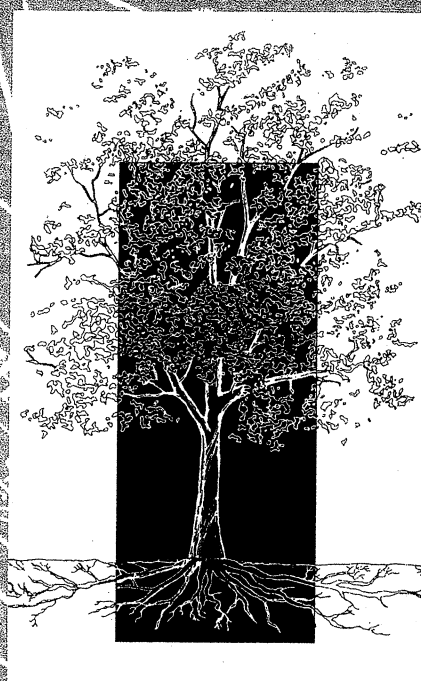
Trees and Development

A Technical Guide to Preservation of Trees During Land Development



Lot 1

Lot 2

Lot 3

Nelda Matheny and James R. Clark

CHAPTER 2

Primer on Tree Biology

Trees do not grow in a random manner; they grow in predictable ways. The patterns by which buds, leaves, trunks, branches, flowers, fruit, and roots develop are defined by a genetic blueprint. Every aspect of a tree's growth adheres to a genetic plan set down through millions of years of evolution. The outward expression of this plan, reflected in characteristics such as tree height and location of flowers, is influenced by the physical environment surrounding the tree. Sunlight, wind, water, minerals, and other factors play a role in the tree's development. Over time, the interaction between genetics and environment results in trees that are marvelously adapted to the sites on which they naturally occur.

If trees are to be preserved during the development of a site, three aspects of a tree's biology must be understood. First, the growth patterns of the tree and the specific requirements of each species (or genetic type) must be considered. Second, the growth of a tree in relation to other trees in the woodland or forest must be assessed. Finally, the tree's potential for future growth and survival must be evaluated, recognizing that the existing environmental conditions, those under which the tree has grown for many years, will change.

The objective of this chapter is to introduce tree growth and development to people involved in the development process. This chapter is intended to provide basic concepts about tree growth as well as some terminology for tree care activities.

HOW TREES GROW

All trees have the same basic structure: roots, trunk, branches, buds, leaves, flowers, and fruit (Figure 2.1).While all trees have these features in common, their forms (the shape created by the trunk and branches) vary widely. Some trees have a single trunk; others have multiple stems. Some have upright, narrow forms, while others are rounded and spreading. Some trees (evergreens) hold their leaves for several years; others (deciduous) shed them each fall. Whatever the specific form, the pattern of growth of the roots, trunk, branches, buds, and leaves is the result of the interaction of the tree's genetic blueprint with the surrounding environment.

For a given environment, trees grow in a manner that optimizes their ability to function, that is, to compete with adjacent trees for light and resources,

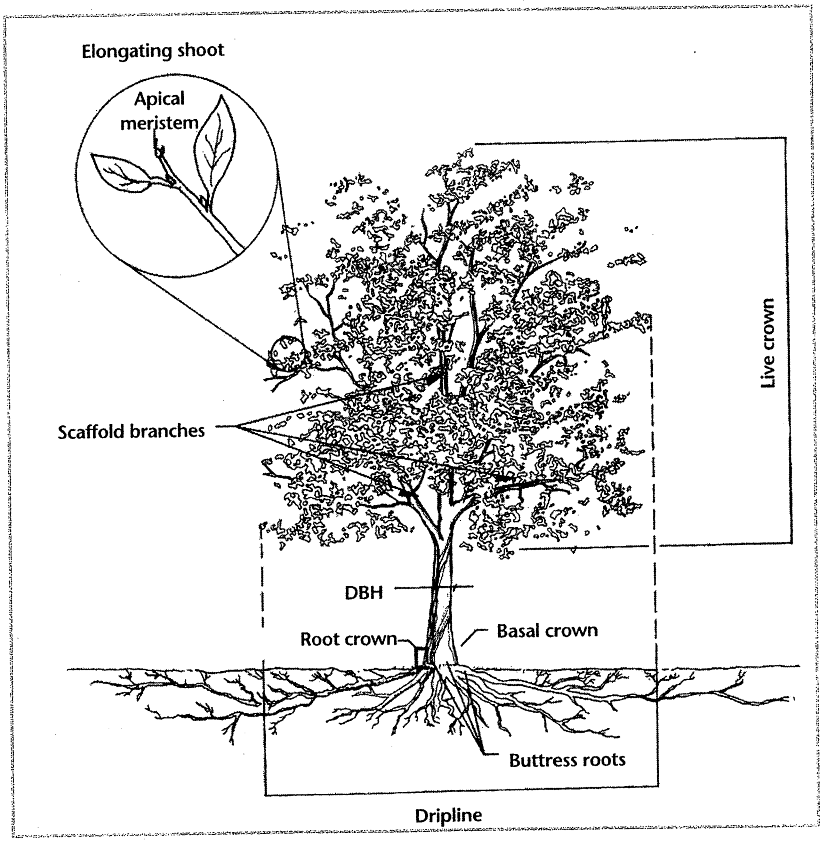


FIGURE 2.1 Components of a tree (DBH = diameter of the trunk measured 4½ feet above ground).

Tree Structure: Frequently Used Terms

Absorbing roots
Common term describing the fine, nonwoody, short-lived roots that absorb water and mineral nutrients and that are often infected with beneficial organisms

Basal area
The cross-sectional area of the trunk based upon measurement at 54 inches (4½ feet) above grade

Basal (or trunk) flare
The increased diameter where the roots and trunk meet (also known as the root flare or buttress)

Broad-leaved
Trees whose foliage is flat and broad

Buttress roots
Large, woody roots emerging from the base of the trunk; contribute to basal flare

Central leader
The main stem, trunk, or bole

Conifer
Trees that bear cones, usually having needled or scale-like foliage

Crown (or canopy)
The leaves and branches of a tree

DBH
Diameter at breast height; the diameter of the trunk measured 54 inches (4½ feet) above grade

Deciduous
Trees that lose their leaves each year

Decurrent
Trees that lack a central leader; the crown is composed of a number of equal-sized branches

Dripline
The edge of the canopy

Evergreen
Trees that maintain foliage throughout the year

Excurrent
Trees having a strong central leader, normally pyramidal in form

Feeder roots
Common term to describe fine, nonwoody, short-lived roots that absorb water and mineral nutrients (see Absorbing Roots)

Multi-trunked
Tree with more than one trunk arising at or near the ground

Root crown
The point at which the trunk and buttress roots meet

Scaffold branches
The major structural support branches that attach to the trunk

Stand
Community of trees sufficiently uniform in species, size, arrangement, and age to be distinguishable as a group

Taper
The change in diameter associated with height or length; related to strength

Zone of rapid taper
The area of root growth where the diameter of the root rapidly diminishes, usually measured 5 to 10 feet from the base of the trunk

to successfully reproduce, to tolerate disturbance, and to tolerate extremes in climate. As a result, there exists within a tree an intimate balance among its component parts and processes. The size and volume of the root area are large enough to adequately supply the crown with water. The transport capacity of the stem is large enough to deliver water to the leaves. The trunk and root systems are strong enough to support the mass and structure of the crown. The amount of foliage and storage capacity are large enough to meet the energy needs of the tree.

The component parts of a tree depend upon each other for growth materials and support. At a given time, the parts of the tree exist in balance with one another. Any alteration to either the environment or to any part of the tree necessitates an adjustment in this internal balance. This process of adjustment is acclimation (also acclimatization). For example, when young trees are transplanted, most of the root system is removed. Once planted, the trees acclimate to new growing conditions by regenerating lost roots. A similar process occurs when construction occurs around trees. They must also acclimate to a new physical environment. The ability to make this adjustment is constrained by the species of tree, its age, structure, and vigor. Not all trees can acclimate to the degree required for their survival.

The Trunk and Crown

The trunk and branches support the foliage and act as a transport highway for water, carbohydrates, and minerals between roots and leaves. In a mature tree, the bulk of its mass is located in the woody parts.

Commonly Encountered Structural Defects in Trees

Cankers
Surface injuries caused by fungi or bacteria

Cavity
An open wound characterized by the presence of decay

Codominant trunks
Stems or branches of equal diameter, often weakly attached

Conks
Fruiting bodies of decay fungi

Decay
Degradation of wood by fungi and bacteria

Decline
Loss of vigor of the entire tree; may be associated with root loss, rendering the tree prone to failure

Dieback
Death of twigs and branches in the upper crown

End weight
Accumulation of mass at the end of a branch

Epicormic shoots
Shoots that arise from latent or adventitious buds

Failure
Loss of branch or trunk due to structural defects

Girdling roots
Roots that encircle the base of the trunk and/or the buttress roots, and which may prevent their growth

Lean
Departure of the trunk from the vertical

Low canopy
Foliage and branches that are close to the ground; therefore, construction within the dripline will require extensive pruning for clearance

Wounds
Injuries on the surface of a trunk or branch

Leaves produce carbohydrates that sustain growth and defend against pests and decay. A healthy, vigorous tree requires a full, dense canopy of leaves to capture solar energy. Any injury or treatment that reduces the amount of foliage will reduce the tree's capacity to produce food and maintain good health. Because the amount of foliage depends on other parts of a tree, any loss in roots, transport capacity, or support will lessen the mass of leaves that can be supported.

Mature trees attain their characteristic large stature through the elongation of shoots as well as expansion of the trunk, roots, and branches. Growth (the creation of new cells and tissues) actually occurs in discrete locations, called meristems. Trees have two types of meristems. The first is associated with elongation of shoots and roots; the second with diameter growth. In shoots, the meristems are contained within protective structures known as buds. In roots, the meristem is found at the ends of small white tips. The activity of these tissues produces the increase in height and spread of the canopy and root system.

The second type of meristem is called the cambium (Figure 2.2). It is responsible for growth in diameter of the trunk, branches, and woody roots. The cambium is a very thin tissue (one or more cells thick), just beneath the bark throughout the tree. If lost through injury or disease, the cambium cannot regenerate in place.

The cambium produces both wood (xylem) and inner bark (phloem). These tissues conduct water, mineral elements, carbohydrates, and other substances. In most temperate climates, the characteristic rings found in the stem represent the increment in wood produced in one growing season. Thus, a tree with 100 annual rings is at least 101 years old (the first rings develop in the young seedling).

While a tree's trunk may be quite large, only a very small amount of xylem and phloem is functional.

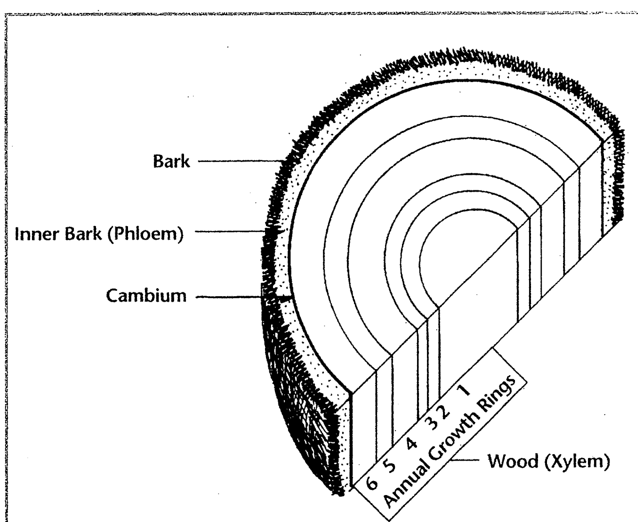


FIGURE 2.2 The cambium is the thin tissue just beneath the bark and is responsible for growth in diameter of the trunk, branches, and woody roots. To the outside, it produces the phloem, which transports carbohydrates. To the inside, the cambium produces xylem, which transports water and mineral elements. Wood is the collective mass of all annual growth rings.

The active elements are found just beneath the outer bark and in the outermost annual rings.

Contrast the development of a tree's trunk with that of a pipe (Figure 2.3). In a pipe, structural support is provided by a thin shell of material. The bulk of the structure is open, allowing transport of materials. In a tree trunk, the situation is exactly the opposite. Only a thin outer shell of tissue is alive—actively producing new cells and providing transport and storage. The vast bulk of the trunk provides only structural support.

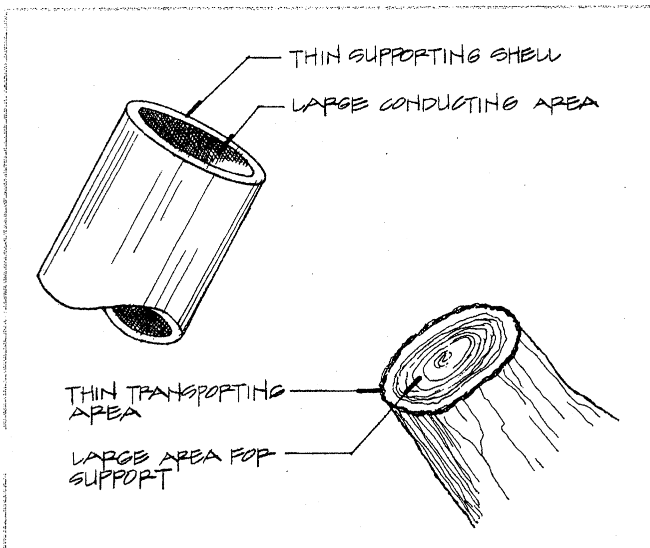


FIGURE 2.3 The structure and function of a tree stem and pipe differ in significant ways. In a pipe, support is provided by a thin shell, with the center open for transport. In a tree trunk, only a thin outer shell is active in transport, with the bulk of the trunk providing support.

Without this narrow shell of functional tissue composed of the cambium, phloem, and active xylem, no water would be moved, no minerals transported, no carbohydrates conducted. When this thin band is broken by injury or disease, the tree can die.

An understanding of meristems and their purpose in the tree leads to an important fact: any injury to meristematic tissues has wide-ranging consequences. While compensatory replacement of shoot and root tips often occurs, this cannot happen with the cambium. Mechanical injury that tears or breaks the bark will kill the cambium (Photo 2.1). The integrity of the cambium is so critical that injuries of 30 to 50 percent of the circumference of the trunk can cause death.

TREE STRUCTURE AND STABILITY

As the tree grows larger, it must continually overcome the force of gravity in order to remain upright. The mass of branches, stems, and leaves is enormous. The tree must also remain upright in strong winds and during snow and ice storms.

The adaptations made by a tree to meet the challenge posed by these forces are numerous, ranging from an increase in wood strength to the shedding of leaves each year. The crowns of most conifers form a cone. This form is called excurrent—the branches radiate from a strong central stem (Photo 2.2). With this pattern of growth, the stress created by wind and snow is distributed proportionally along the stem, thereby increasing stability.

PHOTO 2.1 Mechanical injuries remove the bark and kill the cambium below it, creating the entry point for decay.

This is not the case with most broad-leaved trees, which have an open, spreading form. In these species, the pattern of crown development is decurrent (Photo 2.3). Instead of branches radiating from a single

PHOTO 2.2 Most conifers and many deciduous trees have an excurrent form, in which branches radiate out from a central stem or trunk.

PHOTO 2.3 Most deciduous trees, especially as they mature, have a decurrent form, composed of a number of large branches.

trunk, the crowns of these trees are formed by a number of equally sized branches. Most decurrent trees lose their leaves each autumn. Their bare branches accumulate less snow and ice. Wind passes easily through them. The stress from weight and wind during winter, therefore, is less than that experienced by trees with an excurrent form.

Most trees grow so that the stresses created by wind, precipitation, and gravity are equally distributed along the stem. No point on the trunk becomes a focal point for stress because all points are under a similar load. The result of this growth pattern is taper—the change in diameter of the trunk (and branches) with length. The diameter is greatest at the base, which supports the greatest load and anchors the tree.

Taper develops as the tree sways in the wind and increases in mass. In response to these forces, the trunk grows larger in diameter. A tree growing in an open, windy environment will develop greater taper than one growing in a dense forest stand. It will also be smaller in height and greater in spread.

Branches are subject to the forces of gravity, snow, ice, and wind as well. They also develop taper along their length in response to these conditions. As shoots elongate, diameter is increased near the point of attachment to the trunk. This process is enhanced when the foliage on the branch is evenly distributed along its length. A situation in which the foliage is concentrated at the tip of the branch is known as end weight (Photo 2.4). Excessive end weight, whether it occurs naturally or through improper pruning, is a significant structural defect.

Branches are connected to the rest of the tree by either another branch or at the trunk. The strongest attachments are those in which one member is smaller in size than the one to which it is attached (Photo 2.5); for example, a scaffold limb attached to the main trunk, or a small lateral branch attached to a larger scaffold branch. The weakest attachments are those in which the two members (either branches or trunks) are codominant (equal in size) (Photo 2.6). When this occurs, the members fail to develop strong connecting wood between them. This situation is made worse when the codominant members are pushed against one another.

PHOTO 2.4 Branches with a disproportionate amount of foliage at the ends are said to have "end weight." Limbs with this form are susceptible to failure (note that the branch has been moving downward and is separated from the rest of the canopy).

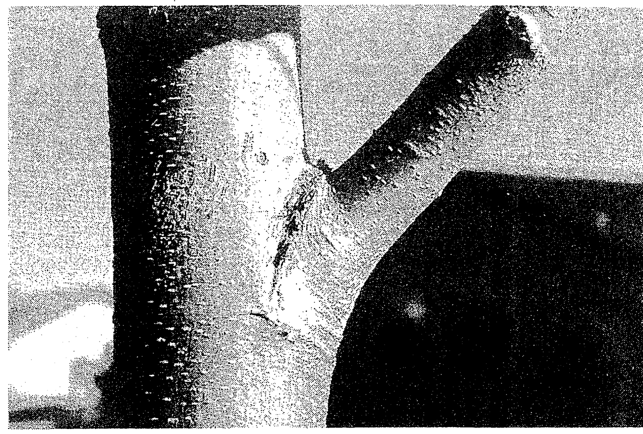


PHOTO 2.5 The strongest attachments between branch and stem develop when the branch is smaller in size than the trunk to which it is attached.

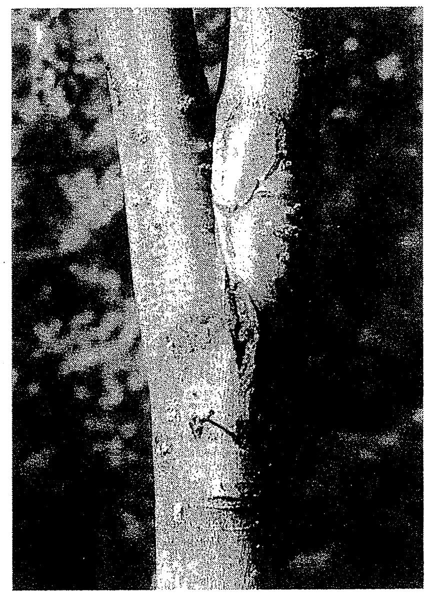


PHOTO 2.6 Codominant attachments occur where the component branches are equal in size. Because strong wood connecting the branches does not develop, these attachments are often weak and the site of failure.

TREE DEFENSE AND WOUND RESPONSE

Injuries to trees do not "heal" like wounds in animals do. Trees cannot replace injured parts with new tissues. Instead, trees grow new tissues over the injured areas. They develop chemical and physical barriers to resist the spread of decay and disease organisms from the injury. This process of defense—of surrounding an injury with barriers—is called compartmentalization.

Decay is the gradual deterioration of wood by fungi and bacteria (Photo 2.7). In the forest, these and other organisms digest fallen trees and branches as well as roots, recycling their components. Decay is

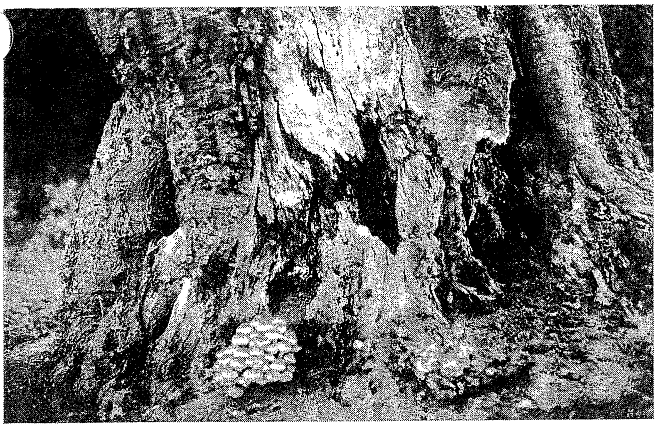


PHOTO 2.7 Decay is the gradual degradation of wood by fungal organisms. Over time, decay may severely reduce the structural stability of the tree.

also present in many standing, living trees. Wounds and other openings permit decay organisms to enter the tree and infect the wood. If the formation and maintenance of defense barriers and compartments is inadequate, decay can spread rapidly, rendering the tree structurally unstable. In valley oak (*Quercus lobata*), approximately 75 percent of all failures (breakage of branches and trunks) are associated with decay.

Wound response patterns in trees are central elements to be considered in planning both their retention during development and subsequent care. Any injury to the tree is a permanent one, requiring an active, energy-using response. Arboricultural treatments are, therefore, often aimed at enhancing compartmentalization. Pruning and other aspects of arboriculture are intended to maximize compartmentalization and minimize the extent of decay. Moreover, a tree's response is related to its health: a vigorous tree is best able to compartmentalize decay, thereby resisting its spread.

Finally, the ability to form and maintain defensive barriers varies by species. Cottonwood (*Populus* spp.) and willows (*Salix* spp.) have very poor compartmentalization response, and decay spreads rapidly through these trees. By contrast, other species, including many oaks (*Quercus* spp.), resist the spread of decay (with the exception of *Quercus lobata*, which is susceptible to decay).

Myths, Fantasies, and Half-Truths about Tree Roots

Myth: Tree roots can grow as deeply as the crown is tall.
Reality: Most tree roots grow within 3 feet of the soil surface. Most fine roots are within the top 18 inches of the soil surface.

Myth: A tree's root zone extends only as far as the edge of the canopy.
Reality: Tree roots extend far beyond the crown and occupy from two to ten times the area beneath the canopy (Figure 2.4).

Myth: In forest settings, roots of adjacent trees are separate from one another.
Reality: Roots of trees in forest stands overlap and comingle, forming a dense mat (Figure 2.5).

Myth: Tree root systems form a circle around the canopy.
Reality: Root growth is highly opportunistic, creating very asymmetric forms.

Myth: Roots seek out water and mineral elements.
Reality: Tree roots proliferate in areas favorable for their growth, where water, nutrients, and oxygen are abundant.

Myth: The entire root system absorbs water and mineral elements.
Reality: Only the small, fine, short-lived roots function in this manner.

Myth: Trees have large taproots that anchor them into the ground.
Reality: Few mature trees possess a significant taproot.

Myth: Tree roots grow independently of other soil organisms.
Reality: Roots of forest trees coexist with many types of fungi and bacteria, forming mycorrhizal associations.

Myth: Root growth occurs only in the spring and fall.
Reality: Tree roots grow any time the soil temperatures is above the range of 32 to 40°F. In irrigated landscapes, the peak period of root growth is midsummer.

THE ROOT SYSTEM

Roots anchor the tree and supply the crown with water and mineral elements absorbed from the soil. Their continued function is an important factor in a tree's survival during construction. In many ways, tree preservation is root system preservation. The best tree retention effort is doomed to failure if root protection is not emphasized during the project. Consultants recognize that grading, construction, utility installation, and other development impacts will in some way reduce the ability of roots to grow and function. For both development and tree preservation to occur on a site, the root system must be protected.

The root system of a typical tree can be described as shallow, spread wide, and horizontally oriented (Figures 2.4 and 2.5). Although we think of some trees as being shallow rooted or having a taproot system, these images are not always borne out in nature. For example, while seedlings and young trees often

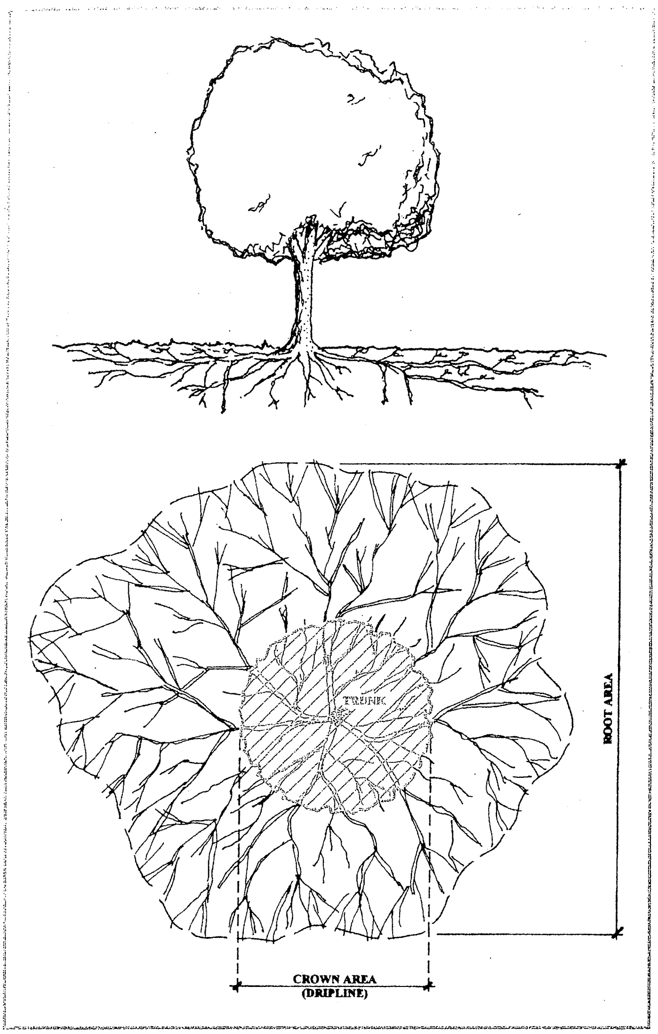


FIGURE 2.4 The root system of a tree can be described as shallow and widespread, extending far beyond the edge of the canopy.

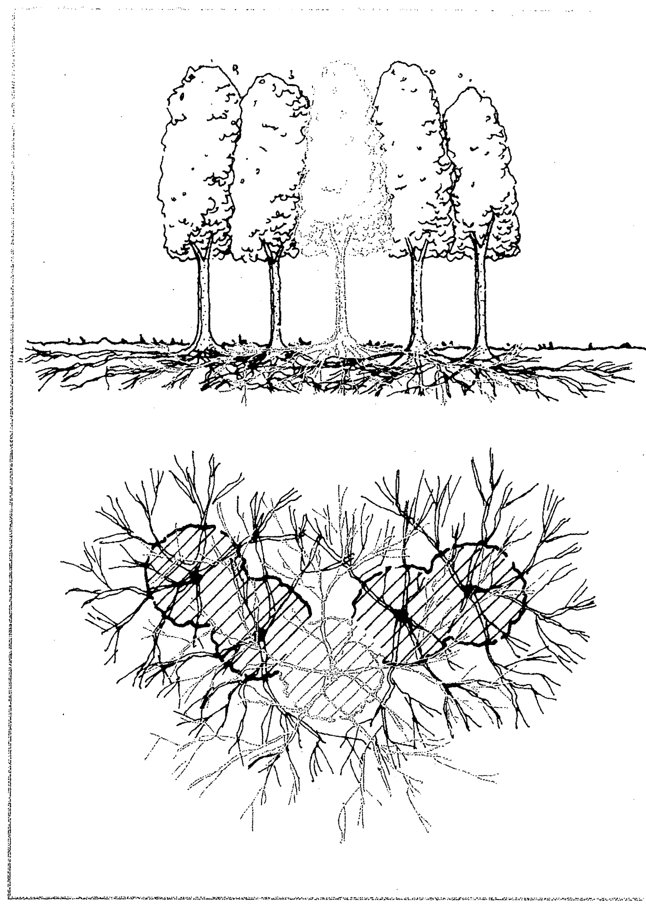


FIGURE 2.5 In forest settings, root systems of individual trees overlap and intertwine, forming a dense mat of roots.

have a taproot (that is, a large, vertically oriented root), mature trees lack such a structure.

Soil and the water table largely determine the structure and depth of a tree root system. Because root growth is largely opportunistic, the chemistry, texture, structure, and depth of the soil will greatly influence the location and extent of root growth. In well-developed forest settings, the soil is a mix of mineral particles, organic matter, water, air, and living organisms. Soil particles and organic matter adhere to form aggregates of varying sizes. These crumbs, clumps, and clods create a matrix of pores, large and small. After a soaking rain, the large (or macro) pores drain, leaving air space. The small (or micro) pores retain water. Roots thrive within this matrix.

Tree roots do not exist alone. Instead, the fine root tips are infected by a wide variety of beneficial fungi. These root–fungi associations, known as mycorrhizae or mycorrhizal associations, are normal and common. Both partners benefit. The fungi aid the tree in the absorption of water and mineral nutrients and may offer some resistance to pathogens. The tree provides the fungi with a supply of carbohydrates.

Unfortunately, construction often results in changes to the soil structure. To create a stable base for buildings, engineers specify that the soil be compacted, which squeezes out the air and water and destroys its inherent structure. Although compaction provides an excellent base for buildings and roads, it leaves little space for tree roots. Moreover, stripping of the organic layer (also known as the duff) removes many fine roots and their fungal associates.

Everyone involved in the development process must recognize the basic conflict between manipulating soil structure for buildings and preserving that structure for tree roots. Tree preservation is synonymous with root preservation, for the tree will die if its roots are killed. The interface between building area and tree protection zone is a critical one in the preservation process.

TREE GROWTH IN FORESTS AND WOODLANDS

Land development frequently converts existing forests and tree-covered land to other uses. As forests and woodlands are cleared for development, individual and small groups of trees (known as remnant lands, greenbelts, and buffer strips) are preserved. Decisions about retaining forest trees on cleared sites must be based on consideration of the potential response of the particular species and individual trees involved as the physical environment around them is altered.

"In a narrow technical sense," a forest is "a vegetation community dominated by trees . . . growing close enough together that the tree tops touch or overlap . . . " (Dunster and Dunster 1996). Also in a technical sense, forests are distinguished from woodlands by the degree to which the tree canopy shades the ground: heavy, almost complete cover in forest versus a more open, parklike arrangement in woodlands. Where canopy cover is less than 30 percent, the vegetation community is considered a woodland; above 30 percent, a forest (Dunster and Dunster 1996).

The basic unit of forest structure is the stand. In forestry terms, a stand is "an aggregation of trees occupying a specific area and sufficiently uniform in composition, age, arrangement, and condition so that it is distinguishable from the forest in adjoining areas" (Dunster and Dunster 1996). The key element in this definition is uniformity in tree development. A forest or woodland may be composed of many stands, representing different species, densities, and age mixes.

The composition and structure of a forest or woodland stand is an important concern to consultants working on development projects. First, individual species differ widely in their environmental requirements and their ability to acclimate to new site conditions. For example, the hardwood, bottomland forests of the southeast United States are frequently dominated by sweetgum (*Liquidambar styraciflua*), black gum (*Nyssa sylvatica*), and red maple (*Acer rubrum*). These species are adapted to wet sites with high water tables. If the site is drained and the water table lowered during development, these species decline. Their failure to acclimate to a site where the water table has been lowered is predictable based upon their requirements. Second, the species present in a stand, their size, and relative densities will change over time (see the following sections). Evaluating the character of a stand and the differential responses of its component species is, therefore, an important aspect of the resource evaluation.

Growth of Forest Trees Following Clearing

Trees that develop and mature in forest stands experience a environment different from isolated trees growing in the open. A tree growing in an open field receives the full impact of the sun and wind and has little competition for light and space when mature. In contrast, a tree in a dense forest receives direct solar radiation only from above and actively competes with its neighbors for space and resources.

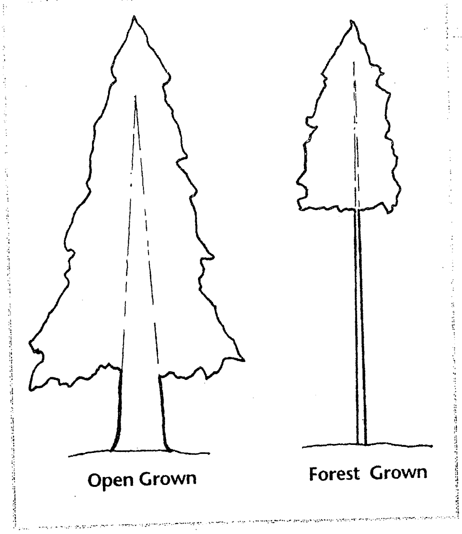


FIGURE 2.6 The relationship among parts of the tree is dependent upon the growing environment. For example, conifers grown in the open, without competition from others, retain more foliage and branches and develop greater trunk taper than trees grown in forest stands.

In each setting, the tree develops a form and structure in response to its environment (Figure 2.6).

When the environment around the tree is changed because of site preparation, preserved trees that had been growing in forest conditions must now survive in the open. They must alter their patterns of shoot, root, and trunk growth to respond to the new environment. If forest trees are unable to acclimate to the increased exposure that results from opening stands, they may fail mechanically shortly after opening or slowly decline, with failure potential slowly increasing over time. Trees that fail may cause personal injury, property damage, power outages, fires, and other catastrophes.

The reasons for the failure of newly exposed trees fail are connected to their history. Trees in forests have grown in response to the environment of a stand and have high crowns and little taper. When surrounding trees are removed, exposure to the elements increases. As trees are exposed along newly created forest edges, they accumulate more snow and experience greater wind speeds (Seischab et al. 1993). Such trees, having little trunk taper, may lack the wood strength to hold themselves upright and are more likely to fail.

Because growth patterns of trees in forests differ from those in the open, one of the key activities for the consultant is to assess the ability of a tree or a stand to acclimate to an altered site. One should not assume that a tree growing well in a forest environment will remain healthy and vigorous following clearing. Given an opportunity to evaluate existing conditions and structure of a forest, one can identify those stands and trees with the greatest likelihood to survive development and thrive in the future. In addition, those trees that may not tolerate change can be identified and development can be directed away from these sensitive areas.

Forest Composition and Change over Time

The composition of forests and woodlands does not remain static but changes over time, and does so in a predictable way. This process of change is called succession, "a series of dynamic changes in ecosystem structure, function, and species composition over time as a result of which one group of organisms succeeds another through stages leading to a potential natural community or climax stage" (Dunster and Dunster 1996).

Succession occurs because the environment within a forest changes as trees age and enlarge. The forest floor becomes shaded and cooler. The tree species that initially colonized the site are not able to regenerate in these altered conditions and eventually decline. As they do so, new species become established. Understanding the patterns of succession within a forest allows the consultant to assess and predict the character of a forest into the future.

For example, the process of succession on abandoned farm fields has been well studied across the United States and illustrates the importance of understanding succession in tree preservation efforts. In the Piedmont area of North Carolina, 20 to 30 years after a field is abandoned, the forest is composed of an overstory of maturing pines with hardwoods filling in the understory (Barbour et al. 1987) (Table 2.1). In this situation, the pines have a potential lifespan of approximately 30 more years. As they age, the overstory pines fail, thereby creating gaps in the canopy. At 60 to 70 years of age, the forest consists of a discontinuous canopy of mature pines with limited longevity. At this point, the best opportunities for tree retention lie in the young hardwoods that are growing beneath the pines. At 150 years after abandonment, the forest would be dominated by mature oak and hickory trees. In this stage, evaluation of individual mature trees would be critical because the oldest trees may be structurally unstable. Below this canopy would be many young oak and hickory trees.

TABLE 2.1 Successional patterns in the North Carolina Piedmont (adapted from Barbour et al. 1987).

Years after abandonment	Tree species
10	First young pines appear: •loblolly (*Pinus taeda*) •shortleaf (*P. echinata*)
60	Pine overstory (trees) with hardwood understory (seedlings and saplings)
100–150	Hardwood overstory develops: •white oak (*Quercus alba*) •post oak (*Q. stellata*) •hickory (*Carya* spp.) •dogwood (*Cornus florida*) •large old-growth pines (*Pinus* spp.)

This pattern of succession can be explained by understanding the basic requirements of the species involved. Pines require bare ground for seed to germinate and grow. They also require full sun to develop; they cannot grow in the shade of other trees. For these reasons, pines proliferate shortly after a field is abandoned (cleared, cultivated, or burned). Over time, the pines shed leaves, branches, and other structures. As this litter accumulates on the forest floor, it forms a layer of organic matter in which pine seeds can no longer germinate. However, the seeds of other species (notably oak and hickory) are able to germinate in the litter layer. The seedlings and saplings that result grow slowly in the understory, below the pines. As the tall pines decline and die, they fall to the ground, creating gaps in the canopy. The oaks and hickories that had been growing slowly in the understory are released, that is, they respond to the new environmental conditions (high amounts of sunlight) and grow rapidly to fill in the gaps. As the mature pine trees die, the species composition of the stand is changed; the pines are replaced by the oaks and hickories that have developed in their shade.

The aspect of succession—change in the species composition of the overstory—is a common one throughout North America. In many forest types, species that initially dominated the stand following disturbance are replaced by others, known as late successional species. The ability of a tree species to grow and develop in the understory is known as "tolerance" or "shade tolerance." Oaks and hickories have high tolerance, while the tolerance of pines is low.

The implications of this pattern for tree preservation are significant. In forest stands in which the early succession/low tolerance species are mature, the best opportunities for long-term preservation will be with the understory, late successional species. For example, in the U.S. Midwest, the overstory of many forests is composed of aspen (*Populus tremuloides*) and birch (*Betula pendula*). These are early successional species that would be succeeded by late successional types such as red oak (*Quercus rubra*) and red maple (*Acer rubrum*). If a development project were to clear all of the understory and remove the oak and maple, only mature and overmature aspen and birches would be retained. These species are likely to fail during storms and offer little long-term potential for preservation. In this situation, retaining the understory preserves the natural pattern of forest succession and allows a canopy of oak and maple to develop (Miller 1997).

The patterns of species composition and succession paths vary widely across North America. For this reason, foresters have described numerous cover types to distinguish among them. Eyre (1980) described cover type as "a descriptive classification of forestland based on present occupancy of an area by tree species." One hundred forty-five cover types have been described for the United States and Canada (Eyre 1980). Similar descriptions are available on a regional basis. For example, 57 cover types have been described for California's hardwood rangelands (Allen 1989). These two references illustrate the diversity of species, form, structure, ecosystems,and landscapes.

Forest Structure

Forest stands possess a wide range of structure—the vertical and horizontal arrangement of trees within the group. Factors determining the structure of a stand include species composition, climate, and time. Stands that arise from catastrophic events such as fire or storms will initially have trees that are uniform in size and age. As the stand develops, its structure becomes more complex. Competition between individuals, differential reproduction by component species, invasion by new species, and variable availability of resources combine to cause differential growth.

In assessing stand development, consultants evaluate the relative size and position of individual trees in stands (Figure 2.7). Four classes are commonly used.

- **Dominant.** Trees with crowns above the upper layer of the canopy and generally receiving light from above and sides. Also known as emergent.
- **Codominant.** Trees that define the general upper edge of the canopy, receiving light primarily from above.
- **Intermediate.** Trees that have been largely overtopped but may receive some light from above.
- **Suppressed.** Trees that have been overtopped, occupy an understory position in the canopy, and grow slowly.

Other terms commonly associated with crown class are edge (existing on the fringe of the stand) and interior (growing in the center of the stand). Edge trees frequently possess asymmetric crowns (heavier on the open side) and trunks that bow out of the stand.

TREE DEVELOPMENT OVER TIME

As forest stands change over time, so do the individual trees that comprise them. Tree growth is dynamic over time, reaching limits defined by the interaction of their genes and the environment. For example, all tree species reach an upper limit of height. They may grow rapidly for a number of years, then slow in

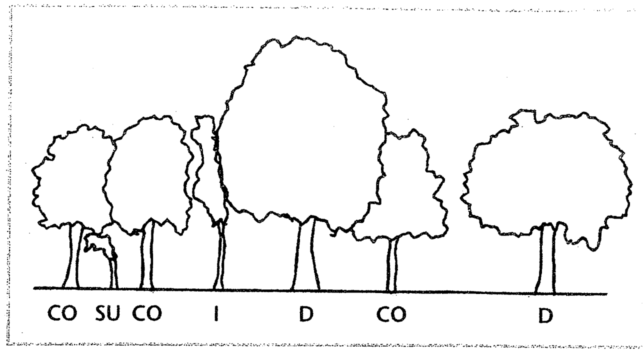


FIGURE 2.7 Crown class is a description of the form of a tree relative to others in the stand, usually described as dominant (D), codominant (CO), intermediate (I), and suppressed (S) (adapted from the Hazard Tree Assessment Program, Recreation and Park Department, City of San Francisco, California).

elongation as mature height is reached. At this point, the tree acts to maintain the existing structure rather than grow larger.

Age-Related Changes

As trees age, a number of changes occur in their development. Many of these changes are associated with the large size that develops over many years. In some mature trees, the distance between the tips of absorbing roots and the top of the tree may be over 500 feet. To efficiently move water, mineral elements, and carbohydrates, the tree must have a highly developed, well-coordinated system of transportation, exchange, and control. Similarly, as the tree increases in size, the mass of branches and leaves that must be held upright against gravity and storms is disproportionately greater. In short, as a tree enlarges, it must expend ever-increasing amounts of energy simply to maintain its structure.

The most significant change associated with old age in trees is a decrease in the relative amount of tissue active in photosynthesis. Because the amount of foliage relative to roots, trunk, and branches declines with age, so do the net carbohydrate resources produced on an annual basis. (It is this production that forms the basic building block of tree growth and defense.) The possible reasons for this decrease are 1) increased maintenance respiration, 2) limited nutrient availability, and 3) reduced gas exchange and photosynthetic potential (Gower et al. 1996). Whatever the fundamental reason for the observed decline in growth, it is clear that old trees are less able to respond to changes brought about by site development. The ability to acclimate to new site conditions and to tolerate environmental stress of all types simply declines with age.

It appears that old age in trees is associated with an increase in susceptibility to disease, decay, and other causes of death (Manion 1981). For example, we observe root rots such as *Phytophthora* to be a significant cause of death in mature oaks (*Quercus* spp.) in California and madrone (*Arbutus menziesii*) in Washington. These root disease organisms are ubiquitous in the soil, but they do not proliferate in dry soil. When trees receive heavy irrigation during the summer, root rots become more prevalent and severe. The susceptibility of trees to these fungi appears to be age dependent. Young seedlings of oak and madrone are frequently observed growing in heavily irrigated landscape beds without symptoms, yet mature trees rapidly succumb to the disease under similar conditions. We do not know if the death of mature trees is the result of a decrease in host resistance or to some change in soil environment due to irrigation. We observe only that the ability of these species to survive infection by root rot appears to decline with age.

A similar situation exists with many pine species, including loblolly (*Pinus taeda*) and Monterey pine (*Pinus radiata*), and susceptibility to bark beetles (Photo 2.8). Attack by bark beetles is a frequent cause of death, and old trees are more susceptible than young trees (Barr et al. 1978). Because this observation appears to be true regardless of the intensity of care and maintenance, we must conclude that host resistance changes with age.

PHOTO 2.8 As some pine trees grow older, they become more susceptible to attack by insects. In this case, bark beetles have infested Monterey pine trees.

How Trees Die

Tree do not live forever. Species, however, vary widely in their potential longevity, with average lifespan ranging from tens to thousands of years (Table 2.2). The extremes in potential lifespan are rather misleading and do not appear to represent the typical tree. Most individual trees survive for only a fraction of

TABLE 2.2 Typical lifespans of selected North American trees in forest settings (Loehle 1988).

Common name	Scientific name	Typical age of mortality	Maximum longevity
Bigleaf maple	*Acer macrophyllum*	150	300
Red maple	*Acer rubrum*	80	150
Sugar maple	*Acer saccharum*	300	400
Paper birch	*Betula papyrifera*	100	140
American beech	*Fagus grandifolia*	300	400
White ash	*Fraxinus americana*	260	300
Sweetgum	*Liquidambar styraciflua*	200	300
Tuliptree	*Liriodendron tulipifera*	200	250
Southern magnolia	*Magnolia grandiflora*	80	120
Colorado spruce	*Picea pungens*	150	350
Lodgepole pine	*Pinus contorta*	120	300
White pine	*Pinus strobus*	200	450
Loblolly pine	*Pinus taeda*	100	300
Balsam poplar	*Populus balsamifera*	100	150
Eastern cottonwood	*Populus deltoides*	60	100
Quaking aspen	*Populus tremuloides*	70	200
Coast live oak	*Quercus agrifolia*	150	—
White oak	*Quercus alba*	300	600
Valley oak	*Quercus lobata*	200	300
Red oak	*Quercus rubra*	200	400
Live oak	*Quercus virginiana*	200	300
Douglas-fir	*Pseudotsuga menziesii*	750	1,200
Black locust	*Robinia pseudoacacia*	60	100
Eastern hemlock	*Tsuga canadensis*	450	800
American elm	*Ulmus americana*	175	300

he potential lifespan of the species. In evaluating trees for preservation during development, consultants must focus less on the maximum potential longevity of a species and more on the landscape lifespan. In its native habitat, white alder (*Alnus rhombifolia*) trees live for 25 to 30 years. In the cultivated landscape, however, these trees die after only 10 to 15 years, even with the best possible care. Monterey pine (*Pinus radiata*) trees live to be 120 years in their native forest along California's central coast. When planted in the San Francisco Bay area, they may live for only 50 to 80 years and in the Central Valley of California, only 25 years.

Tree death is frequently a slow and complex process. While diseases such as Dutch elm and oak wilt may kill a tree quickly, a gradual death involving a number of factors is more common (Clark and Matheny 1991). Most trees die from one of three causes: structural failure, environmental degradation, or pest infestation. A single factor may not be severe enough to cause death, but the cumulative effect of two or more stresses can be.

For consultants, the question of how tree health, environmental stress, pest organisms, and other factors move from weakening the tree to killing it is a critical one. The pattern of death for many trees can be described as a "mortality spiral" (Clark and Matheny 1991) (Figure 2.8). For example, the most common causes of death of both coast live oak (*Quercus agrifolia*) growing in the San Francisco Bay area, and water oak (*Quercus aquatica*) in the Southern United States are structural failure and root rot (*Armillaria mellea*). The degree of each problem is aggravated by frequent summer irrigation, drought, changes in grade, mechanical injury to roots, and defoliation by oak moth. These predisposing factors reduce tree health and the ability to combat the spread of fungi. Over a period of years, decay and *Armillaria* affect more and more of the tree's wood, until either death or structural failure occurs.

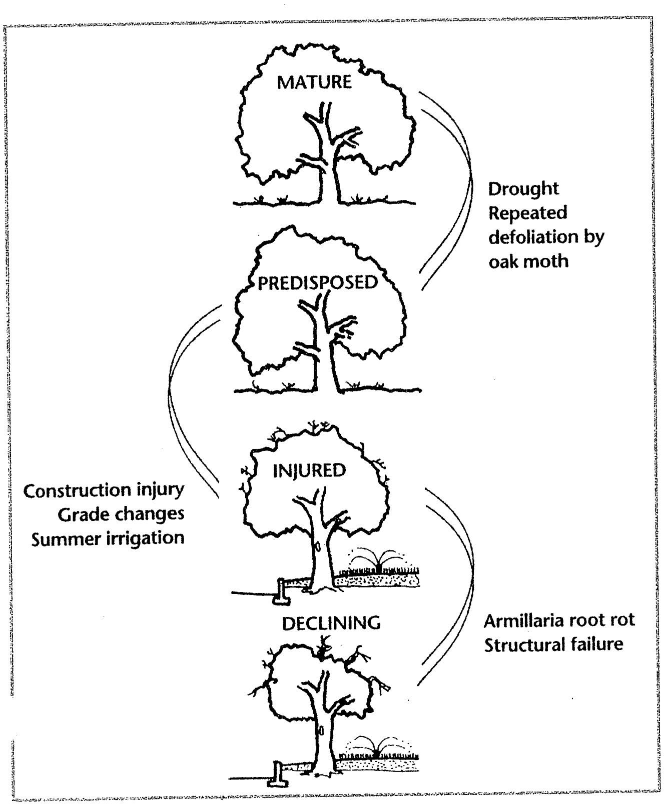


FIGURE 2.8 A mortality spiral for coast live oak (*Quercus agrifolia*). Drought, construction impact, and over-irrigation are important stresses that increase the susceptibility of the tree to decay and root disease.

A similar situation exists for Monterey pine (*Pinus radiata*). A frequent cause of death is the five-spined engraver beetle (*Ips* spp.). Healthy Monterey pines usually resist attack by producing large amounts of pitch that kills the beetles. Trees weakened by a variety of predisposing factors are less able to either manufacture pitch or produce it in amounts sufficient to kill the beetles. Predisposing conditions are those that decrease health and vigor and may include drought stress and infestations of the red turpentine beetle (*Dendroctonus valens*) (Koehler et al. 1978). In addition, wounding the tree (by pruning, for example) during the growing season attracts adult bark beetles. Once the tree is infested with the engraver beetles, chemical control is rarely effective. The most effective control programs are those that prevent the predisposing factors.

In both of these examples, there is no control for the cause of death (structural failure, *Armillaria* fungus, *Ips* beetle). To prevent death from these causes, the tree must be maintained in good health without predisposing stresses. Once decay is extensive or the *Ips* infestation is heavy, there is no treatment or cure.

Predisposing factors are keys to understanding and preventing the decline and death of trees. Soil compaction, changes in grade, mechanical injury, changes in the environment around the tree, and changes in drainage may not kill the tree by themselves. But they may so weaken a tree that death by some other cause occurs; the further a tree is along the mortality spiral, the less likely it is to escape from it and survive. Prevention of stress and maintenance of health are the key elements in tree longevity.

SUMMARY

Trees grow in predictable patterns. Their shapes, sizes, and features are all determined by the interaction of a genetic blueprint with the surrounding environment. Over time, the parts of a tree—the leaves, roots, branches, and stem—exist in intimate balance with each other. This balance allows these parts to share resources, bear weight, compete with neighbors, and defend against pests in a integrated manner. When this balance is disturbed, either by injuring the tree or changing the environment around it, the tree responds so as to re-establish it. The ability to respond to change is a function of the species, health, age, and structure. When the extent of change is too great, the tree becomes weakened and subject to attack by pests.

The pattern of decline and death is not a random one, but is often species dependent. As a tree ages, its capacity to overcome injury, adapt to changes in its site environment, and to resist pests declines. It is for this reason that retention of old trees during development requires special attention, minimal disturbance, and a program of long-term care.

REFERENCES

Allen, B., R. Evett, B. Holzmann, and A. Martin. 1989. *Rangeland Cover Type Descriptions for California Hardwood Rangelands*. Sacramento: California Department of Forestry and Fire Protection. Forest and Rangeland Resources Assessment Program. 318 pp.

Barbour, M., J. Burk, and W. Pitts. 1987. *Terrestrial Plant Ecology*. 2nd edition. Menlo Park, CA: Benjamin/Cummings Co. 634 pp.

Barr, B., D. Hanson, and C. Koehler. 1981. *Red Turpentine Beetle: A Pest of Pines*. University of California Cooperative Extension. Leaflet 20155. 4 pp.

Clark, J., and N. Matheny. 1991. Management of mature trees. *Journal of Arboriculture*. 17:173–183.

Dunster, J., and K. Dunster. 1996. *Dictionary of Natural Resource Management*. Vancouver: University of British Columbia Press. 363 pp.

Eyre, F. (editor). 1980. *Forest Cover Types of the United States and Canada*. Washington, DC: Society of American Foresters. 148 pp.

Gower, S., R. McMurtrie, and D. Murty. 1996. Aboveground net primary production decline with stand age: Potential causes. *Trees*. 11:378–382.

Koehler, C., D. Wood, and A. Scarlett. 1978. *Bark Beetles in California Forest Trees*. University of California Cooperative Extension. Leaflet 21034. 8 pp.

Loehle, C. 1988. Tree life history strategies: The role of defenses. *Canadian Journal of Forest Research*. 18:209–222.

Manion, P. 1981. *Tree Disease Concepts*. Englewood Cliffs, NJ: Prentice-Hall. 399 pp.

Miller, Robert. 1997. University of Wisconsin, Stevens Point. Personal communication. January.

Seischab, F., J. Bernard, and M. Eberle. 1993. Glaze storm damage to western New York forest communities. *Bulletin of the Torrey Botanical Club*. 120:64–72.