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DECLINE OF HARDWOODS: POSSIBLE CAUSES

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Declines of hardwoods have been widely publicized during the past few years, mostly in the popular and semi-popular press, but increasingly in technical publications as research workers have continued studies of possible causes of these disorders and remedies for them. A number of common characteristics allow the classification of declines as a distinct group of tree diseases. Symptoms are those of general debilitation, including reduced growth, twig and branch dieback, rootlet mortality, reduction of carbohydrate reserves, etc. Usually there is a gradual intensification of symptoms, often terminating in death of trees. Affected trees are generally incapable of responding strongly to favorable environmental factors. Single causal agents are capable of producing only a portion of the symptom complex. A variety of biotic and abiotic agents appear to be involved together as a causal complex. Thus, for our purposes, decline is a progressive general deterioration, often ending in death of trees, for which single exclusive causes have not been isolated.

SYMPTOMS OF DECLINE

Symptoms of decline are generally well known, and I shall do little more than list some of the common ones here. The first externally visible symptoms are usually those of reduced growth. Both twig elongation and diameter growth are reduced, such reductions occurring from one to several years before the onset of other symptoms. As internodes of twigs become shorter, foliage may take on a tufted appearance and entire crowns may appear thin.

Accompanying or preceding growth reductions, and in part responsible for them, are reductions in stored food reserves, particularly carbohydrates, in the roots of trees. In fact, reduction of stored reserves is considered by some to be the principal symptom of decline, other symptoms being more or less directly caused by the associated reduction of ability of trees to adapt to the constantly changing physical and biological factors of their environment.

Early symptoms of decline in roadside trees, particularly sugar maple, are scorching of leaves, premature autumn coloration and loss of leaves. As twigs and branches subsequently begin to die, trees may take on a stag-headed appearance. Dieback is the most conspicuous symptom of decline, and it occurs in two general ways: 1) twigs and branches may die during the dormant season, there being no apparent specific reason for death; 2) cankers caused by fungi may develop on weakened branches, causing their death inconspicuously during the dormant season or conspicuously as "flagging" while trees are in foliage. As terminal branches die and crown density is progressively reduced, sprout growth may develop on the trunk and major structural branches of trees.

In the late stages of decline, trees are subject to a number of additional troubles, particularly root rots and injury by bark and wood-boring insects. In extreme cases, trees are killed within a few years. More commonly, however, decline progresses slowly or symptoms may become static. Considering shade and street trees, the principal effect of decline is to drastically shorten their useful lifespan, necessitating their removal for aesthetic reasons or reasons of public safety before they actually die.

CAUSES OF DECLINE

General Considerations. — In many cases decline can be easily and satisfactorily explained in terms of obvious adverse factors in the environment of trees. Some common examples include local changes in drainage patterns caused by construction of new highways, sudden exposure of edge trees as land is cleared through wooded areas, injury and desiccation of roots of roadside trees as drainage ditches are maintained by highway departments, effects of drainage from salt or sand-salt storage piles used for highway snow and ice control, repeated severe defoliation by insects, and "decadence" of residual hardwoods left suddenly exposed in logged-over forest stands. Similarly, decline of sugar maple is largely a problem of roadside trees, and one can correctly make the trite generalization that it is caused by the presence, maintenance and use of roads.

But if one is inclined to go any deeper in examining the cases of decline, particularly in consideration of examples such as the last two, he quickly finds himself considering interactions of a potentially large number of physical and biological factors, the relative weights of which vary with time, locality and tree species. He quickly also discovers that one man is technically ill-equipped to explore the effects of more than a few of them. It should therefore be kept in mind that although causal factors may be considered individually as in the following discussion, this is done as a matter of convenience. Trees normally respond not to single factors but to a high-order interaction of the components of their constantly changing environment.

In considering causes of decline I find it useful to recognize three general types or combinations of causal factors: 1) predisposing factors which weaken trees or reduce their ability to withstand adverse conditions, 2) inciting factors which are responsible for the first general symptoms of decline, and 3) contributing factors which intensify or perpetuate the disorder. In each category there are qualitative factors (eg. soil type), the effects of which are exerted as a function of time, and quantitative factors (eg., dosage of salt to roadside trees) which may operate in combination with time but not as a function of it.

Predisposing factors or factor combinations most often include soil-site conditions and characteristics of the local climate. For example, decline of red oak in southeastern New York is most conspicuous on ridgetops and west slopes where soils are shallow and rapidly drained, or on other sites where available moisture is in short supply during summer dry periods. The mortality that often terminates oak decline usually occurs during periods of extreme moisture stress in late summer.

Inciting factors, either confirmed or suggested, include defoliating insects, severe drought, salt, extreme winter temperatures in the absence of normal snow cover, virus infections, and increased soil temperatures with concomitant changes in soil microflora. Evidence for these and other factors as incitants varies from strong (defoliation and oak decline) to tenuous (virus involvement in ash dieback). Much of it in either case is circumstantial.

Contributing factors include most of those just mentioned plus bark-and wood-boring insects, fungus pathogens that cause cankers and root rots, late and early frosts, and a host of less obvious possibilities. It should be recognized that some factors may occur in all three types of causal roles and that their effects are seldom independent or direct.

Let us now consider in more detail some of the factors that have been implicated as causes of declines.

The Involvement of Insects

Defoliation. — Severe or complete defoliation by locally high populations of lepidopterous insects has been directly and circumstantially implicated in declines of oaks and sugar maple in wooded areas. Leaf-rolling insects are most importantly involved, although others such as the forest tent caterpillar, the maple webworm and certain cankerworms have also been implicated.

In a study of decline and mortality of red and scarlet oaks in Pennsylvania, J. M. Staley (1965) noted a consistent association of defoliation by oak leaf rollers (*Croesia semipurpurana* and *C. albicomana*) with subsequent appearance of initial symptoms of decline. Artificial defoliation of young trees resulted in similar symptoms (growth reductions, production of Lammas shoots with distorted chlorotic foliage), and Staley concluded ". . . . that foliar symptoms of oak decline and symptoms of leaf roller defoliation are identical and that in the absence of other possible primary factors, such as root rot or drought, insect defoliation alone could be a primary cause of oak decline".

Oak decline has also been conspicuous in areas of southern New England and adjacent parts of New York and New Jersey in recent years. Severe defoliation is known to have occurred in these areas although the insects most involved have been different (Linden looper, spring cankerworm and other members of the Geometridae).

Effects of defoliation on sugar maple are best illustrated by the so-called maple blight that occurred in Wisconsin beginning in 1956 (Giese, et al. 1964). There is little doubt in this case that insect defoliators were primarily responsible for the disease, and the rapidity of demise of trees serves to exclude it from the general category of declines. It is mentioned here as an excellent recent example of the potential of insect defoliation as a cause of pathological responses in trees. For our purposes it can be considered to be an accelerated type of decline.

The defoliation was caused by a complex of lepidopterous insects whose larval (feeding) activity overlapped throughout much of the period when maples are in foliage. The most important of these were two leaf rollers, *Sparganothus acerivorana* and *Acleris chalybeana*, and the maple webworm, *Tetralopha asperatella* (Giese and Benjamin, 1964). In another area the saddled prominent, *Heterocampa guttivita* caused severe defoliation that preceded symptoms of maple blight (Giese, Kapler and Benjamin, 1964).

Even here, however, we cannot point to a single casual factor. Conditions of subnormal rainfall had existed in the maple blight areas before defoliations occurred, and when effects of various degrees of artificial defoliation and soil moisture reduction on sugar maple were tested (Skilling, 1964), it was found that ". . . . soil moisture reduction served to increase the effects of defoliation in terms of growth reduction, branch dieback and tree mortality".

The clear role of insect defoliators in genesis of maple blight in Wisconsin contrasts sharply with their role in sugar maple decline in New York woodlands as studied by R. C. Hibben (1962). In the latter state, heavy insect defoliations had been known to occur in only a few of the areas where maple decline was found. In such areas, dieback and occasional death of trees had been reported to be a consequence of repeated defoliation by the forest tent caterpillar, *Malacosoma disstria,* but the only factor common to all areas where the decline occurred was a past stand history of thinning or logging.

The seasonal timing of defoliation is an important determinant of subsequent damage to hardwoods. Insects that feed early or late in the growing season are likely to cause less net damage than those that are active during July and early August. This generalization is well illustrated by the timing of peak activity of defoliators associated with both oak decline and maple blight. It also helps to explain why the forest tent caterpillar, an early-season defoliator, has not been more importantly implicated in decline of sugar maple.

If trees are heavily or completely defoliated early in the season, a second flush of foliage is produced within a few weeks. While such foliage may show various abnormalities in size, form and density of leaves, it is active in photosynthesis long enough to allow some replenishment of food reserves that were expended for its production. Also, new terminal buds are set and hardened soon enough so that early frost damage is avoided. The effect of late-season defoliation is to reduce net phosynthesis for the season. In this case the majority of terminal buds remain closed until the following spring.

When defoliation occurs in midseason, a new flush of dwarfed, chlorotic and abnormally shaped leaves is produced at the further expense of stored food reserves that were normally depleted during the first growth flush. During the short remainder of the season these new leaves can not replenish much of the food reserve that will be necessary for the growth of the next year. In addition, twigs and buds produced during the second growth flush may still be succulent and susceptible to frost damage in autumn. When this occurs, dieback symptoms are likely to be very conspicuous the following year.

Borers. — The role of bark boring insects in decline is a contributory but often important one. These insects are attracted to weakened, already declining trees, but if high populations of the insects are present, even healthy trees may be attacked and considerably damaged.

The role of the bronze birch borer in birch dieback is typical of the general situation and has been concisely reviewed by J. Clark (1961).

> "Prior to the occurrence of dieback, logging of softwoods from mixed stands and failure to harvest mature birch had left the northeastern forests in a condition conducive to the buildup of high populations of the bronze birch borer (*Agrilus anxius* Gory), a native buprestid beetle. Therefore, when dieback was first observed in central New Brunswick it was suspected that the injury was due to increased activity of this insect, but a detailed study . . . . .showed that the early crown symptoms often occurred in trees having no borer galleries. . . .However, borer attacks are usually associated with advanced symptoms of dieback and there is little doubt that the larval girdling of the phloem and outer xylen is a major factor in the rapid death of diseased trees. In fact, ... without these attacks perhaps many of the affected trees would have survived."

A close relative of the bronze birch borer, the two-lined chestnut borer, *Agrilus bilineatus,* is involved in the demise of declining oaks in just the same way. Galleries of this insect are almost invariably found girdling the trunks of dying oaks.

Sucking insects. — Few sucking insects (aphids, hoppers, scales) have been implicated as causes of deline. One recent example, however, is provided in New York State where heavy infestations of the oystershell scale, *Lepidosaphes ulmi,* have been reported to be the incitant of a dieback of beech in forested areas (DeGroot, 1965).

Possibly more important than this type of direct involvement of sucking insects is their potential role as vectors of virus diseases. This possibility was pointed out by J. Clark (1961) with reference to birch dieback, and it does find precedent in the leafhopper transmission of other virus diseases of trees, one of the more notable being the lethal phloem necrosis disease of American elm.

The Contribution of Fungi

Pathogenic fungi are known contributors to declines of oaks, maple, and white ash, causing cankers above ground and/or decay of roots below, but only on trees already weakened by other factors.

Cankers. — Stem and branch cankers are directly responsible for much of the mortality of branches that characterizes the ash dieback disease. Studies at the State University College of Forestry at Syracuse University led to the discovery of two fungi capable of causing the cankers and thus reproducing part of the dieback syndrome (Silverborg and Brandt, 1957; Ross, 1964). But cankers were not invariably a symptom of the disease, and there was evidence that inoculations with the causal fungi, *Cytophoma pruinosa* and *Fusicoccum* sp., resulted in canker development only when trees were under moisture stress. Ross (1966) concluded that the canker fungi "...are secondary agents ... and serve primarily to accelerate death of the tree after its growth rate has been reduced by periods of low rainfall".

Root diseases. — A number of root infecting fungi have been found during studies of roots of declining oaks, maple and birch. The most common and best known of these is the shoestring fungus, *Armillaria mellea,* which attacks roots of many oaks and maples in the later stages of decline. However, evidence from studies of maple decline in New Hampshire and New York (Lacasse and Rich, 1964; Hibben, 1964), maple blight in Wisonsin (Houston and Kuntz, 1964), oak decline in Pennsylvania (Staley, 1965) and birch dieback in Nova Scotia (Redmond, 1955) all indicate that root-infecting fungi are at most contributors to decline.

The Possibility of Virus Involvement

There are relatively few recognized virus diseases of North American forest trees, and only one of these, phloem necrosis of elm, is definitely known to be responsible for death of trees. There is no evidence that virus infection is involved in current declines of oaks, maple, beech or black cherry (although the last-named species could be susceptible to a number of virus diseases found in the rose family). Considering diebacks of birch and ash, however, there is a possibility that viruses or virus complexes are involved as contributing or even inciting factors. Evidence to this effect is strongest in the case of birch dieback. As summarized by J. Clark (1961) the following points support the theory of virus involvement. 1) Some of the crown symptoms of birch dieback are characteristic of known virus diseases of other kinds of plants. 2) Some of the early crown symptoms of the disease were successfully transmitted to healthy trees by grafting (Berbee, 1957). 3) Drastic reductions in radial growth, characteristic of the early stages of dieback were not related to measurable climatic factors, were not paralleled by temporary reductions in growth of healthy trees, and were relatively greatest in symptomatic trees that had previously been most vigorous (Clark and Barter, 1958). 4) Field observations, reports of new occurrence and studies of radial growth patterns of birch in widely separated areas all indicated that the disease had spread from central New Brunswick.

A comparison of Clark's points with what is presently known about ash dieback might be instructive at least in pointing out needs for further research. 1) Some of the crown symptoms associated with ash dieback are characteristic of known virus diseases of other plants. These include chlorotic spots and rings, irregular chlorotic sectors and line patterns, green spots and rings in chlorotic or reddish tissue, reddish spots and rings in green tissue, premature reddening of leaves (Hibben, 1966), occasional witches' brooms associated with or apparently independent of stem injuries, dwarfing and some distortion of foliage and apparent reduced development of lateral twigs. 2) At least one virus has been transmitted from leaves of declining ash to herbaceous hosts (Hibben, 1966), although there are no reports of transmission of part of the dieback syndrome from diseased to healthy ash trees. The geographic distributions of recognized ash viruses relative to that of ash dieback are not known, and symptoms specifically suggestive of virus infection do not occur on all declining ash trees. 3) The single study of responses of healthy and symptomatic ash trees to climatic factors (Ross 1966) considered only a 13-year period. Study of weather and tree growth patterns over a longer period is needed to see if the recent unusual growth reductions in symptomatic ash have been associated with unusual weather patterns. If so, strength would be lent to the now generaly accepted hypothesis that ash dieback is a product of drought-induced reduction of vigor and increased susceptibility to facultative canker parasites. If similar drought periods (eg., in the 1930's) were not associated with similar growth and canker susceptibility responses, then the recent presence of some extraneous, possibily infectious, factor would be indicated. 4) Reports of occurrence of ash dieback during the past 25 years would suggest that it has spread radially from a locus in southeastern New York. This possibility, characteristic of an infectious disorder, could be checked by studies of annual growth rates of white ash, coupled with analyses of climatic factors at divergent geographic locations.

In short, there is a possibility of significant virus involvement in ash dieback and a strong probability of it with respect to birch dieback.,

Moisture deficiencies.

Moisture deficiencies can be involved in declines in several ways, both direct and indirect.

Extreme deficiency can actually cause desiccation and mortality of rootlets, wilting, scorch and death of leaves, and ultimately, death of an entire tree. Such effects were visible on many species in the Northeast in 1964 and 1965 and in parts of southern Ontario in 1966.

Moderate deficiency, undetectable on the basis of external symptoms, has been shown to reduce the rate of photosynthesis but not the rate of respiration. The practical result of this in trees is less accumulation of stored food reserves necessary for subsequent growth. When moisture is limiting in this way, correlations between rainfall of one growing season and growth during the next one can often be detected. If such deficiencies are more severe and prolonged, the net result may be an unusual dependency of annual growth upon rainfall during the first half of the same season. More will be said about this later.

Moisture stress is known to increase the susceptibility of many trees to canker diseases. Perhaps less directly, moisture stress also decreases the resistance of trees to facultative root parasites such as *Armillaria mellea*.

A succession of relatively dry years may favor populations of defoliating insects. Severe moisture stress renders trees attractive to bark beetles and borers which ordinarily do not successfully attack healthy trees well supplied with moisture.

With the exception of birch dieback, moisture deficiencies have been shown to be causally involved in all declines that have been investigated. The involvement is well-defined in oak decline, ash dieback and maple blight, less so in decline of woodland and roadside maples, sweetgum blight and declines of beech, black cherry and other species which thus far have received relatively little study. At the same time, however, it must be noted that investigators of birch dieback, notably Clark and Barter (1958) have made large contributions to our understanding of other declines by developing or adapting techniques for the study of relationships between tree growth and symptom expression and recorded characteristics of local weather.

Perhaps the best recent use of climatological analyses to determine the role of moisture deficiencies is found in J. M. Staley's study of oak decline (1965). Staley reasoned that if moisture stresses were involved in decline and mortality of oaks, there should be some unusual climatic "events" detectable from weather data recorded near oak decline areas. He accordingly calculated and ranked probabilities of occurrence of drought periods in 2 separate areas before and during the time when decline and mortality of oaks occurred. His calculations showed that decline and mortality were associated with somewhat unusual moisture stresses but that equal or greater moisture deficiencies in earlier years had not been associated with sustained growth reductions or mortality. Thus, some other factor (leaf-roller defoliation) was probably the principal incitant of decline. Staley therefore judged that seasonal precipitation deficiencies were most important in "contributing to the carbohydrate deficiency that underlies the initial symptoms of decline" and in combining with root mortality and borer attack "to produce the symptoms of extreme moisture stress that accompany the ultimate death of the stem.

The involvement of moisture deficiencies in decline of maples is probably similar: i.e., a predisposing and contributing role. The interaction of moisture supply and defoliation in maple blight has already been mentioned. In his recent evaluation of sugar maple decline, A. H. Westing (1966) states that "a deficiency of precipitation (translated into a soil-water deficiency) appears to be the most important of the abiotic (environmental) factors contributing to the decline of our sugar maples". He cites the following points as evidence: 1) the decline syndrome, although ill-defined, is the syndrome of water stress; 2) several unusually dry seasons, in sequence since 1962, have occurred in the Northeast since 1949 and have been temporally associated with the advent or intensification of maple decline; and 3) former declines of sugar maple just after the turn of the century and again in the 1930's were associated with drought periods.

The involvement of drought in declines is really not surprising when viewed in perspective. Large portions of the ranges of presently affected species lie in climatic zones characterized by periods of time each season when moisture available from the soil is limited or absent. These periods are most frequent in the latter part of the growing season (August and September) after trees have made all or nearly all of their seasonal growth but often occur during June and July as well. Their effects are seen in relationships between seasonal rainfall and growth. Figure 1 illustrates the rainfall-dependency of a group of sugar maple trees during the 40-year period from 1926 through 1965 at Ithaca, New York. Although the latter half of the period was characterized by an extremely close correlation between annual radial growth and total rainfall during May,

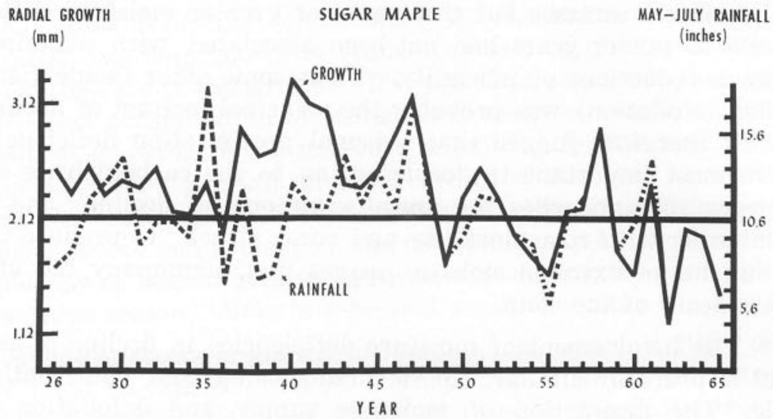

Figure 1. Relationship of annual radial growth of sugar maple to total rainfall during the months of May through July at Ithaca, New York, 1962-1965. Horizontal line is the 40-year mean of both growth and rainfall. 26

June and July of the same year, the reasons why such an obvious rainfall dependency began are obscure. However, the point may be made that when annual growth of trees becomes this closely regulated by variation in a single environmental factor (in this case, rainfall during a 3-month peroid), this in itself is a grossly abnormal situation in the northeastern United States and might well be a symptom of decline. In the same study from which Figure 1 was derived, similar but less conspicuous effects were seen in relationships between rainfall and growth of white ash and red oak.

Changes in climate.

The possible involvement of climatic change in declines has been mentioned by several investigators, and the general topic of climate and forest diseases has been reviewed by G. H. Hepting (1963). While there is evidence that a warming trend occurred through several decades until the early 1940's and that associated drought periods caused noticeable damage to trees, the trend has not continued during the past 20 years when declines, of ash, oaks, and maple, for example, have become most conspicuous. Again using Ithaca, New York as an example, the average annual temperature during the drought years 1962-1965 was more than 1°F colder than the previous 20 years. The average annual temperature from 1946 through 1965 was 0.8 F cooler than the 1926-1945 period, and the cooler temperatures, were associated with an average of 1.1 inches more annual rainfall than the previous 20-year period. The critical months of May-July were both cooler (1.66°F) and drier (0.60 inches less total rainfall) than the previous 20-year period. It seems, therefore, that weather patterns may be more fruitful than climatic changes as a subject for further study.

Salt and decline of roadside trees.

It must now be considered a fact that salt, as used for highway snow and ice control, is a common cause of decline of roadside trees, particularly sugar maples. Evidence to this effect has been accumulated in a number of separate studies in different areas. However, it is also well apparent that salting of roads does not alone insure that nearby sugar maples will decline. Prime requisites for salt injury are location of a tree close to a salted road (eg., 30 feet or less) and in a position to receive drainage from the road (Lacasse and Rich, 1964). As recently pointed out by Holmes and Baker (1966), many other factors including the amount of salt applied, timing of application with respect to snow plowing, soil characteristics, aspect and slope of the terrain, dates of application, depth and duration of frost in the soil, depth of plowed snow piles, amount of runoff from melted snow before the ground thaws, and inherent susceptibility of individual trees may all determine the extent of salt injury to a particular roadside maple.

Still largely unresolved are the reasons why trees, sugar maples in particular, are injured by salt. Evidence from several sources suggests that sodium and/or chloride ions may depress the uptake of certain essential nutrient elements, and that concentrations of chloride ion sufficient for direct toxicity may be accumulated in trees that are exposed periodically to high concentrations of salt in the soil solution. Sugar maple appears to be more susceptible to injury than many other species commonly planted along roadsides.

The involvement of air pollution.

Trees growing in and near urban and industrial areas are frequently exposed to damaging concentrations of a number of toxic gases. Injuries caused by sulfur dioxide, fluorine, ozone, peroxyacetyl nitrate and other gases are well known in such areas. The number of species that can be effectively used as street trees in large metropolitan areas appears to be limited in part by their tolerance to chronic injury by air pollutants. As a general rule, coniferous trees are more susceptible than deciduous species to this sort of damage. Accordingly, most observers now discount the idea that air pollutants are playing a major role in current declines of hardwoods, at least as they occur away from urban areas.

Site factors.

The easiest group of factors to identify as predisposing or contributing to decline of hardwoods are site factors — characteristics of specific locations where decline occurs. Thus, it is noted that oak decline is most conspicuous on ridgetops and south to west slopes where moisture supply most frequently becomes limiting. Roadside maples are most likely to show signs of distress if they are located below road grade in a position to receive drainage from the road. Declining trees are frequently growing in compacted, infertile soil. Rooting space may be sharply restricted by placement of trees in narrow lawns between sidewalk and curb. The involvement of site factors such as these in decline should be relatively obvious to anyone who has training or experience in horticulture or forestry. It is for this reason that I have emphasized some of the less obvious causes of decline during the past few minutes.

SUMMARY AND SUGGESTIONS FOR PREVENTION

We have considered several confirmed and possible causes of decline including insects, fungi, viruses, moisture stress, climatic changes, physical and chemical injuries and soil-site factors. The point has been made that decline is produced by inter actions of these factors and that the interactions may be strengthened by the passage of time. One clear general characteristic of declines of hardwoods is the sharply reduced ability of symptomatic trees to respond to favorable circumstances or to resist damage by unfavorable factors. Accordingly, it seems most reasonable to think in terms of prevention rather than cure of declines. We can exert some degree of direct or indirect control over a number of the factors I have discussed. This, of course, is an easier matter with shade and ornamental trees than with those in the forest.

One practical way to conclude the topic of declines of hardwoods is to apply some of the foregoing ideas to 3 general suggestions for their prevention.

1. Identify sites where decline is most likely to occur, and avoid them in establishing new trees of the same species.

2. Initiate and maintain a program of regular watering, fertilization and pest control for high-value trees.

3. Remember that the useful lifespan of a tree may be very much shorter than its total or potential lifespan. If trees must be planted in locations where rooting space is limited, physical or chemical damage is likely or there is no provision for regular care, this should be done with the knowledge that removal and replacement will be necessary much sooner than if the same trees were established under more favorable circumstances.

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