour day.	Level 1: If people can identify tree species it takes about 1-3 days to get them comfortable with the system. Level 2: Much more intense training on extra tools (resistograph, drill test, etc.). They can learn in a day, but it takes a lot of field work to become proficient.	No specific amount of training. We use certified arborists and monitor their work until we are comfortable with their expertise.	A minimum one day training session is required for state employees. This includes a field session to “calibrate” trainees on real, live trees. In terms of supervision, when the 2-tiered system is used, the local manager reviews all hazard trees and spot checks the first crew.	At least a full day workshop. Advanced invasive techniques may be better left in the hands of higher trained professionals.
Have you measured the success of your risk assessment system?	Not systematically.	Yes, through surveys of people who use the system. In fact, the feedback we receive determines the changes we make to the system.	Not directly, no. Indirectly, user have told use how helpful and valuable it is.	12,000 copies of the first two editions of our manual are in use. Sites using our system typically remove less than 1 % of their trees on an annual basis.	The guidelines use the latest research available from the Bartlett Tree Research Laboratories and others. Currently, the guidelines and information presented in the field guide are used as standards for the tree care industry.
Is there other information that you would like to share about your system?	No response given.	It is flexible enough to a adopt to most situations.	No response given.	Our system is simple to use, requires minimal training for implementation, empowers local managers to make decisions, and can be easily adapted for fit local needs. We recommend that hazard tree assessment systems should be fully documented and backed up by a policy statement.	The updated second edition now features 58 color photographs, and 43 illustrations on 34 pages. New sections have been added on evaluating root decay, basic tree biomechanics, introduction to tropical tree defects, and safety issues facing arborists. It is formatted in a compact 7” by 6.5 “ size, and is printed on sturdy paper with laminated front and back covers.

APPENDIX1. Summary of survey responses, as provided by the authors of urban tree risk rating manuals or systems, published in the U.S. - *continued*

Appendix 1. Summary of survey responses, as provided by the authors of urban tree risk rating manuals or systems, published in the U.S.

Are you aware of other published tree risk assessment systems that are designed for use in urban areas?	No response given.	The USFS system (unpublished) and ISA's.	San Francisco uses Lee Paine's system, modified for use in urban areas.	No response given.	No response given.
Do you have a training manual that is available for purchase or distribution? If so, what is the title, cost, and ordering information?	Yes, but we do not sell it. Limited quantities may be available upon request. Cost: Not for sale	Manual is currently being updated. Cost: Price will be determined by the final product.	Yes, the title is: *A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas.* Cost: Retail: $45.00 Member: $35.00	Yes, the title is: *How to Detect, Asses and Correct Hazard Trees in Recreational Areas.* Cost: 3rd Edition is currently being written. Cost is expected to be approximately $20.00.	Yes, the title is: *Evaluating Trees for Defects* Cost: $22.95 U.S. plus $3.00 S&H
Contact Information	Bartlett Tree Research Laboratories 13768 Hamilton Rd. Charlotte, NC 28278 Contact: Tom Smiley P: 704-588-1150 F: 704-588-5152 E-mail: bartlett.com	Colorado Tree Coalition P.O Box 270968 Fort Collins, CO 80523-0968 Contact: Ralph Zentz P: 970-221-6302 F: 970-221-6849 E-mail: rzentz@ci.fortcollins.co.us	ISA PO Box 3129 Champaign, IL 61826-3129 Contact: ISA E-mail: ias@isa-arbor.com	Minnesota DNR 1201 E. Highway 2 Grand Rapids, MN 55744 Contact: Jana Albers P: 218-327-4234 F: 218-327-4391 E-mail: jana.albers@dnr.state.mn.us	Safetrees 532 22nd St. NE Rochester, MN 55906 Contact: Ed Hayes Fax: 507-282-5739 E-mail: ehayes@safetrees.com website: www. Safetrees.com

APPENDIX 2. California Tree Failure Report Form

Accession #____________

Date of Report ____________________________

CALIFORNIA TREE FAILURE REPORT

University of California, Davis, CA 95616

Tree Genus ___________________________________

Species _____________________________________

Cultivar (if known) ______________________________

Common name ________________________________

Approx. age ______yrs., Height ______ft., DBH ______in.

Crown spread ______

Tree Owner _________________________________

Site: County _________________________________

City _______________________________________

Address/Park _________________________________

_____ Site category (choose one): 1-Residential 2-Street
3-Park 4-School 5-Highway 6-Parking lot 7-Mall 8-Other

DETAILS OF TREE FAILURE

-1 Date of failure: __________________ (Mo/Day/Yr)
-2 Time of failure: __________________ (Hr/AM or PM)
____ -3 Location of failure on tree (choose one)
1-Trunk: ____ft. above ground, ____inches break diam.
at ground level? ____ (Y/N)
2-Branch: ____ft. from attachment, ____in. break diam.
at point of attachment? ____ (Y/N)
branch attachment ____ ft. high on trunk
estimated branch angle at point of failure ____
weight concentrated at end of branch? ____ (Y/N)
3-Root (including uprooting)
____ -4 Site use (choose one) (Explain on p.2 Additional Info)
1-Undeveloped
2-Low use (intermittent vehicles and/or people)
3-Medium use (permanent structures, intermittent vehicles and/or people)
4-High use (permanent structures, frequent vehicles and/or people)
____ -5 Stand type:
1-Natural 2-Planted 3-Mixed
____ -6 Tree occurring
1-Alone (at least one crown diameter apart)
2-In a group (less than one crown diameter apart)
3-Altered stand (trees removed from stand)

TREE STRUCTURAL DEFECTS

____ -7 Choose up to three, in the order of importance
____ 1-Failed portion dead 8-Embedded bark in crotch
____ 2-Multiple trunks/codom. stems 9-Crook or sweep
3-Dense crown 10-Leaning trunk
4-Heavy lateral limbs (describe p. 11-Cracks or splits
5-Uneven branch distribution: (one 12-Kinked or girdling roots
6-Uneven branch distribution: (top 13-None apparent
7-Multiple branches at same point 14-Other (describe p. 2)

TREE DECAY OR INJURY

____ -8 Type of decay at failure location (choose one)
1-Root rot
2-Heart rot
3-Sap rot
4-Heart rot and sap rot
5-No decay noted
____ -9 Extent of decay or cavity (% cross-sectional area)
(For root failure estimate % structural roots decayed)
1- 25% or less 4- 75-100%
2- 25-50% 5-Unknown
3- 50-75% 6-None
____ ## Fungal sporophores or conks found near failure location?
1-Yes 2-No
____ ## Other injury at failure location
____ (Choose up to three, in order of importance)
____ 1-Mechanical 4-Animal 7-Fire
2-Lightning 5-Chemical 8-None
3-Insect 6-Vehicle 9-Other (p. 2)
____ ## Other injury, entire tree (same choices as 11)
____ (Choose up to three, in order of importance)
____

MAINTENANCE HISTORY

____ -13 Pruning at failure location (Choose up to three)
____ 1-Heading cuts - moderate - cut diameter ____ in.
____ 2-Heading cuts - severe - cut diameter ____ in.
3-Thinning cuts (or drop-crotching) 6-Root pruning
4-Lion-tailing 7-No pruning
5-Flush cuts 8-Other (p. 2)
____ -14 Pruning on entire tree (Same choices as 13)
____ (Choose up to three)
____
____ -15 Other maintenance (Choose up to two)
____ 1-Cable/hardware failure 4-Cavity treatment
2-Staking/props 5-Injections
3-Girdling wire, rope, etc. 6-None

SOIL AND ROOT CONDITIONS AT SITE

____ -16 Restricted roots (Choose up to two)
____ 1-Raised planter or bed 4-Root cutting
2-Container or boxed tree 5-Not applicable
3-Root barriers 6-Other (p. 2)
____ -17 Irrigation
1-None 3-More than once per mo.
2-Less than once per mo. 4-More than 3X per mo.
____ -18 Ground cover under tree (Choose up to two)
____ 1-Bare soil 6-Shrubs
2-Mulch 7-Mixed planting
3-Turf 8-Paving
4-Native cover 9-Other
5-Herbaceous plants
____ -19 Soil in tree vicinity (Choose one)
1-Good condition 3-Saturated 5-Shallow
2-Compacted 4-Dry 6-Other (p. 2)
____ -20 Site topography/soil changes (Choose up to two)
____ 1-Excavation-depth _____ft., distance from trunk ____ ft.
2-Grade change - cut 5-Streambank erosion
3-Grade change - fill 6-Not applicable
4-Slope erosion

WEATHER AT TIME OF FAILURE

____ -21 Wind speed:
1-Low (less than 5 mph)
2-Moderate (5-25 mph)
3-High (25+ mph)
____ -22 Wind
1-Gusty
2-Steady
____ -23 Wind in prevailing direction for season?
1-Yes
2-No
____ -24 If branch failure, was wind direction (Omit if no wind)
1-Parallel to
2-At right angles to branch direction?
-25 Temperature: ________ degrees F
____ -26 Precipitation (Choose one)
1-Rain 4-Fog or mist
2-Snow 5-None
3-Ice

Appendix 2. California Tree Failure Report Form - *continued*

I. Briefly, in your own words, why did this tree failure occur?

II. Results of this tree failure (i.e., property damage, personal injury, etc.):

III. Damage estimate (costs for clean-up; indicate other costs if known):

IV. Additional information and comments:

Person reporting ____ Date ____________

Title ____________________________ Agency ______________________________

Address

____

Telephone ( ) ______________________ FAX ( ) ______________________

Please complete this report to the fullest extent, include any available photographs, and send to TREE FAILURE REPORT, UCCE, 625 Miramontes, Suite 200, Half Moon Bay, 94019-1942. This form may be photocopied. Direct any questions to Larry Costello or Katherine Jones,Cooperative Extension, San Mateo County (650) 726-9059, or to Alison Berry (530) 752-0130.

Additional copies of this form and return envelopes can be requested from Katherine Jones, UCCE, 625 Miramontes Suite 200, Half Moon Bay, CA 94019.

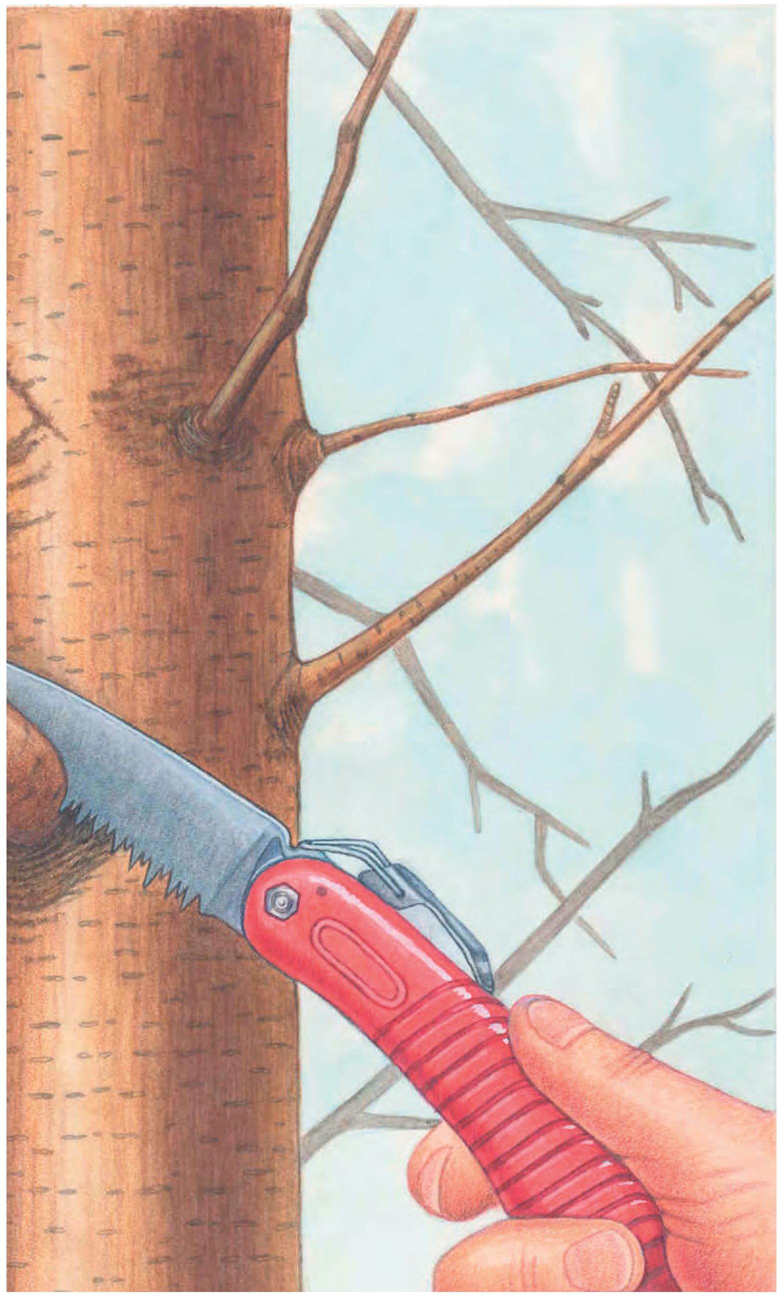
The information in this report will remain confidential, and will only be used to develop statistical and general information about tree failures by species and type of failure.

A.M. Berry, L.R. Costello, R.W. Harris

Revised 9/22/93

APPENDIX 3

HOW to Prune Trees



United States Department of Agriculture

Prepared by Forest Service

Northeastern Area State & Private Forestry

NA-FR-01-95

(*adapted version - February 2003*)

Table of Contents

Introduction

The objective of pruning is to produce strong, healthy, attractive plants. By understanding how, when and why to prune, and by following a few simple principles, this objective can be achieved.

Reasons For Pruning

The main reasons for pruning ornamental and shade trees include safety, health, and aesthetics. In addition, pruning can be used to stimulate fruit production and increase the value of timber. Pruning for safety (Fig. 1A) involves removing branches that could fall and cause injury or property damage, trimming branches that interfere with lines of sight on streets or driveways, and removing branches that grow into utility lines. Safety pruning can be largely avoided by carefully choosing species that will not grow beyond the space available to them, and have strength and form characteristics that are suited to the site.

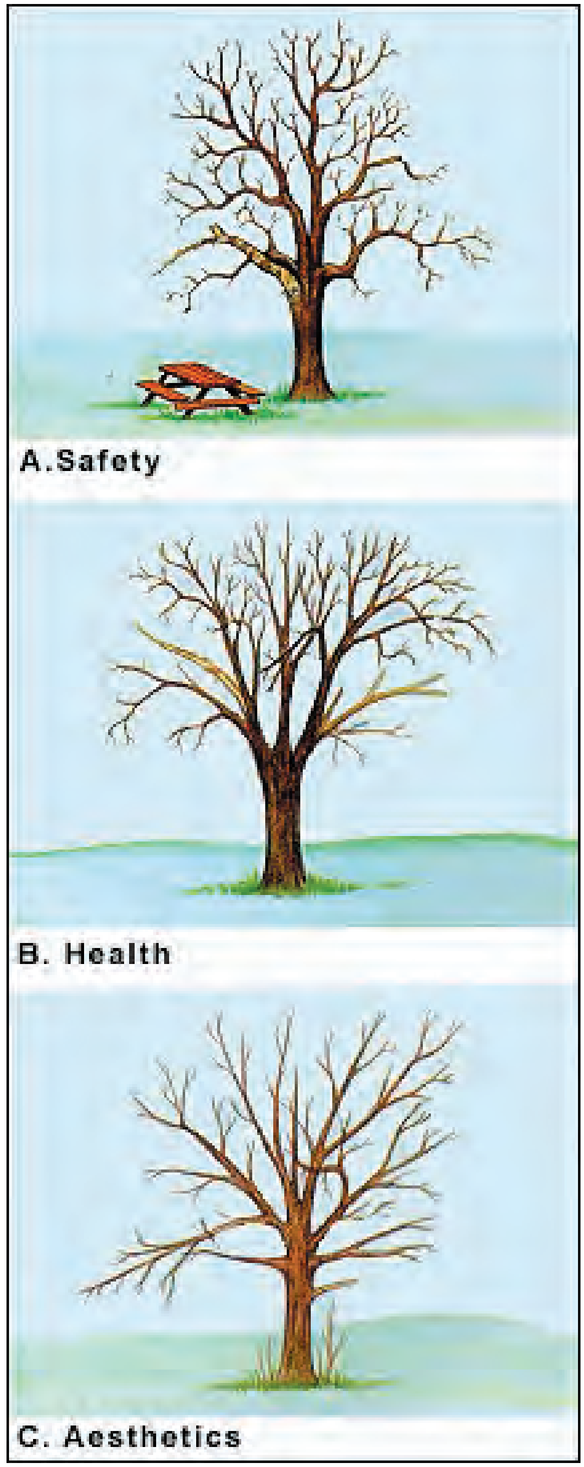


Figure 1. *Reasons for pruning*

Pruning for health (Fig. 1B) involves removing diseased or insect-infested wood, thinning the crown to increase airflow and reduce some pest problems, and removing crossing and rubbing branches. Pruning can best be used to encourage trees to develop a strong structure and reduce the likelihood of damage during severe weather. Removing broken or damaged limbs encourages wound closure. Pruning for aesthetics (Fig. 1C) involves enhancing the natural form and character of trees or stimulating flower production. Pruning for form can be especially important on open-grown trees that do very little self-pruning.

All woody plants shed branches in response to shading and competition. Branches that do not produce enough carbohydrates from photosynthesis to sustain themselves die and are eventually shed; the resulting wounds are sealed by woundwood (callus). Branches that are poorly attached may be broken off by wind and accumulation of snow and ice. Branches removed by such natural forces often result in large, ragged wounds that rarely seal. Pruning as a cultural practice can be used to supplement or replace these natural processes and increase the strength and longevity of plants.

Trees have many forms, but the most common types are pyramidal (excurrent) or spherical (decurrent). Trees with pyramidal crowns, e.g., most conifers, have a strong central stem and lateral branches that are more or less horizontal and do not compete with the central stem for dominance. Trees with spherical crowns, e.g., most hardwoods, have many lateral branches that may compete for dominance.

To reduce the need for pruning it is best to consider a tree's natural form. It is very difficult to impose an unnatural form on a tree without a commitment to constant maintenance. Pollarding and topiary are extreme examples of pruning to create a desired, unnatural effect. Pollarding is the practice of pruning trees annually to remove all new growth. The following year, a profusion of new branches is produced at the ends of the branches. Topiary involves pruning trees and shrubs into geometric or animal shapes. Both pollarding and topiary are specialized applications that involve pruning to change the natural form of trees. As topiary demonstrates, given enough care and attention, plants can be pruned into nearly any form. Yet just as proper pruning can enhance the form or character of plants, improper pruning can destroy it.

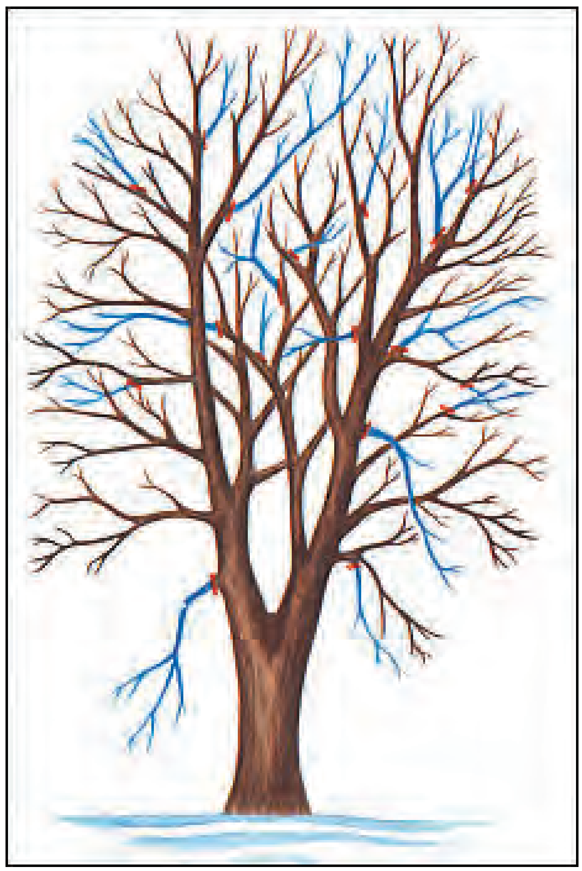


Figure 2. *Crown thinning - branches to be removed are shaded in blue; pruning cuts should be made at the red lines. No more than one-fourth of the living branches should be removed at one time.*

Pruning Approaches

Producing strong structure should be the emphasis when pruning young trees. As trees mature, the aim of pruning will shift to maintaining tree structure, form, health and appearance.

Proper pruning cuts are made at a node, the point at which one branch or twig attaches to another. In the spring of the year growth begins at buds, and twigs grow until a new node is formed. The length of a branch between nodes is called an internode.

The most common types of pruning are:

1. Crown Thinning (Fig. 2)

Crown thinning, primarily for hardwoods, is the selective removal of branches to increase light penetration and air movement throughout the crown of a tree. The intent is to maintain or develop a tree's structure and form. To avoid unnecessary stress and prevent excessive production of epicormic sprouts, no more than one-quarter of the living crown should be removed at a time. If it is necessary to remove more, it should be done over successive years.

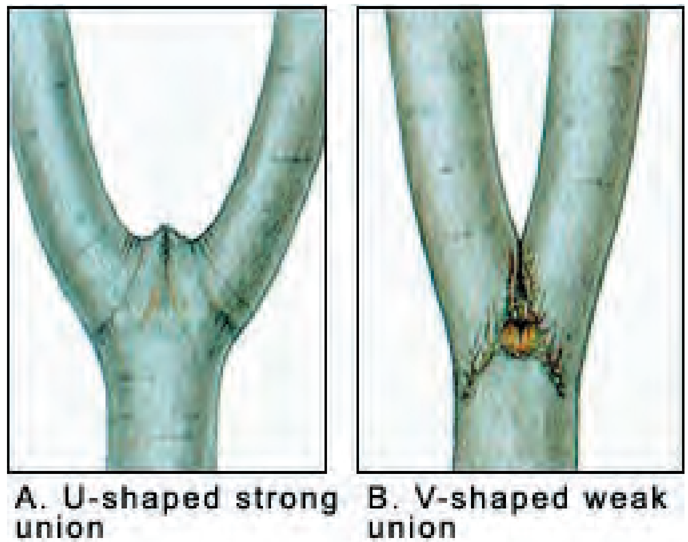


Figure 3. *Type of branch unions.*

Branches with strong U-shaped angles of attachment should be retained (Fig 3A). Branches with narrow, V-shaped angles of attachment often form included bark and should be removed (Fig. 3B). Included bark forms when two branches grow at sharply acute angles to one another, producing a wedge of inward-rolled bark between them. Included bark prevents strong attachment of branches, often causing a crack at the point below where the branches meet. Codominant stems that are approximately the same size and arise from the same position often form included bark. Removing some of the lateral branches from a codominant stem can reduce its growth enough to allow the other stem to become dominant.

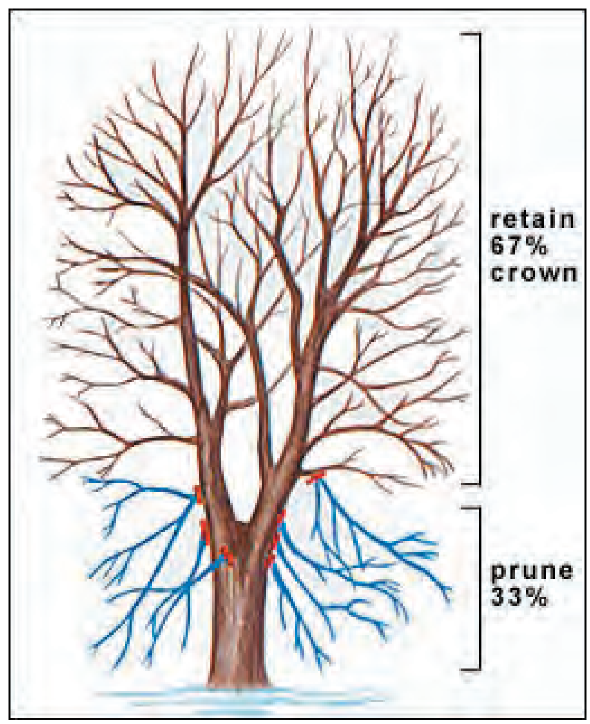


Figure 4. *Crown raising - branches to be removed are shaded in blue; pruning cuts should be made where indicated with red lines. The ratio of live crown to total tree height should be at least two-thirds.*

Lateral branches should be no more than one-half to three-quarters of the diameter of the stem at the point of attachment. Avoid producing "lion's tails," tufts of branches and foliage at the ends of branches, caused by removing all inner lateral branches and foliage. Lion's tails can result in sunscalding, abundant epicormic sprouts, and weak branch structure and breakage. Branches that rub or cross another branch should be removed.

Conifers that have branches in whorls and pyramidal crowns rarely need crown thinning except to restore a dominant leader. Occasionally, the leader of a tree may be damaged and multiple branches may become codominant. Select the strongest leader and remove competing branches to prevent the development of codominant stems.

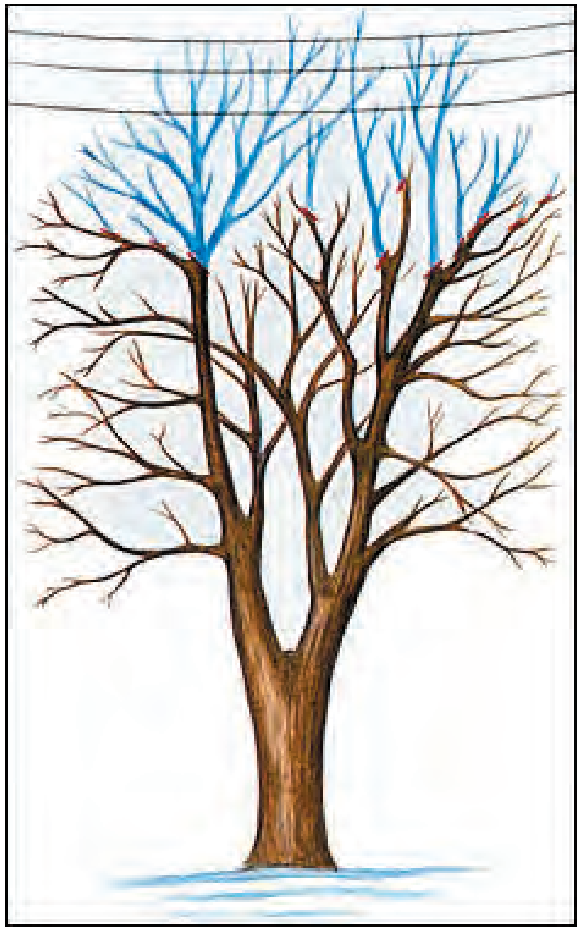


Figure 5. *Crown reduction - branches to be removed are shaded in blue; pruning cuts should be made where indicated with red lines. To prevent branch dieback, cuts should be made at lateral branches that are at least one-third the diameter of the stem at their union.*

2. Crown Raising (Fig. 4)

Crown raising is the practice of removing branches from the bottom of the crown of a tree to provide clearance for pedestrians, vehicles, buildings, lines of site, or to develop a clear stem for timber production. Also, removing lower branches on white pines can prevent blister rust. For street trees the minimum clearance is often specified by municipal ordinance. After pruning, the ratio of the living crown to total tree height should be at least two-thirds (e.g., a 12 m tree should have living branches on at least the upper 8 m).

On young trees "temporary" branches may be retained along the stem to encourage taper and protect trees from vandalism and sun scald. Less vigorous shoots should be selected as temporary branches and should be about 10 to 15 cm apart along the stem. They should be pruned annually to slow their growth and should be removed eventually.

3. Crown Reduction (Fig. 5)

Crown reduction pruning is most often used when a tree has grown too large for its permitted space. This method, sometimes called drop crotch pruning, is preferred to topping because it results in a more natural appearance, increases the time before pruning is needed again, and minimizes stress (see drop crotch cuts in the next section).

Crown reduction pruning, a method of last resort, often results in large pruning wounds to stems that may lead to decay. This method should never be used on a tree with a pyramidal growth form. A better long term solution is to remove the tree and replace it with a tree that will not grow beyond the available space.

Pruning Cuts

Pruning cuts should be made so that only branch tissue is removed and stem tissue is not damaged. At the point where the branch attaches to the stem, branch and stem tissues remain separate, but are contiguous. If only branch tissues are cut when pruning, the stem tissues of the tree will probably not become decayed, and the wound will seal more effectively.

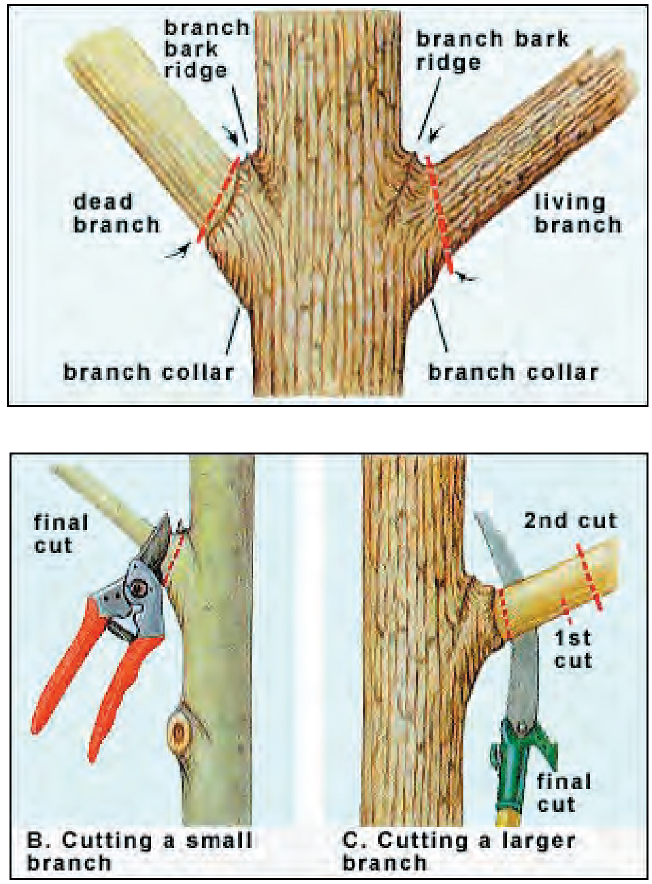


Figure 6. *Pruning cuts.*

1. Pruning living branches (Fig. 6)

To find the proper place to cut a branch, look for the branch collar that grows from the stem tissue at the underside of the base of the branch (Fig. 6A). On the upper surface, there is usually a branch bark ridge that runs (more or less) parallel to the branch angle, along the stem of the tree. A proper pruning cut does not damage either the branch bark ridge or the branch collar.

A proper cut begins just outside the branch bark ridge and angles down away from the stem of the tree, avoiding injury to the branch collar (Fig. 6B). Make the cut as close as possible to the stem in the branch axil, but outside the branch bark ridge, so that stem tissue is not injured and the wound can seal in the shortest time possible. If the cut is too far from the stem, leaving a branch stub, the branch tissue usually dies and woundwood forms from the stem tissue. Wound closure is delayed because the woundwood must seal over the stub that was left.

The quality of pruning cuts can be evaluated by examining pruning wounds after one growing season. A concentric ring of woundwood will form from proper pruning cuts (Fig. 6B). Flush cuts made inside the branch bark ridge or branch collar, result in pronounced development of woundwood on the sides of the pruning wounds with very little woundwood forming on the top or bottom (Fig. 7D). As described above, stub cuts result in the death of the remaining branch and woundwood forms around the base from stem tissues.

When pruning small branches with hand pruners, make sure the tools are sharp enough to cut the branches cleanly without tearing. Branches large enough to require saws should be supported with one hand while the cuts are made. If the branch is too large to support, make a three-step pruning cut to prevent bark ripping (Fig. 6C).

1. The first cut is a shallow notch made on the underside of the branch, outside the branch collar. This cut will prevent a falling branch from tearing the stem tissue as it pulls away from the tree.

2. The second cut should be outside the first cut, all the way through the branch, leaving a short stub.

3. The stub is then cut just outside the branch bark ridge/branch collar, completing the operation.

2. Pruning dead branches (Fig. 6)

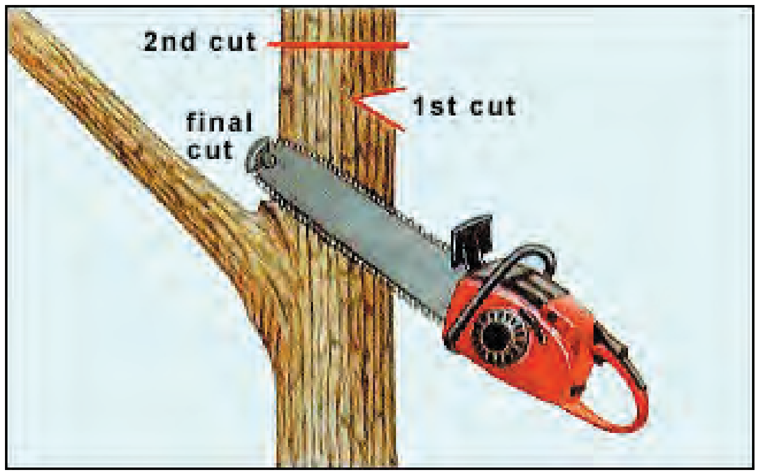


Figure 6. *Pruning cuts.*

Prune dead branches in much the same way as live branches. Making the correct cut is usually easy because the branch collar and the branch bark ridge can be distinguished from the dead branch because they continue to grow (Fig. 6A). Make the pruning cut just outside of the ring of woundwood tissue that has formed, being careful not to cause unnecessary injury (Fig. 6C). Large dead branches should be supported with one hand or cut with the three-step method, just as live branches. Cutting large living branches with the three step method is more critical because of the greater likelihood of bark ripping.

3. Drop Crotch Cuts (Fig. 6D)

A proper cut begins just above the branch bark ridge and extends through the stem parallel to the branch bark ridge. Usually, the stem being removed is too large to be supported with one hand, so the three cut method should be used.

1. With the first cut, make a notch on the side of the stem away from the branch to be retained, well above the branch crotch.

2. Begin the second cut inside the branch crotch, staying well above the branch bark ridge, and cut through the stem above the notch.

3. Cut the remaining stub just inside the branch bark ridge through the stem parallel to the branch bark ridge.

To prevent the abundant growth of epicormic sprouts on the stem below the cut, or dieback of the stem to a lower lateral branch, make the cut at a lateral branch that is at least one-third of the diameter of the stem at their union.

Pruning Practices That Harm Trees

Topping and tipping (Fig. 7A, 7B) are pruning practices that harm trees and should not be used. Crown reduction pruning is the preferred method to reduce the size or height of the crown of a tree, but is rarely needed and should be used infrequently.

Topping, the pruning of large upright branches between nodes, is sometimes done to reduce the height of a tree (Fig. 7A). Tipping is the practice of cutting lateral branches between nodes (Fig. 7B) to reduce crown width.

These practices invariably result in the development of epicormic sprouts, or in the death of the cut branch back to the next lateral branch below. These epicormic sprouts are weakly attached to the stem and eventually will be supported by a decaying branch.

Improper pruning cuts cause unnecessary injury and bark ripping (Fig. 7C). Flush cuts injure stem tissues and can result in decay (Fig. 7D). Stub cuts delay wound closure and can provide entry to canker fungi that kill the cambium, delaying or preventing woundwood formation (Fig. 7E).

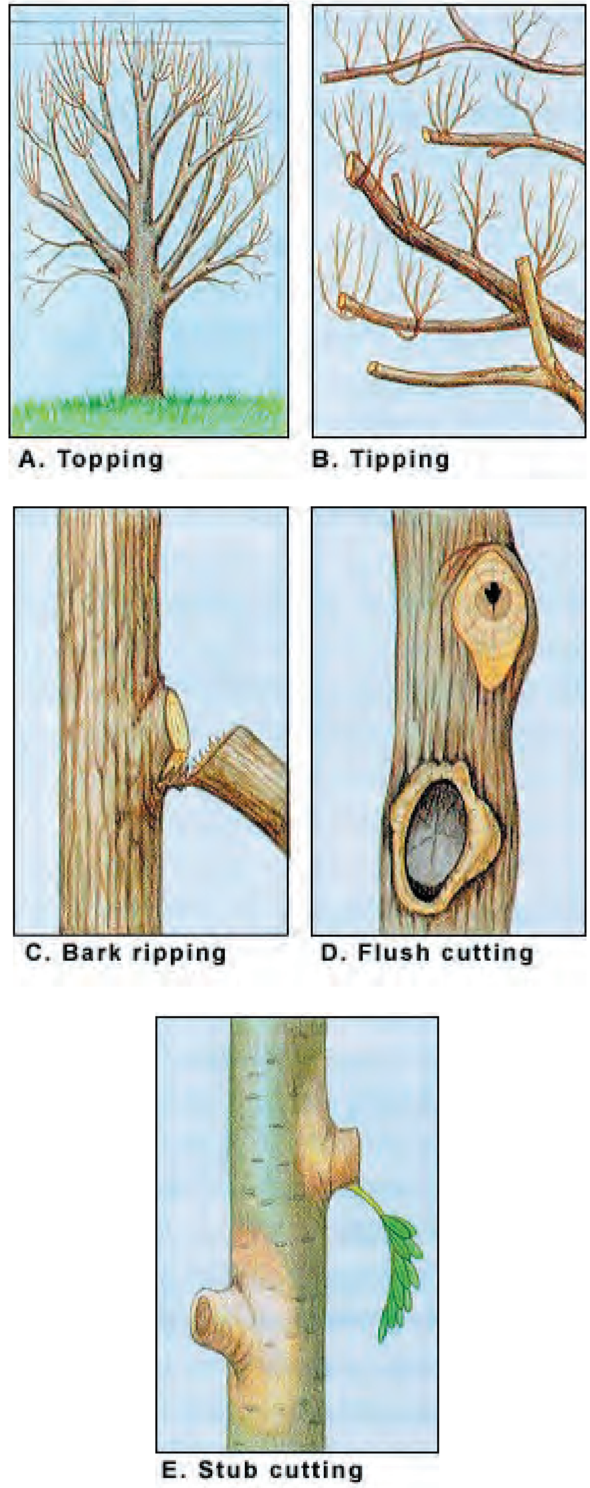


Figure 7. *Practices that harm trees.*

When to Prune

Conifers may be pruned any time of year, but pruning during the dormant season may minimize sap and resin flow from cut branches.

Hardwood trees and shrubs without showy flowers: prune in the dormant season to easily visualize the structure of the tree, to maximize wound closure in the growing season after pruning, to reduce the chance of transmitting disease, and to discourage excessive sap flow from wounds.

Recent wounds and the chemical scents they emit can actually attract insects that spread tree disease. In particular, wounded elm wood is known to attract bark beetles that harbor spores of the Dutch elm disease fungus, and open wounds on oaks are known to attract beetles that spread the oak wilt fungus. Take care to prune these trees during the correct time of year to prevent spread of these fatal diseases. Contact your local tree disease specialist to find out when to prune these tree species in your area. Usually, the best time is during the late fall and winter.

Flowering trees and shrubs: these should also be pruned during the dormant season for the same reasons stated above; however, to preserve the current year's flower crop, prune according to the following schedule:

- Trees and shrubs that flower in early spring (redbud, dogwood, etc.) should be pruned immediately after flowering (flower buds arise the year before they flush, and will form on the new growth).
- Many flowering trees are susceptible to fireblight, a bacterial disease that can be spread by pruning. These trees, including many varieties of crabapple, hawthorn, pear, mountain ash, flowering quince and pyracantha, should be pruned during the dormant season. Check with your county extension agent or a horticulturist for additional information.
- Trees and shrubs that flower in the summer or fall always should be pruned during the dormant season (flower buds will form on new twigs during the next growing season, and the flowers will flush normally).

Dead branches: can be removed any time of the year.

Pruning Tools

Proper tools are essential for satisfactory pruning (Fig.6). The choice of which tool to use depends largely on the size of branches to be pruned and the amount of pruning to be done. If possible, test a tool before you buy it to ensure it suits your specific needs. As with most things, higher quality often equates to higher cost.

Generally speaking, the smaller a branch is when pruned, the sooner the wound created will seal. Hand pruners are used to prune small branches (under 2.5 cm diameter) and many different kinds are available. Hand pruners can be grouped into by-pass or anvil styles based on the blade configuration. Anvil style pruners have a straight blade that cuts the branch against a small anvil or block as the handles are squeezed. By-pass pruners use a curved cutting blade that slides past a broader lower blade, much like scissors. To prevent unnecessary tearing or crushing of tissues, it is best to use a by-pass style pruner. Left- or right-handed types can be purchased.

Slightly larger branches that cannot be cut with a hand pruner may be cut with small pruning saws (up to 10 cm) or lopping shears (up to 7 cm diameter) with larger cutting surfaces and greater leverage. Lopping shears are also available in by-pass and anvil styles. For branches too large to be cut with a hand pruner or lopping shears, pruning saws must be used. Pruning saws differ greatly in handle styles, the length and shape of the blade, and the layout and type of teeth. Most have tempered metal blades that retain their sharpness for many pruning cuts. Unlike most other saws, pruning saws are often designed to cut on the "pull-stroke."

Chain saws are preferred when pruning branches larger than about 10 cm. Chainsaws should be used only by qualified individuals. To avoid the need to cut branches greater than 10 cm diameter, prune when branches are small.

Pole pruners must be used to cut branches beyond reach. Generally, pruning heads can cut branches up to 4.4 cm diameter and are available in the by-pass and anvil styles. Once again, the by-pass type is preferred. For cutting larger branches, saw blades can be fastened directly to the pruning head, or a separate saw head can be purchased. Because of the danger of electrocution, pole pruners should not be used near utility lines except by qualified utility line clearance personnel.

To ensure that satisfactory cuts are made and to reduce fatigue, keep your pruning tools sharp and in good working condition. Hand pruners, lopping shears, and pole pruners should be periodically sharpened with a sharpening stone. Replacement blades are available for many styles. Pruning saws should be professionally sharpened or periodically replaced. To reduce cost, many styles have replaceable blades.

Tools should be clean and sanitized as well as sharp. Although sanitizing tools may be inconvenient and seldom practiced, doing so may prevent the spread of disease from infected to healthy trees on contaminated tools. Tools become contaminated when they come into contact with fungi, bacteria, viruses and other microorganisms that cause disease in trees. Most pathogens need some way of entering the tree to cause disease, and fresh wounds are perfect places for infections to begin. Microorganisms on tool surfaces are easily introduced into susceptible trees when subsequent cuts are made. The need for sanitizing tools can be greatly reduced by pruning during the dormant season.

If sanitizing is necessary it should be practiced as follows: before each branch is cut, sanitize pruning tools with either 70% denatured alcohol, or with liquid household bleach diluted 1 to 9 with water (1 part bleach, 9 parts water). Tools should be immersed in the solution, preferably for 1-2 minutes, and wood particles should be wiped from all cutting surfaces. Bleach is corrosive to metal surfaces, so tools should be thoroughly cleaned with soap and water after each use.

Treating Wounds

Tree sap, gums, and resins are the natural means by which trees combat invasion by pathogens. Although unsightly, sap flow from pruning wounds is not generally harmful; however, excessive "bleeding" can weaken trees.

When oaks or elms are wounded during a critical time of year (usually spring for oaks, or throughout the growing season for elms) either from storms, other unforeseen mechanical wounds, or from necessary branch removals some type of wound dressing should be applied to the wound. Do this immediately after the wound is created. In most other instances, wound dressings are unnecessary, and may even be detrimental. Wound dressings will not stop decay or cure infectious diseases. They may actually interfere with the protective benefits of tree gums and resins, and prevent wound surfaces from closing as quickly as they might under natural conditions. The only benefit of wound dressings is to prevent introduction of pathogens in the specific cases of Dutch elm disease and oak wilt.

Pruning Guidelines

To encourage the development of a strong, healthy tree, consider the following guidelines when pruning.

General

- Prune first for safety, next for health, and finally for aesthetics.
- Never prune trees that are touching or near utility lines; instead consult your local utility company.
- Avoid pruning trees when you might increase susceptibility to important pests (e.g. in areas where oak wilt exists, avoid pruning oaks in the spring and early summer; prune trees susceptible to fireblight only during the dormant season).
- Use the following decision guide for size of branches to be removed: 1) under 5 cm diameter - go ahead, 2) between 5 and 10 cm diameter - think twice, and 3) greater than 10 cm diameter - have a good reason.

Crown Thinning

- Assess how a tree will be pruned from the top down.
- Favor branches with strong, U-shaped angles of attachment. Remove branches with weak, V-shaped angles of attachment and/or included bark.
- Ideally, lateral branches should be evenly spaced on the main stem of young trees.
- Remove any branches that rub or cross another branch.
- Make sure that lateral branches are no more than one-half to three-quarters of the diameter of the stem to discourage the development of co-dominant stems.
- Do not remove more than one-quarter of the living crown of a tree at one time. If it is necessary to remove more, do it over successive years.

Crown Raising

- Always maintain live branches on at least two-thirds of a tree's total height. Removing too many lower branches will hinder the development of a strong stem.
- Remove basal sprouts and vigorous epicormic sprouts.

Crown Reduction

- Use crown reduction pruning only when absolutely necessary. Make the pruning cut at a lateral branch that is at least one-third the diameter of the stem to be removed.
- If it is necessary to remove more than half of the foliage from a branch, remove the entire branch.

Glossary

Branch Axil: the angle formed where a branch joins another branch or stem of a woody plant.

Branch Bark Ridge: a ridge of bark that forms in a branch crotch and partially around the stem resulting from the growth of the stem and branch tissues against one another.

Branch Collar: a "shoulder" or bulge formed at the base of a branch by the annual production of overlapping layers of branch and stem tissues.

Crown Raising: a method of pruning to provide clearance for pedestrians, vehicles, buildings, lines of sight, and vistas by removing lower branches.

Crown Reduction Pruning: a method of pruning used to reduce the height of a tree. Branches are cut back to laterals that are at least one-third the diameter of the limb being removed.

Crown Thinning: a method of pruning to increase light penetration and air movement through the crown of a tree by selective removal of branches.

Callus: see woundwood.

Decurrent: a major tree form resulting from weak apical control. Trees with this form have several to many lateral branches that compete with the central stem for dominance resulting in a spherical or globose crown. Most hardwood trees have decurrent forms.

Epicormic Sprout: a shoot that arises from latent or adventitious buds; also known as water sprouts that occur on stems and branches and suckers that are produced from the base of trees. In older wood, epicormic shoots often result from severe defoliation or radical pruning.

Excurrent: a major tree form resulting from strong apical control. Trees with this form have a strong central stem and pyramidal shape. Lateral branches rarely compete for dominance. Most conifers and a few hardwoods, such as sweetgum and tuliptree, have excurrent forms.

Flush Cuts: pruning cuts that originate inside the branch bark ridge or the branch collar, causing unnecessary injury to stem tissues.

Included Bark: bark enclosed between branches with narrow angles of attachment, forming a wedge between the branches.

Pollarding: the annual removal of all of the previous year's growth, resulting in a flush of slender shoots and branches each spring.

Stub Cuts: pruning cuts made too far outside the branch bark ridge or branch collar, that leave branch tissue attached to the stem.

Tipping: a poor maintenance practice used to control the size of tree crowns; involves the cutting of branches at right angles leaving long stubs.

Topping: a poor maintenance practice often used to control the size of trees; involves the indiscriminate cutting of branches and stems at right angles leaving long stubs. Synonyms include rounding-over, heading-back, dehorning, capping and hat-racking. Topping is often improperly referred to as pollarding.

Topiary: the pruning and training of a plant into a desired geometric or animal shape.

Woundwood: lignified, differentiated tissues produced on woody plants as a response to wounding (also known as callus tissue).

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How to Prune Trees was written to help people properly prune the trees they care about. If you doubt your ability to safely prune large trees, please hire a professional arborist. Information in this publication can be used to interview and hire a competent arborist.

Glossary

Balled-and-burlapped = Trees and shrubs harvested with the root system enclosed in a soil ball that is held together with burlap and twine, a wire basket, or both.

Bare-root = Trees and shrubs harvested with an exposed root system and with no soil covering their roots.

Barrier zone = An anatomical and chemical wall formed by the cambium tissue as part of the compartmentalization of decay within trees. It separates wood formed before wounding from wood that will form after wounding.

Bole = (Trunk) The main stem of a tree below its first major branch.

Branch bark ridge = Ridge of bark that forms at the junction of the branch and stem. An upturned branch bark ridge indicates a strong branch union. An inrolled branch bark ridge indicates a weak branch union.

Branch collar = A "shoulder" or bulge formed at the base of a branch by the annual production of overlapping layers of branch and stem tissues.

Cabling and bracing = The practice of adding a support system to a tree to reduce the stress on weak branch unions. Materials used include both flexible and rigid braces, metal cables, synthetic-fiber rope, and metal anchoring devices.

Cambium = Layer of living cells between the bark and wood surface that produces a new layer of wood each year.

Canker = Area of dead bark and cambium anywhere on the tree's surface. Cankers can be caused by fungi, insects, weather, or mechanical damage such as lantern-burns or mowers.

Canker-rot = Fungal infection that causes an external canker and extensive internal decay.

Canopy = The topmost layer of twigs and foliage in a tree or group of trees.

Cavity = Hollow area in stem, branch, or root where the wood has decayed and is now missing.

Codominant stems = Stems that are equal in size and relative importance.

Compartmentalization = A physiological process which creates chemical and mechanical boundaries to resist organisms, such as decay fungi. It results in the separation of healthy tissues and infected tissues by reaction and barrier zones.

Conk = Fruiting body of a fungus. Fruiting bodies on trees indicate advanced decay.

Container-grown = Plant material grown in a nursery and placed in a container before shipping.

Crack = Separation of the wood, a fissure, or a deep split in the bark and wood of a tree.

Critical root radius (CRR) = Defines the area of the root system nearest the stem that is critical for the stability and vitality of the tree. The area is determined by allowing 1.5 feet of root radius for each inch of stem diameter at breast height (d.b.h.).

Crown = Portions of the tree above the main stem or trunk; the branches, twigs and leaves.

Deadwood = Non-living wood within a tree. Deadwood is structurally unsound because of pre-existing defects and/or rapid decomposition of the wood.

Decay = Fungal and bacterial decomposition of woody tissues. The decay process reduces structural soundness and stability over a period of years.

Decayed wood = Wood that has rooted or is missing.

Decline = General loss of vigor. It is usually accompanied by crown symptoms, such as branch dieback.

Defect = Any structural weakness or deformity in the tree's branches, stem, or root system. Tree defects can be of two kinds: injury or disease that seriously weakens the stems, roots, or branches or trees, predisposing them to fail *or* structural problems arising from poor tree architecture, including V-shaped crotches in stems and branches that lead to weak unions, shallow rooting habits, inherently brittle wood, etc.

Defective tree = Tree with one or more defects.

D.B.H. = Diameter of the tree measured at breast height, 4.5 feet from the ground.

Dieback = Death of a branch or branches, generally from the tip towards the main stem.

Dripline = The area directly below the branches of a tree.

Epicormic branch = Branches that form on large, old stems or branches as a result of a serious disturbance, such as, improper pruning, disease or extensive dieback in the crown. Epicormic branches usually form weak unions with their stems.

Failure = Breakage of stems or branches or loss of mechanical support in the root system. Trees can fail due to defects or during severe storms.

Fire scar = Triangular scar at the base of a tree due to a past fire. A cavity is generally associated with a fire scar.

Fracture = Cracking or breakage of wood in branches, stems or roots.

Fruiting bodies = Structures where fungal spores are produced. Examples are mushrooms, conks, and shelf fungi. They are indicators of advanced decay.

Hazard tree = A tree that has structural defects in the roots, stem, or branches that may cause the tree or tree part to fail, where such failure may cause property damage or personal injury.

Improper pruning = When removing branches, cutting into the branch collar, cutting flush to the stem, leaving long branch stubs, or removing too many branches at one time.

Included bark = Layers of bark that have formed inside the tree at a branch union or fork between codominant stems. These ingrown layers of bark make a branch union weak.

Increment core = Sample of wood extracted from a tree by an increment borer. The core shows the annual rings.

Inrolled bark or wood = Bark or wood tissues that have turned inward and continue to grow inside the tree. See rams-horning.

Inrolled crack = See Rams-horning.

Inspection = Systematic method of examining trees for visible defects and assessing risk of potential failure.

Lean = Describes a tree trunk that is not growing perpendicular to the ground. If the angle is greater than 45 degrees, it may be hazardous.

Natural target pruning = Method of removing branches that preserves the tree's natural defenses. Only branch tissue is removed leaving the branch collar intact. See diagrams for conifers and hardwoods in the Appendix 3.

Poor architecture = Growth pattern indicates structural imbalance and weakness in the branch, stem, or tree.

Rams-horning = Process that occurs when two wound margins grow together and their bark and wood layers begin to turn inward. The inrolling tissues curl and form the rams-horn over a period of years.

Root collar = The base of the stem where the primary roots first begin to branch away from the stem. Normally, this area appears swollen or flared and is located near or at the soil level.

Seam = Evidence that a tree has successfully closed over a wound. Wound margins meet and grow together. In time, seams become indistinct and less hazardous.

Shell = In trees with wood decay, the shell is the newest and outermost layers of wood that are decay free. Safe shell limits require 1 inch of sound shell for each 6 inches of stem diameter.

Snag tree = A dead, usually hollow or limbless, tree that is left on the site for wildlife habitat purposes.

Stem girdling roots (SGR) = Roots that encircle or run tangentially to a tree's stem, eventually compressing the woody and non-woody tissues of the stem.

Target = A person or object within 1.5 times the tree height of a defective tree.

Tipping = Removal of branch tips, usually to decrease the tree's width.

Topping = Removal of the top portion of a tree's live crown, usually to decrease the tree's height.

Tree architecture = Natural growth habit or branching pattern that is characteristic for each tree species.

Tree lawns = The planting area that occurs between street curbs and sidewalks. Also commonly referred to as boulevards, parkways, or medians.

Tree risk management plan = A management plan that focuses on the prevention and correction of hazardous tree defects, and provides a written, systematic procedure for inspecting and evaluating hazardous trees and correcting them before they become unacceptable risks.

Uneven-aged management system = A management system where trees of varying species and with different life expectancies are planted as replacement trees.

Weak branch union = An epicormic branch or branch union with included bark.

Windthrow = Failure of the root system in anchoring the tree to the ground. Often trees are blown over by winds during severe storms.

Wound = Any injury to the bark, cambium, or wood.

Woundwood = Lignified, differentiated tissues produced on woody plants as a response to wounding (also known as callus tissue).

Index

A

B

C

D

E

F

G

H

Q

R

S

T

U

V

W