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MANAGEMENT OF MATURE TREES

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Abstract. *The management of mature trees involves the application of cultural treatments in the context of a tree biology which changes with time. Key elements in understanding of the biology of old trees are the life history strategy of individual species, the limitations on growth that develop due to structural and resource availability considerations, and the causes of mortality in forest and landscape trees. Since the biology of the tree changes with time, so must its management. Arborists can play a central role in the maintenance of a mature, stable condition. They identify routine and remedial treatments, as well as assess the ability of a tree to respond to such treatment. However, the capacity of an arborist to restore a declining tree to a stable condition is questionable.*

A primary responsibility of the arborist is to develop management programs for urban trees. This is a complex task because of the large number of species and the range of environmental conditions encountered. Arborists must be able to modify management strategies and applications to account for differences in plant character and physical environment. In short, tree management programs integrate species and site differences into both general approaches and specific actions.

Tree biology is dynamic, changing as the tree ages (3). Age-related changes include decreased rates of net carbon assimilation, decreased rates of growth in all organs, increased susceptibility to disease, insect and other stresses and altered patterns of dry matter partitioning (Table 1). Such changes are related to one another, in that they reflect the complex interactions required for the growth and development of a woody plant. Indeed, age-related changes are fundamentally associated with the increased size and complexity which result as a tree grows larger.

These changes in tree biology were summarized by Goff and West (9) who observed, "Trees slow in growth as they approach maximum age, and become more vulnerable to disease, wind and other causes of death." Yet, traditional management approaches for mature trees are similar to those applied to young, more vigorous stock. This paper develops a central theme that maintenance considerations must change as the tree proceeds from juvenile to mature to senescent stages of development.

Biology of Mature Trees

Life history strategies, resources and defense. Loehle (11) suggested that life span and life history patterns in trees are determined by resources allocation patterns. To Loehle's thinking, the development of a strong defense system is central to longevity. He characterized defense as resistance to decay organisms and insect attack, as well as retention of wood strength. Development and continued renewal of this defense system maintains structural integrity. As Loehle put it, "...increased longevity...requires specific investment in chemical and structural defenses..." Shigo (19) observed, "An organism stays alive so long as it has enough energy to grow and defend itself." In both views, the idea that defense leads to structural stability is a central one.

Growth and defense depend upon the availability of resources (carbohydrate, mineral elements, water, radiant energy, etc.) and they compete for these resources as part of a finely tuned system of internal partitioning. Thus, when resources become limiting, either growth or the defense system, or both, suffer.

Trees differ in their life history strategy with

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respect to the costs and benefits associated with growth and defense (11). In trees with relatively fast rates of growth (using data of 1), fewer resources are partitioned into defense. In slower growing trees, more resources are allocated to defense. Loehle observed that growth rate was "a significant predictor of longevity," with slow-growing species having greater longevity. This does not mean that fast-growing trees may not have long life spans. Loehle suggested that the longevity of such fast-growing species is a direct function of their ability to maintain rapid growth rates (using tuliptree, *Liriodendron tulipifera,* as an example). When growth rate declines, these species become susceptible to disease organisms, simply because the development of the decay is more rapid than the rate of addition of new tissue. Shigo (19) characterized this concept as "Trees survive as long as they can form new parts in new positions faster than old parts are breaking down."

Loehle's analysis also distinguished between angiosperms and gymnosperms in other characters that might be related to longevity: heat content (a measure of energy in wood), wood specific gravity, and decay resistance (using the observations of 25). In gymnosperms, decay resistance (which assessed only passive resistance and not active responses like compartmentalization) was correlated with longevity. In angiosperms, decay resistance was not related to longevity but heat content was. Loehle concluded that investment of energy in wood was incompatible with fast growth rates.

This series of observations about tree life history strategy and longevity offers several important ideas for the management of mature trees. First, two broad patterns in the overall tree development define longevity. The first relies upon the maintenance of rapid growth rates. Deciduous trees which are early succession species (shade intolerant pioneers) predominant in this group. The second pattern focuses upon investment in defense, and has gymnosperms and shade tolerant, late succession angiosperms as predominant species. Second, the key elements of practical management for maximizing longevity must support these strategies by providing the cultural requirements for both rapid growth and production of strong defense. This would include management of soil fertility, moisture and structure as well as biotic and environmental stress. Third, since decay is a critical component to longevity, practices that minimize decay and its effects on structure, such as pruning, must be an integral part of management.

Resource allocation in mature trees. In the views of Loehle and Shigo, a key element in tree longevity is an adequate resource supply, which permits either rapid growth rates or significant investment in defense. While not specifically addressing tree longevity, a number of authors have viewed limitations on resource availability as critical to the long-term success of plants (see 5). In this view, as overall size increases, the relative proportion of photosynthetic tissue to non-photosynthetic tissue decreases. Thus, there are fewer leaves to support a larger plant body with carbohydrates. Moreover, the maintenance respiration costs associated with larger size and the accumulation of wound response compartments increase as well. This lowers the amount of carbohydrate available for growth (elongation, diameter, etc.). It also reduces the synthesis of defense chemicals (phenolics and related chemicals) substantially. Indeed, these materials have a cost of synthesis twice that of wood.

Nooden (13) described the overall decline in net productivity of mature trees as having two causes. First, the loss of meristematic activity over time leads to a decline in the renewal of leaves. Thus, the net annual gain in carbohydrate resources decreases with age. Second, the structural complexity associated with a numerous meristematic

Table 1. Comparative development of young, mature and declining trees.

Character	*Young*	*Mature*	*Declining*
Relative size and complexity of organism	Low	High	High
Annual net productivity of carbohydrate	Moderate	High	Low
Ratio of PSN* to non-PSN tissue	High	Low	Low
Relative maintenance demand	Low	High	High
Mass:energy**	1:100	1:1	1:0.5
Ability to respond to environmental change	High	Moderate	Low

*PSN = photosynthetic
**From O'Callaghan (14).

organs leads to nutritional transport difficulties. This may be related to the binding of nutrients in structural tissues and to decreases in conductive efficiencies due to structural and compartmentalization developments.

Resource availability is generally associated with carbohydrate supply. However, mineral elements may also play a role in defining productivity of mature trees. The binding of mineral elements into structural tissues has been suggested as important in the decline of productivity (6). This situation may be important in those landscape settings where both natural and supplemental inputs of mineral elements are limited. A large tree growing in a maintained lawn, with annual removal of leaves, may be more subject to nutrient stress than one growing in a landscape bed, receiving supplemental fertilizer applications (see 10).

In another approach to the same basic issue of overall productivity, O'Callaghan (14) examined net productivity in terms of mass:energy ratio, using the analysis of Ossenbruggen (15). In young trees, the mass:energy ratio may be 1:100, indicating a large surplus of energy over mass (Table 1). As a tree develops this ratio continually declines, reaching a point of equilibrium, a mass:energy ratio (M:E) of 1:1, at maturity. A response to disturbance and stress will also cause a decline in the ratio. Shigo (19) suggested an M:E of 1:0.5, as being critical; below that point irrevocable decline occurs.

O'Callaghan stressed consideration of M:E when evaluating tree health, especially with respect to the influence of practices such as pruning upon the ratio. Unfortunately, there is no simple method of monitoring M:E ratio.

Stability and balance. Trees develop in balance with their environment, attaining size, form and vigor in response to environmental conditions. In this manner, survival occurs and growth is optimized for a given environment. There are numerous examples of the development of this internal balance in trees. Shoot:root ratio reflects the relative growth of root and crown in a given environment, influenced by site fertility and moisture. The shoot:root is lower under conditions of poor nutrition (4) or/and chronic drought (22). Some woody plants acclimate to the reduced light intensity seen in the forest understory, shade gardens or urban canyons by producing foliage, branches and crowns which maximize the interception of radiant energy.

In the face of a changing environment, a tree must alter its growth patterns to reestablish internal balance. This response must be seen as an active process, directly related to resource partitioning. In the general case, increases in resource allocation to one organ result in a decrease to another. Waring and Schlesinger (24) evaluated the impact of a variety of environmental stresses on the resource allocation patterns of forest trees (Table 2). They suggested that individual stress factors, such as drought or nutrient deficiency, act on both root and shoot development.

While Waring and Schlesinger did not discuss a time frame for the effect of environmental stress on allocation, stability and balance are not attained either in the short-term time frame or by the implementation of single actions. Stability and

Table 2. Changes in relative carbon allocation patterns associated with various environmental stresses.

Stress	*Root growth*	*Shoot growth*	*Stem taper*	*Foliage mass*	*Other*
Shade	Reduced	Increased?	Reduced	?	Umbrella-shaped crown
Drought	Increased	Decreased	Increased	Reduced	Loss of older foliage
Mechanical	?	Reduced?	Increased	Reduced?	Asymmetric form
Nutrient deficiency	Increased	Decreased	Increased	Reduced	—
Nutrient surplus	Decreased	Increased	Decreased	Increased	—

From Waring (23), adapted from Waring and Schlesinger (24). Shoot growth column added by Clark and Matheny.

balance are instead a reflection of long-term programs of care and on-going management activity. This is critical to arboricultural practice, for we cannot view these issues in the context of a single action. Since "tree health is a long-term process", programs of restoration and management must be implemented over 5-50 years, rather than within single seasons (14).

We suggest that the maintenance of a balance between growth and the environment is a basic requirement for continue development and longevity. In order to maintain internal balance, the tree must either exist in a stable environment or respond to changes in that environment. In urban and landscape settings, we encounter changing environments far more often than stable ones. Thus, the growth of urban trees is frequently disrupted, by all number of events (from site construction to landscape renovation to irrigation frequency).

Arborists must strive to maintain stable growing conditions, through long-term programs of care. In addition, the arborist may act to facilitate the restoration of balance within a tree whose environment has been disturbed. Given the nature of balance in trees, it is far easier to maintain a mature tree on an undisturbed site than it is to restore balance following disturbance.

Why Trees Die

Unlike annual, biennial, and some perennial plants, trees do not appear to have fixed life spans (3, 13). Most references contrast "typical" and "normal" life span to maximal potential. If trees do not have fixed life spans, then why do they die? Nooden (13) suggested that rather than a "distinctive internally programmed degeneration," trees experience an increased vulnerability with age. The cause of this degeneration should be of prime concern to arborists, for understanding why trees die gives us insight into how to maximize the ultimate potential life span of a species. If the causes of degeneration can be prevented with routine care, then life span should be maximized.

There does not appear to be any single cause of death in trees, rather multiple paths may occur. Sinclair and Hudler (20) examined the patterns of tree decline. They observed that decline could result from: 1) chronic irritation of a single agent (e.g. iron chlorosis of *Quercus palustris),* 2) acute injury followed by a secondary stress (e.g. construction damage followed by root disease), 3) predisposition caused by one or more agents that both incite and contribute to decline, and 4) group senescence in response to stress (e.g. birch dieback). The development of decline (defined as the premature progressive loss of health) may occur for either single or multiple reasons.

If there are many paths to death in trees, how frequently does each occur? Reiners and Reiners (16) studied the patterns of mortality in an oak-hickory forest in New Jersey. Of the 484 trees examined, 323 were killed by windthrow. The remaining 161 were killed by disease, insect, stress, lightning and *old age* (italics added). For mature and old forests in the Pacific Northwest, pathogens, wind, competition, and physiological disorders may be the typical causes of mortality (8). DeBell and Franklin (7) observed that the proximate cause of death in a stand of Douglas-fir *(Pseudotsuga menziesii)*—western hemlock *(Tsuga heterophylla)* changed over a 36-year study period. Early in the study, the primary cause of death in Douglas-fir were bark beetles. As time progressed, root and butt rots became the major cause of mortality, often resulting in windthrow.

Franklin *et al.* (8) listed a number of causes of death in forest trees, ranging from abiotic factors such as fire and wind to biotic factors such as disease. However, they cautioned that while the proximate cause of death might be obvious, the more fundamental causes of death may not be as clear. For example, the immediate cause of death for a tree which has been blown-down in a windstorm (i.e. structural failure) is quite clear. Yet, the susceptibility of that specimen to mechanical failure could have been increased by a number of a factors, such as root or stem disease. Moreover, the intensity of this disease infection may have been increased due to predisposing biotic or abiotic factors. For the arborist, the way to treat this tree and prevent its mechanical failure was to prevent and/or minimize both the disease itself and the stress factors that enhanced the development of that disease.

Franklin *et al.* adapted the "decline disease spiral" proposed by Manion (12) into a more general form, the "mortality spiral", where a series of sequential events result in death. In general, none of these individual factors or events is alone sufficient to cause death. Rather, it is their cumulative effect which is important, with each step reducing the vigor and increasing the susceptibility of the tree to stress. They observed, "As the tree progresses along this spiral, its opportunities to escape death become more limited."

We are not aware of mortality studies for mature trees in urban and/or landscape situations. It seems clear that windthrow, while so significant in the mortality of forest trees, is not a central cause of the death of urban plants. For landscape trees, several patterns of death seem more plausible: *structural failure, environmental degradation and parasitic invasion* (Table 3). Structural failure is the collapse of the tree's framework, for whatever reason. It may be entire, with complete crown failure, or partial, with the loss of scaffold branches. Environmental degradation may occur in acute or chronic fashion. Examples of acute degradation might include flooding, fire, "bulldozer disease", etc. Chronic degradation might encompass soil compaction, reduced fertility and competition. Parasitic invasion may be any living organism.

Management practices, such as poor pruning or inappropriate irrigation, may affect each of these three patterns. This can be seen in a proposed "mortality spiral" for coast live oak *(Quercus agrifolia)* (Figure 1). Vigor of established coast live oak trees may be reduced by extended drought and/or defoliation by oak moth. When such trees are injured during development, or when normal water regimes are altered, they become susceptible to root and crown rots, such as *Armillaria.* These pathogens do not normally attack vigorously growing trees, but once the trees become stressed and injured the diseases become significant problems. When a tree has reached this point it has moved from a stage of maturity to one of "decline". For a tree in decline (to paraphrase 8), opportunities to escape death are limited.

A similar scenario exists with white birch *(Betula papyrifera) (17).* Mature trees, when stressed by drought, competition from turf, poor pruning and/or attack by leaf miners, are colonized by the bronze birch borer. Most often, white birch trees attacked by this insect are killed.

The goal of arboricultural management should be to create a stable crown structure, to minimize environmental disturbance and to minimize parasite infection. In so doing, the onset of decline and the entry into the mortality spiral will be delayed, with maximum longevity the result. For the arborist, the practical question is: "What management techniques can be applied to a tree to avert or postpone the development of the mortality spiral?"

The Concept of Robustness

Arborists must strive to avoid the three causes of death of landscape trees: structural failure, environmental degradation and parasitic attack. The effectiveness of management procedures in this process is dependent upon the ability of the tree to respond in a positive manner. This ability, which we term *robustness,* characterizes the capacity of a tree to either reestablish a functional balance in response to change or break out of the mortality spiral.

Robustness embodies vigor, resource availability and the genetic adaptations that allow a plant to respond to change. For example, in mid-elevation forests of the northwest, Pacific silver fir *(Abies amabilis)* may exist as small, suppressed trees for many years. The normal pattern of succession would have these trees respond to a gap in the overstory by changing from a shade-acclimated tree to one acclimated to full-sun. This may occur over several years. The ability of an individual fir to respond to the alteration in forest structure is a

Table 3. Patterns of death in landscape trees.

Structural failure	branch, crown and stem failure, uprooting, decay, girdling
Environmental degradation	
Acute	flooding, fire, vandalism, construction injury, drought, high or low temperature
Chronic	soil toxicity, soil compaction, air pollution, restricted growing space, low fertility, severe pruning
Parasitic invasion	insect, fungus, bacterium, virus, mycoplasma-like organism, parasitic plant

reflection of its robustness.

Similarly, when development occurs near to mature plants, their short-term survival depends upon an ability to tolerate drought stress caused by root and soil disturbance, until the balance between root, crown and stem can be reestablished. This process is also a reflection fo robustness. In short, robust trees tolerate construction injury, as well as other stresses, while less robust individuals move deeper into a mortality spiral.

Maturity vs. Decline

Mature trees are those being close to maximum height and exhibiting reduced shoot elongation (either as decreased elongation or a reduced number of flushes per year) (Table 4). At maturity, the degree of apical control frequently lessens and a rounded crown results. Mature trees generally possess sound structure, even though inherent structural problems and numerous internal compartments may be present. They appear healthy and vigorous and may persist in this condition for long periods of time; indeed, for much of their life span.

In contrast, declining or senescent trees appear less vigorous, because of adverse environmental stress, structural failures or simple old age (Table 4). Their growth rates may be slow or nonexistent. Indeed, they may experience reductions in size and mass due to the loss of large branches. The development of irregular crowns does not necessarily lead to structural instability, and trees in this condition may live for some time. However, the potential life span of trees in a state of decline seems more limited, and the likelihood of death is much greater. Even with outside intervention, a state of decline may be irreversible. Such trees are deep into the mortality spiral.

In the the natural course of events, mature trees will eventually go into decline and die. At some point along the mortality spiral, a tree undergoes the transition from maturity to decline. The primary goal of management of mature trees is to prevent (or more accurately, delay) this transition from the mature to declining stage, to interrupt the mortality spiral before it becomes irreversible. For example, the coast live oak *(Quercus agrifolia)* is considered mature at 50 years and has a potential life span of 300 years. The ability to attain the additional 250 years of potential life is a direct function of delaying the transition from a stage of maturity to one of decline.

Management Approaches for Optimizing Tree Longevity

In managing mature trees, the arborist must recognize that death is inevitable. The effort expended in optimizing tree longevity should occur in the context of current plant condition, longterm potential and the cost of treatment. Thus, knowledge of potential life spans for species involved is a critical component of decision-making. The management of potentially short-lived trees will be different from that of longer-lived specimens. In the Pacific Northwest, treatment of

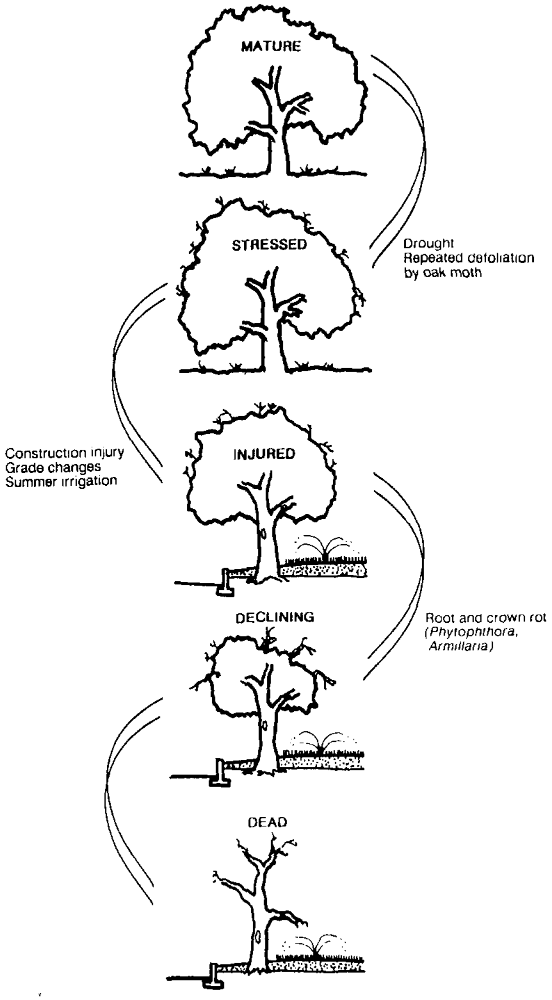

Figure 1. Proposed mortality spiral for California live oak *(Quercus agrifolia)*.

black cottonwood *(Populus trichocarpa)* and Douglas-fir must acknowledge the differences in potential longevity (approximately 100 vs. 1000 years).

Individual species differ in their "life history strategy" (11). Trees with rapid growth rates generally have shorter longevity than trees that grow more slowly (11). This pattern is true for both angiosperms and gymnosperms. Loehle observed that trees that allocate relatively small proportions of resources to defense, fall rapidly into decline when their growth rate slows. Typical examples of this pattern are members of the genera *Alnus, Salix,* and *Liriodendron.* In contrast, trees that allocate a greater proportion of resources to defense, may experience slower growth rates, but may be inherently longer-lived. Examples of this pattern include most conifers and *Quercus.*

In addition, consideration of a tree's potential longevity involves individual genotype, current condition and environmental stability. Individuals within a species may differ in the strength of their compartmentalization response. Unstable crown forms, the presence of stem rots, and history of poor growing conditions are examples of restrictions on development that may not be overcome by the best arboricultural treatment. Finally, the intensity of environmental disturbance or stress may exceed the capacity of the tree to survive.

Given a basic knowledge of species life history, an arborist may approach the care and management of mature trees by focusing preventative care on two objectives: avoiding entry into a mortality spiral and preventing death from acute causes. We believe that entry in to a mortality spiral is dependent upon declines in overall plant robustness as well as disturbance in the established tree—site balance. Entry into a spiral can be prevented to a significant degree. We propose that avoiding the transition from a state of maturity to one of decline is the key to optimizing longevity. Therefore, an arborist must be able to distinguish between growth patterns normal for the species and those that indicate decline (Table 2).

Arborists play an active role in optimizing tree longevity, using two strategies: 1) developing a stable physical structure and 2) developing a stable environment. These strategies encompass management concerns related to death by structural failure, environmental degradation and parasitic invasion.

Development of a stable tree structure. A stable structure is one that adequately supports the weight of the branches, leaves and fruit and is resistant to effects of wind. The arborist strives to maximize the stability of the structure by preventing (or minimizing) the creation of internal and external defects in several ways. First, early crown training programs and use of proper pruning practice enhance development of a stable form. Implementation of standard guidelines such as the American National Standard Institute (ANSI) Z133.1 Standard, the National Arborist Association pruning standards and the Western Chapter ISA Pruning Standards will assist in maximizing structural stability. Second, the regular evaluation of structure permits an on-going assessment of stability. Britton (2) discussed the significance of root—crown inspection as a routine part of tree care operations. Third, the implementation of cabling, bracing and other external enhancements of structure provide support to unstable canopies.

However, the normal developmental pattern of a tree will result in the creation of defects. For ex-

Table 4. Characteristics of mature and declining trees.

Character	*Mature tree*	*Declining tree*
Shoot elongation—		
extent	normal for species	greatly reduced
pattern	normal for species	single flush only
Crown form	normal—some loss of apical control	stag-headed, dieback
Foliage development	normal	reduced size and density
Foliage retention (evergreens)	normal	poor
Presence of epicormic shoots	generally absent	present
Compartmentalization response	normal for species	reduced
Wound-wood formation	normal for species	inhibited/reduced
Integrity of bark	strong	weak
Susceptibility to parasites	normal for species	increased
Reproductive behavior	normal, may be cyclic	may produce stress crops
Stress response	normal	reduced
Fall coloration	normal	premature

ample, internal decay is a common and normal event in tree development. This is especially true for those species with fast-growth rates and/or weak compartmentalization responses. Despite the best activities of the arborist, the development of structural instability may be inevitable. In this light, assessment of stability may also be seen as a way of assessing the potential for failure. Many guides for assessing hazard potential include comprehensive methodology for critiquing structure.

The integrity of internal structure cannot always be assessed with simple external examination. In the Puget Sound region, there have been failures of large Douglas-firs, apparently free of external defects, which possessed extensive internal decay. Given these experiences, arborists must look for methods of examining internal structure directly (such as increment cores).

Hazard assessment procedures frequently suggest that the critical point in trunk decay is reached when 33% of wood strength is lost (21). This is roughly equivalent to a 70% loss in total wood diameter. Calculations of this index involve the proportion of sound to decayed wood. Arborists should consider this standard as a guide. Wagener (21) indicated that it was based on field experience, and was applicable to *conifers* (emphasis added). He suggested the index was less applicable to hardwoods, due to basic differences among the two groups in crown form, mechanical properties of wood, and failure patterns. Thus, arborists must be more conservative in the application of the one-third loss of strength standard when examining hardwoods.

Development of a stable environment. The creation and maintenance of a stable environment around a mature tree has at least two aspects. First, a stable environment involves minimizing the degree of change and disturbance in the tree's growing space. To some degree this means preventing or minimizing the gross disturbances associated with such issues as adjacent construction. In such situations, the short-term response of the plant is survival.

Creation of a stable environment may require seeing subtle site/environmental changes in a new perspective. Simple changes in site situations may have large, negative ramifications. For example, in the Pacific Northwest, native plant communities are adapted to an annual pattern of precipitation where summer drought is an annual occurrence. A frequent and common change to these communities during development is the addition of summer irrigation, ostensibly to minimize the effects of the dry summer. Unfortunately, supplemental irrigation allows the ever-present root rots like *Phytophthora* to grow rapidly. The all-too-common result is the development of severe root rot infestation and the loss of the large native trees. A similar situation exists in California, with its native oaks and *Armillaria* root rot.

Second, a stable environment also involves a pattern of long-term care that facilitates growth and development, creating good growing conditions. This pattern of care recognizes the need to maintain vigor, and avoid predisposing external stresses. Schoeneweiss (18) identified drought, cold, defoliation, low soil aeration, nutrient deficiency, chemical injury and mechanical damage as the primary predisposing stresses in landscape settings. Since entry into a mortality spiral starts with stressed trees, avoiding the development of such stresses, through routine programs of irrigation, plant selection and pest management, is potentially a very significant component to longevity. This is especially true for those fast-growing species whose longevity is dependent upon the maintenance of rapid growth rates.

Utility of arboricultural treatments. The arborist has a number of arboricultural treatments, such as pruning and fertilization, to employ in the maintenance of both structure and environment. An optimal management program begins these treatments early in the life of the tree, thereby creating a continuum of stability (Table 5). For example, supplemental irrigation and fertilization may reduce the susceptibility of birch to borer attack (17). However, these treatments must be applied on a continuing, long-term basis. They must also be increased as the tree grows larger. The message is clear; maintaining vigor and internal balance, creating the stable environment needed for maximum longevity, is a long-term, on-going process.

While long-term programs of tree care are beneficial, the application of arboricultural practices to the mature trees that have not had such care represents a change in their environment. Such a change will alter the tree's internal balance which must then be restored. Thus, arboricultural practices may, in of themselves, act as a stress on the mature tree. The arborist must weigh the benefits accrued with a practice against the costs to the tree. Each standard practice has positive and negative aspects (Table 6) that must be weighed before employing it.

Treatments such as pruning, fertilization, removal of flowers and pest management should be applied in a manner that reflects the current situation and long-term objectives. For example, a crown restructure treatment may be required for safety reasons. However, this treatment will induce a series of wound response actions within the tree, which will require energy and alter the structure—function relationship within the stem. Alternatively, application of supplemental fertilizer may be required to correct existing soil and/or plant nutrient deficiencies. Yet, the effect of improved soil fertility may be to increase the development of disease organisms and/or alter shoot:root in favor of shoot growth.

In summary, we suggest that the arborist must view traditional treatments as additional disturbances to the tree's environment. The value of these treatments can only be assessed by the degree to which they enhance the survival of the tree, over both the short- and long-term.

Managing Trees in Decline

Arborists are frequently called into situations where mature trees are already under significant environmental or internal stress, perhaps where a tree is deep into a mortality spiral. The goal of management in such situations is to remove the tree from the mortality spiral and facilitate reestablishment of a site—tree balance. In this light, we suggest that solutions must be viewed in a long-term context, as observed by O'Callaghan (14). Even the most robust, large, mature trees are inherently slow to respond to change, whether the change is positive or negative.

Pruning. Creating a stable structure may be straight forward, especially where pruning and other traditional treatments can be effectively applied. We caution that response to pruning wounds is an active process, involving the commitment of significant resources. Overall shoot and diameter growth by trees that have undergone severe pruning may be limited for some period of time. Therefore, pruning can inflict an additional stress on declining trees.

We cannot recommend severe (hard) pruning as a treatment for re-invigorating trees in decline. Living tissues should be retained to the extent that structure is not compromised. We believe the traditional trade-off of removing large branches and directing resources to a smaller number of shoots is misleading. The shoot response to such situations is short-lived. We are aware of no evidence to suggest that hard pruning either increases overall foliage area and mass or improves stress responses over longer periods of time.

Table 5. Arboricultural practices that enhance longevity.

Promotion of a stable environment	Plant the right plant in the right place Irrigate according to species requirement Maintain existing/adequate drainage Monitor and maintain soil fertility Develop a pest management program Minimize soil compaction Minimize grade and other soil change
Development of stable structure	Plant material with well-developed structure (root and crown) Develop early crown training program Prune to natural targets Minimize mechanical injury

Table 6. Potential effects of common arboricultural treatments on tree biology.

Treatment	*Advantage*	*Disadvantage*
Pruning	Decrease non-PSN[1] biomass Increase leaf area? Increase structural stability	Increase compartmentalization Decrease PSN production
Fertilization and irrigation	Increase resource availability Increase PSN capacity	Increase shoot:root Reduce mycorrhizae Increase root disease
Removal of flowers	Reduce competition for resources Eliminate allergenic responses	Reduce aesthetic quality?
Pest management	Avoid predisposing stress Enhance resource availability	?

[1]PSN = photosynthetic

Moreover, the stimulation of latent and adventitious buds to develop adds an additional need for pruning in years hence.

In situations involving declining trees, we must also recognize that the development of a stable environment is in direct conflict with the need for supplemental treatments. Addition of fertilizers, supplemental irrigation, use of mulches, implementation of pest management programs etc., are all changes to the existing site conditions. Each may have either positive and negative consequences on the development of the tree in its environment.

Fertilization. We suggested early in this paper that patterns of resource allocation as well as the overall degree of resource availability defined robustness, the ability of mature trees to respond to change. Typical and traditional arboricultural practices act on the general patterns of resource allocation. Waring and Schlesinger (24) defined the changes in allocation of carbon resources as a function of a variety of environmental stresses (Table 2). They noted the often reciprocal nature of allocation to roots and shoots, i.e., where a stress increased allocation to roots, carbon transport to the crown was decreased (and vice versa).

These observations hold potential significance for arborists. Waring and Schlesinger suggested that nutrient excess will decrease the relative proportion of carbon allocated to roots. If so, then should not supplemental applications of fertilizer have the same effect? They did not define the problem in this manner. However, using this approach, we might question the utility of the standard practice of fertilizing a tree with root injury. If the effect of fertilization is to decrease the relative proportion of carbon allocated to the root system (as Waring and Schlesinger suggest), then the application of fertilizer in such a situation would be detrimental to the overall development of the tree. Alternatively, if the tree is in decline due to the chronic deficiency of one or more mineral elements, then fertilization must occur.

By definition, declining trees are senescent and the chances for survival, even with the most appropriate treatments must be considered problematic. We suggest that the use of "heroic" efforts to preserve trees must be done judiciously. The arborist must rely on experience in assessing the survival potential for a tree in decline.

Summary

The biology of trees changes with time, as the tree develops from a young sapling to a mature specimen to a declining individual. These changes influence all aspects of growth and development. As such, the management of trees must reflect the changing character of structure and function. In addition, management must consider the long-term consequences of environmental change, whether natural vs. man-made or short- vs. long-term.

In order to provide tree care to optimize life-span, arborists must be aware of the potential life-span of a tree, its life history strategy and its common patterns of death. They must consider the application of treatments such as pruning and fertilization in the context of the history of care and positive/negative consequences of that treatment to the tree. In addition, tree care to maximize life-span is a long-term, on-going process. It is not one of short-term, single treatments.

Practical applications for the arborist

Developing tree management programs—how and when to prune, irrigate, fertilize and provide pest control—is one of the most important tasks an arborist faces. It is a complex task because arborists deal with many types of trees growing under many different conditions. Another complication is that the maintenance needs of a tree change as it grows from youth, through maturity and into old age. We need to recognize what those changes are, so that we can modify how we care for trees, depending on their condition and ability to respond to treatments.

Old, declining trees are different than mature trees. They often have fewer, smaller and paler leaves. They contain more dead wood. Decay is more extensive. The amount of energy they can produce may not be able to meet demands for growth and survival. Trees have a limited life span. They cannot remain in a stable condition forever.

Probably the most important difference to recognize when caring for old, declining trees is that they have a limited ability to respond to our treatments. For instance, a mature tree may survive a period of drought, and resume a normal appearance once water is supplied. An old, declining tree, however, may simply deteriorate further. It cannot respond to our attempt to revitalize it.

One way to visualize the transition from mature tree to death is the "mortality spiral" (Figure 1). The mature tree gradually declines as it encounters more and more stresses, such as drought, insect defoliation and construction injury. Death may or may not result from any one single factor, but when a variety of stresses are added together, the tree cannot recover. Ultimately, it dies.

Tree management must be viewed as long-term care, not as single treatments, applied when something is wrong. As arborists, we must create a strong, stable tree structure, minimize unfavorable environmental changes and minimize insect and disease attack. A few important management techniques that accomplish this are:

- train trees when they are young to develop a strong branch structure;
- prune mature trees conservatively to avoid excessive thinning and wounding'
- observe "target pruning" to minimize decay development;
- plant the right tree in the right place, so the needs of the tree match its environment;
- irrigate and fertilize judiciously, considering the tree's native environment and past culture;
- protect the tree from environmental degradation, such as soil compaction, deicing salt, root injury, mechanical damage, etc.;
- develop species-appropriate programs for pest management.

The arborist should strive to maintain vigorous trees and prevent their entry into a mortality spiral. For trees already within a mortality spiral, we would do well to ask about the chances that our treatments will enable the tree to break out its state of decline, or whether it has deteriorated too far. In the latter case, removal and replacement may be the best course.

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Résumé. La gestion des arbres ayant atteint la maturité implique l'application de traitements culturaux appropriés dans le contexte d'une biologie de l'arbre qui évolue dans le temps. Les éléments clés pour la compréhension de la biologie des vieux arbres sont: l'histoire de la statégie de survie de chaque espèce, les limitations de croissance qui se développent en raisons de considérations de structure et de disponibilité des ressources, et les causes de mortalité des arbres forestiers et de paysagement. Puisque la biologie de l'arbre évolue avec le temps, de même en sera sûrement sa gestion. Les arboriculteurs peuvent jouer un rôle majeur dans le maintien d'une condition à maturité stable. Ils identifient des traitements routiniers et curatifs, tout comme ils évaluent l'habilité d'un arbre à répondre à tel traitement. Cependant, la capacité d'un arboriculteur à rétablir un arbre dépérissant vers un état stable est à questionner.

Zusammenfassung: Die Verwaltung von erwachsenen Bäumen hängt davon ab, die passenden, kulturellen Behandlungen im Zusammenhang mit der ständig-ändernden Biologie eines Baumes anzuwenden. Wichtige Elemente um die Biologie von alten Bäumen zu verstehen sind: die Lebensgeschichtestrategie von bestimmten Arten, die Wachstumhindernisse bezogen auf strukturelle überlegungen und die Verfügbarkeit von Speicherstoffen, und die Ursache der Sterblichkeit unter Forst- und Landschaftsbäumen. Wie im Laufe der Zeit die Biologie eines Baumes sich ändert, so auch ihre Verwaltung. Arboristen können in der Instandehaltung von einem reifen, stabilen Zustand eine zentrale Rolle spielen. Sie weisen auf routine und heilende Behandlungen, und auch messen sie die Fähigkeit eines Baumes auf die Behandlung zu reagieren. Allerdings ist die Fähigkeit von Arboristen einem verfallenen Baum zu heilen fragwürdig.

ABSTRACT

STROBEL G. and R. GRAY. 1990. **Dutch elm disease**. Am. Nurseryman 171(7): 64-69.

Dutch elm disease has inestimally damaged the beauty of the urban landscape. The origin of Dutch elm disease remains a mystery. England's C. Brasier contends that the disease come to Europe aboard the trans-Siberian railway completed during the war. Researchers have yet to find *C. ulmi* in Asia or uncover all of the tragic accidents leading ultimately to the fungus's arrival in the US. In the '70s, a research group in Montana had an idea that seemed to have some merit; to find a natural bacterium that would antagonize the Dutch elm disease fungus, *C. ulmi*. Certain strains of *Pseudomonas syringae* not only inhibited the fungus, but killed it. In 1980, the Chevron Chemical Co. of San Francisco began extensive field tests. After four years and millions of dollars, the company had little success with *P. syringae*. Holland's R. J. Scheffer discovered that the bacterium treatment could be effective. He treated 7,000 European elms suitably sized for street tree use, leaving an equal number of untreated as the control. The treated population consistently contained significantly fewer diseased trees than the control group. Dr. C. W. Murdock of the University of Maine, Orono, has extensively tested natural strains of *P. syringae* in some of New England's American elms. His results are similar to Scheffer's.