

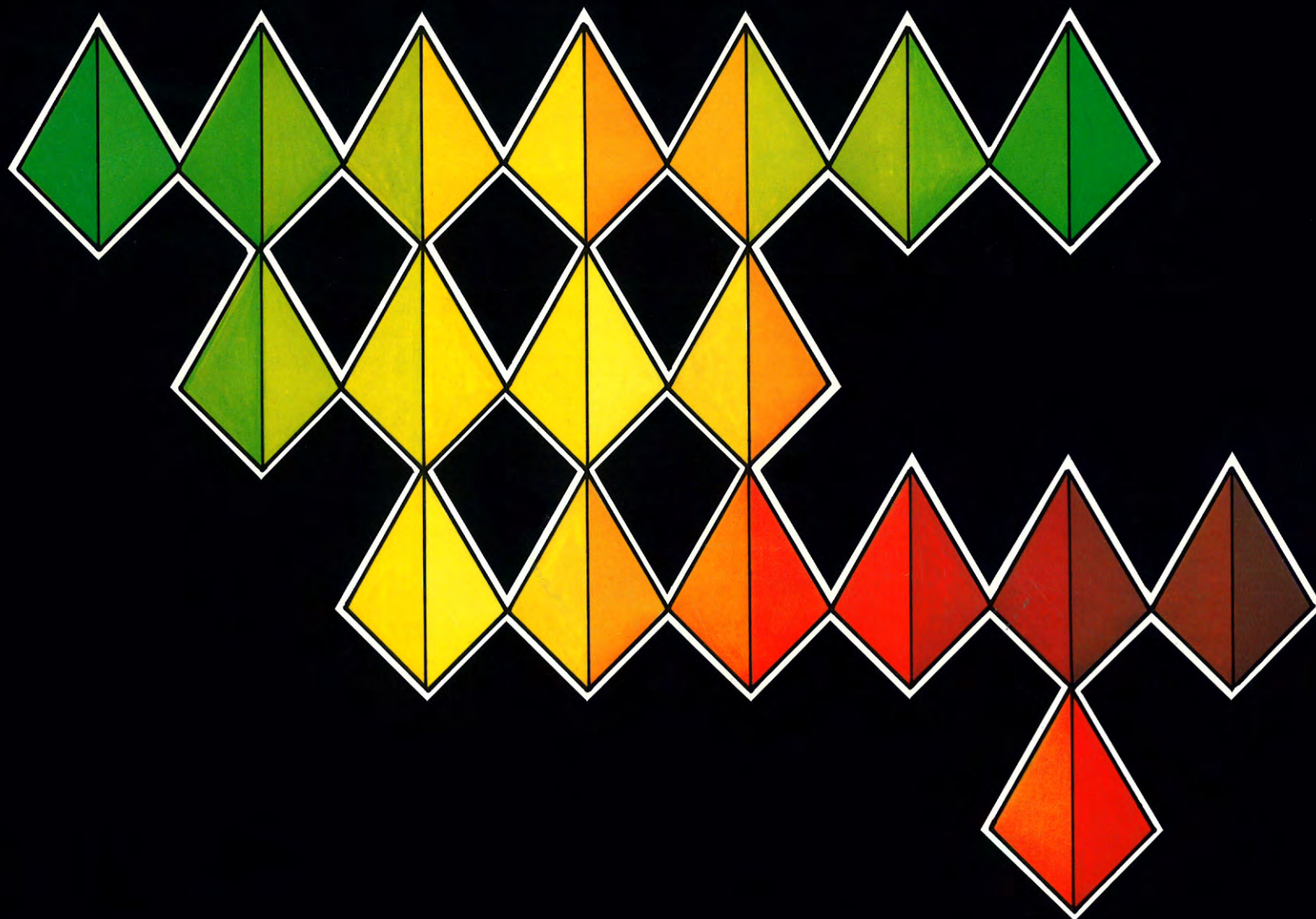


United States
Department of
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Forest Service

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Stress Triggered Tree Diseases The Diebacks and Declines



Foreword

Traditionally, dieback and decline diseases of trees have been described in generalities, attributed to unknown or mysterious causes, and thought to be beyond the scope of human intervention. This publication provides a basis for understanding and coping with these diseases. Discussed are concepts relating to: (1) diagnosing the factors that initiate the disease; (2) describing symptoms and disease development; (3) determining the role of secondary-action organisms; and (4) developing appropriate control measures.

The concepts presented here are drawn from more than 15 years of research on diebacks and declines conducted by the author and by his colleagues, Drs. Johnson Parker and Philip M. Wargo. Dr. Wargo's research on the relationship of stress-induced changes in trees and susceptibility to microorganisms has especially contributed to our understanding of these complex diseases.

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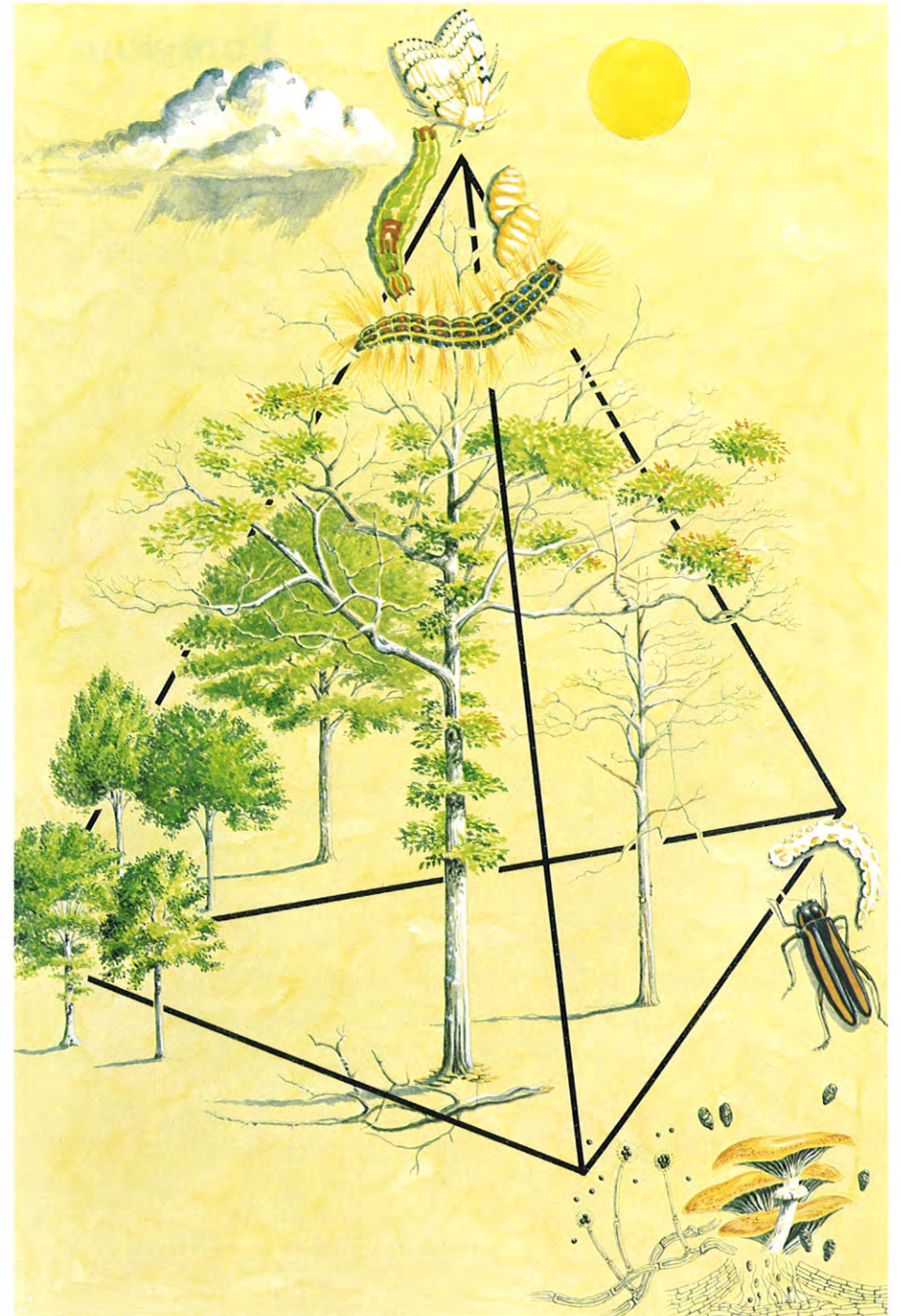
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Introduction

In recent decades, dieback and decline diseases have killed or damaged millions of trees in the northeastern United States. Most hardwood tree species probably have been affected by dieback and decline diseases at some point, but relatively few species have suffered greatly. Unfortunately, the species affected most severely are among the most important ones. And the incidence and severity of these diseases seems on the rise. In this publication, special emphasis is placed on the decline and mortality of oak initiated by gypsy moth defoliation. The significant impact of this widespread defoliation in recent years has prompted great concern and considerable research.

Diebacks and declines are complex diseases and, while they differ from each other in specific details, they share certain relationships of cause and effect. Each is initiated by an adverse environmental factor—**Stress**—and each is culminated by often lethal attacks by organisms that are otherwise insignificant. As their condition worsens, affected trees show common symptom patterns; that is, they dieback, decline, and ultimately may die. A general framework for the dieback-decline diseases is shown in Figure 1.

The dieback and decline disease can be expressed by the following word equations:



These equations imply that when the stress abates, and in the absence of lethal attacks by secondary organisms, trees can recover over a period of time or growing seasons.

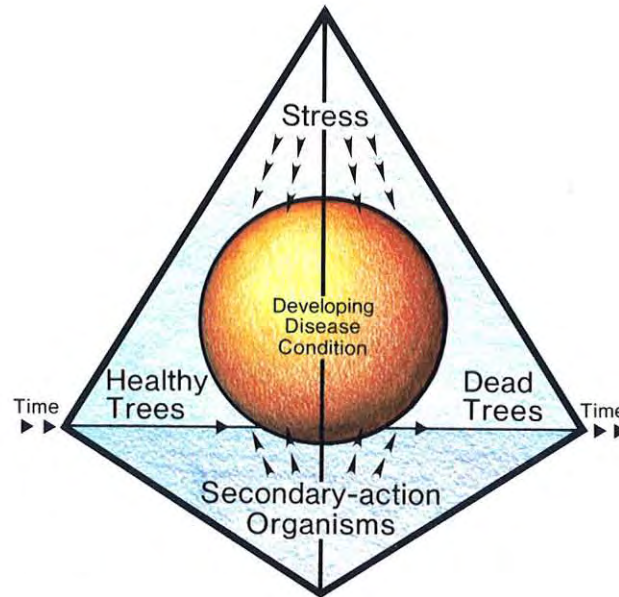
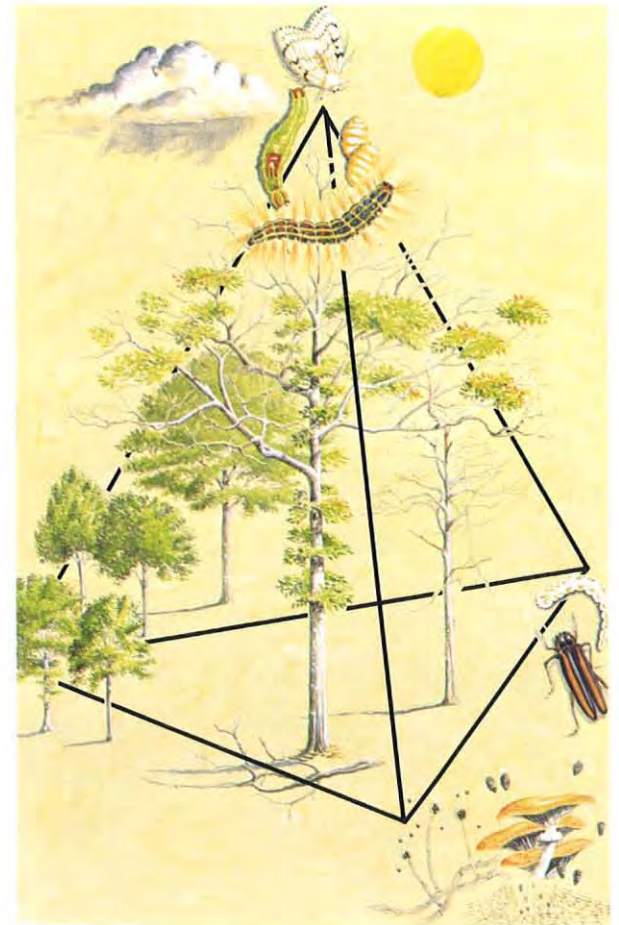


Figure 1

A conceptual framework for the dieback-decline diseases. Healthy trees are affected by environmental stress; over time, trees altered by that stress are invaded at some point by secondary-action organisms. The disease condition develops and trees dieback, decline, and ultimately may die.



Important Diebacks and Declines: Nature, Causes, and General Relationships

Ash Dieback

Dieback of white ash, and occasionally of green ash (Fig. 2), is typical of dieback and decline diseases. It is initiated by the stress of water shortage. Especially severe outbreaks were associated with periods of low rainfall in the 1930's and more recently from 1950 to the early 1960's.

The onset of ash dieback is signaled by the reduced growth of stems and twigs. This is followed successively by the death of terminal buds and branches and by the production, often at nodes, of small, sparse and chlorotic leaves. Affected crowns appear thin and tufted.

On some trees, leaves prematurely acquire the characteristic purple-bronze color of autumn and drop early. As trees progressively die back, in toward the trunk and down toward the ground, bole sprouts often develop. Finally, the trees die.

Soon after the onset of symptoms, reddish-brown to orange-yellow cankers develop on the branches and on smooth bark of the main stem. When these cankers girdle twigs or stems, they contribute markedly to the dieback process. At least two canker fungi, *Cytophoma pruinosa* and a *Fusicoccum* species, attack bark tissues made susceptible by water shortages. These fungi, common inhabitants of bark of shaded, lower crown branches, are thought to contribute under normal conditions to the death and "self-pruning" of lower branches so characteristic of forest-growth ash trees.

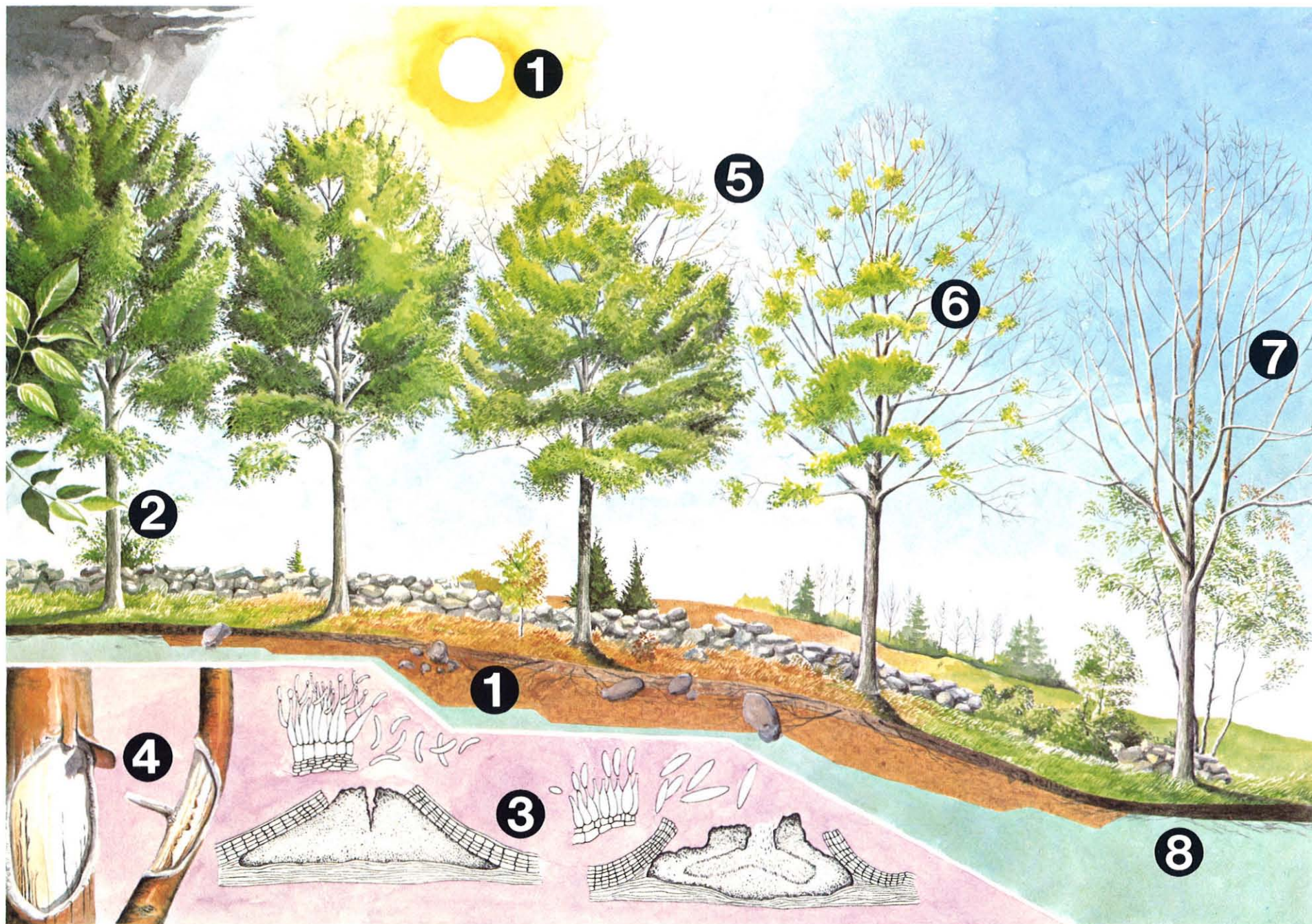
Ash dieback, as shown in Figure 2, can be thought of as a "system" whose word equations can be stated:



Other factors may be involved in ash dieback. Ash trees are hosts for viruses and mycoplasmas, and they are highly susceptible to injury from air pollution. How much these factors may contribute to ash dieback is uncertain; it may be significant that while the abatement of the disease generally has coincided with abatement of drought periods, the dieback and decline of ash has continued in some areas where there are viruses, mycoplasmas, and high levels of air pollution.

Figure 2

Dieback of ash begins when water shortages (1) alter the bark of healthy ash trees (2) and predispose it to attack by fungi (3) that cause cankers on branches and stems (4). The condition worsens over time and affected trees may continue to dieback (5), decline (6), and die (7)—even after the stress has abated and water tables have been restored (8).



Beech Bark Disease

The environmental stress factors that predispose trees to attack by secondary organisms can be abiotic, such as the water shortage associated with ash dieback, or they can be biotic. Such is the case with beech bark disease (Fig. 3).

Beech bark disease is initiated when the beech scale (*Cryptococcus fagisuga*), a tiny, wingless insect, feeds on the bark of beech trees. The white, “wooly” wax secreted by the insect as it feeds is the first evidence of the disease. Heavily infested trees may appear whitewashed.

Since its accidental introduction to Nova Scotia shortly before the turn of the century, the beech scale has spread slowly south and west. It now is found as far south as east-central Pennsylvania, and as far west as western New York.

As with other diebacks and declines, the effects of the stress agent alone usually are not sufficient to kill trees. The massive tree mortality that follows shortly after a buildup of beech scale results from the invasion of scale-altered bark by another organism—in this case, the canker fungus, *Nectria coccinea* var. *faginata*. Early signs of infection include a dark, weeping exudate known as a tarry spot or slime flux. Later, white sporodochia with long cylindrical spores (the asexual stage) and especially red perithecia with ascospores borne in asci (the sexual stage) often develop in great abundance in areas of bark previously inhabited by the beech scale. The presence of the fungus fruiting bodies is sure evidence that bark tissues have been killed. Often, bark tissues are killed in local patches and the wood beneath becomes invaded by wood borers and decay fungi. Trees may break off at these points—a condition known as beech snap.

The beech bark disease system, therefore, can be expressed by the equations:

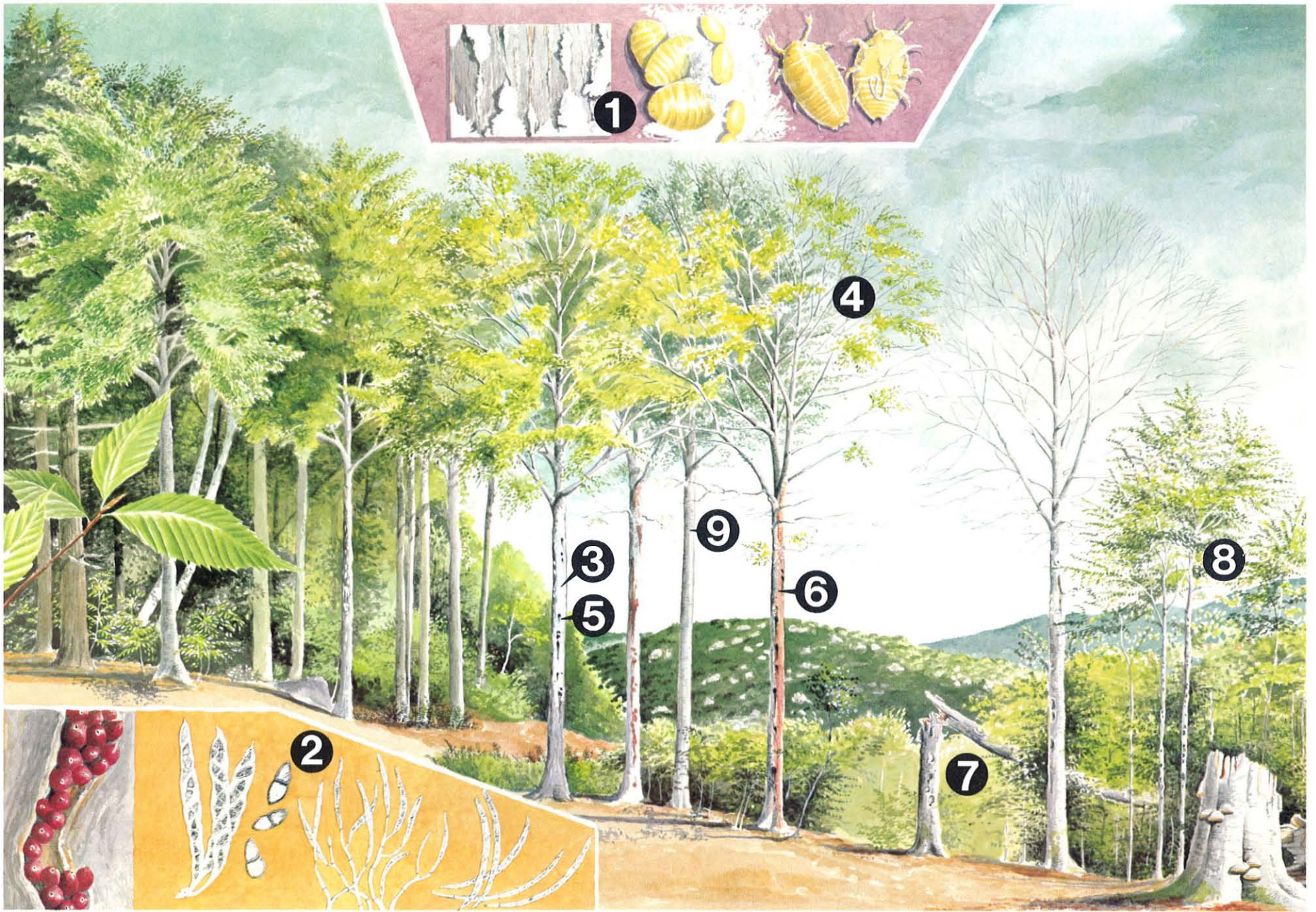


In many forests where large numbers of old, mature trees were either cut or killed by the disease, dense thickets of young beech trees have developed from root suckers. Often, these emerging stands are heavily infested by another insect, *Xylococculus betulae*. Small, young beech trees usually are quite resistant to *C. fagisuga*, but erumpent wounds created by *Xylococculus* provide places on these young stems for the beech scale and, subsequently, for *Nectria*.

In areas where the disease is widespread, there may be trees that are free of signs of the beech scale insect or *Nectria* fungus. This offers hope that resistance to the disease may occur in nature.

Figure 3

Beech bark disease occurs when bark tissues, altered by the feeding of the beech scale *Cryptococcus fagisuga* (1), are invaded and killed by a canker fungus, *Nectria coccinea* var. *faginata* (2). Heavily infested trees often appear whitewashed from the “wooly” wax secreted by the insect (3). As the disease progresses, the tree crown can become thin and chlorotic (4). Infection by *Nectria* is signaled by the appearance of dark, weeping exudates on the bark (5), and by red fruit bodies (6). Trees may snap off when wood beneath killed bark tissues becomes decayed (7). Eventually, in the aftermath of heavy mortality, a thicket forest of root sprouts may develop that is highly defective (8). Occasionally, an apparently resistant tree can be found (9).





Maple Declines

Several different diebacks and declines of sugar maple have been recognized. Figures 4-7 depict these diseases affecting trees growing along a roadside, in a sugar bush and in the forest.

Roadside maples

The decline of sugar maple along roadsides (Fig. 5) occurs when trees are subjected to the effects of road salting in winter or are affected by water shortages associated with drought or road paving. Many of the declining roadside trees were planted a century or more ago and are now over-mature. Often, the root system of these trees, encroached upon when roads were widened and later paved, loses its ability to meet the growing trees' demands for moisture. Injured and weakened roots provide avenues for entrance for many organisms—and often set the stage for decay and deterioration.

Sugar maple is especially sensitive to both sodium and chloride ions of deicing salt. The greatly increased use of this chemical in recent years has hastened the decline of many trees already struggling for survival in the roadside environment. Deteriorating trees, whose thin crowns support sparse clumps of small leaves that often prematurely exhibit fall coloration, and rows of stumps bordering roadsides of the Northeast testify to the magnitude of this problem.



Figure 5

Along roadsides, trees are stressed by drought, road paving, and especially by deicing salt. As trees decline, their weakened and killed tissues often are invaded by a host of organisms including decay fungi.

Figure 4

Declines of sugar maple occur in the forest (left), in the sugarbush (center), and along highways (right).

Sugarbush maples

In recent years, many old sugar maple trees have declined and died in sugarbushes of the Northeast. While the reasons for this are not thoroughly understood, the decline has been most severe in sugarbushes that have been subjected to drought, heavy grazing, or over-tapping and heavy traffic by farm machinery used in the sap gathering process. Many of the seriously affected trees are overmature and have been heavily tapped for many years. These trees usually are riddled with decay associated with tapholes and root wounds made by cattle or machinery. Decline in these sugarbushes often is accelerated by insect defoliation. Studies have shown that wounds such as tapholes are not closed over as rapidly by trees that have been defoliated; coupled with drought, damaged roots, and over-tapping, the effects of defoliation can be devastating. In fact, defoliation itself is a primary factor that initiates maple decline, and it has been especially serious in some forest environments.



Figure 6

Decay fungi complete the decline of maples growing in the sugarbush. Here, the major stresses of overtapping and of injuries to roots made by cattle and machinery weaken trees, making them susceptible to attack by organisms that break down woody tissues.

Forest maples

Maple decline in the forest often occurs after defoliation by a number of insects including leafrollers and webworms, the saddled prominent, and the forest tent caterpillar. Declining trees are marked by terminal dieback, progressive deterioration of the crowns inward and downward, and the production of “clumps” of foliage on sprouts. Death of weakened twigs can be hastened by attacks by weakly pathogenic fungi such as *Steganosporum ovatum*, and root systems of defoliated trees often are rapidly invaded and killed by the shoestring root rot fungus, *Armillaria mellea*.

Defoliation-initiated maple decline can be expressed by the equations:

Healthy maple trees	+	defoliation	=	altered trees (root food reserves reduced, dieback begins)
Altered trees	+	defoliation	=	trees altered further (food reserves depleted, decline continues)
Altered trees	+	<i>A. mellea</i> and <i>S. ovatum</i>	=	altered trees invaded (trees decline, die)

The relationship between defoliation and attack by organisms such as *A. mellea* is discussed in greater detail in sections on oak decline and mortality after defoliation by the gypsy moth.

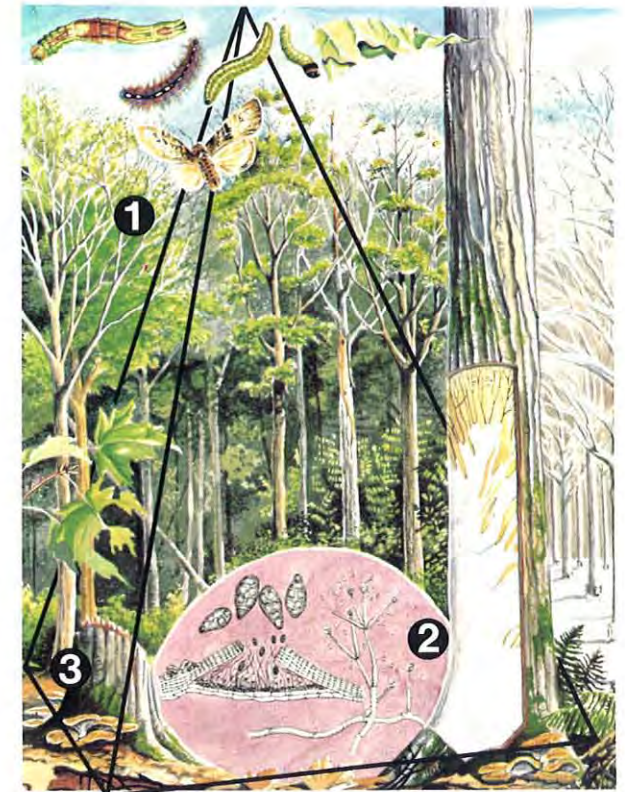


Figure 7

Defoliation (1) is the major stress factor in the decline of forest maples. Severely defoliated trees suffer marked branch dieback, and are susceptible to attack by several organisms including twig fungi (2) and *A. mellea*, the shoestring root rot fungus (3).

Reducing or Preventing Diebacks and Declines: General Concepts

The unique relationships of cause and effect and patterns of distribution discussed previously must be considered when attempting to control or prevent dieback and decline diseases. Control measures for diseases caused by primary, highly pathogenic organisms usually are directed against the pathogen itself. But control measures for dieback and declines usually focus on **reducing or preventing the predisposing stress factor**.

These relationships affect the approach taken by both pathologists and plant breeders to control these diseases. Thus, pathologists are more concerned with discovering why trees have suddenly become susceptible to attack by organisms of secondary action and with the “spread” and intensification of initiating stress factors, than with classical studies of reproduction, buildup, and dispersal of the organisms themselves. Likewise, plant breeders are not as concerned with developing resistance to secondary-action organisms directly as with developing resistance to the factors that predispose the trees to those organisms.

Forest and Woodlot

Some of the ways that diebacks and declines can be reduced in the forest and in urban areas are illustrated in Figures 8 and 9. When the stress factors are biotic, direct actions such as spraying can reduce or prevent the effects of severe infestations by sucking or defoliating insects. But the control of abiotic stress factors may be more difficult. In the forest, thinning to remove weak or dying trees reduces competition for moisture and nutrients; and encouraging species best adapted to the site may help minimize the effects of stresses such as drought and frost. In some situations, converting from one

forest type to another that is better suited to the site—perhaps by clearing and planting—may be the most appropriate solution. Reducing the number of logging wounds and associated decay will enable trees to better tolerate effects of added stress.

In the sugarbush, actions should be directed toward keeping trees as healthy as possible and toward reducing the adverse effects of wounds from cattle trampling, and from excessive tapping and other activities associated with producing maple sugar. Overtapping in general and probably any tapping the season following a severe defoliation should be avoided.

Figure 8

Ways to reduce diebacks and declines in the forest include timber stand improvement to remove defective, weak, or dying trees, and thinnings to reduce competition (stress) for moisture and nutrients and to favor species best suited to the site (1); converting one forest type to another better suited to the site (2); controlling outbreaks of defoliating insects when necessary or feasible (3); and reducing the number of wounds from careless logging or overtapping (4).



Urban Environments

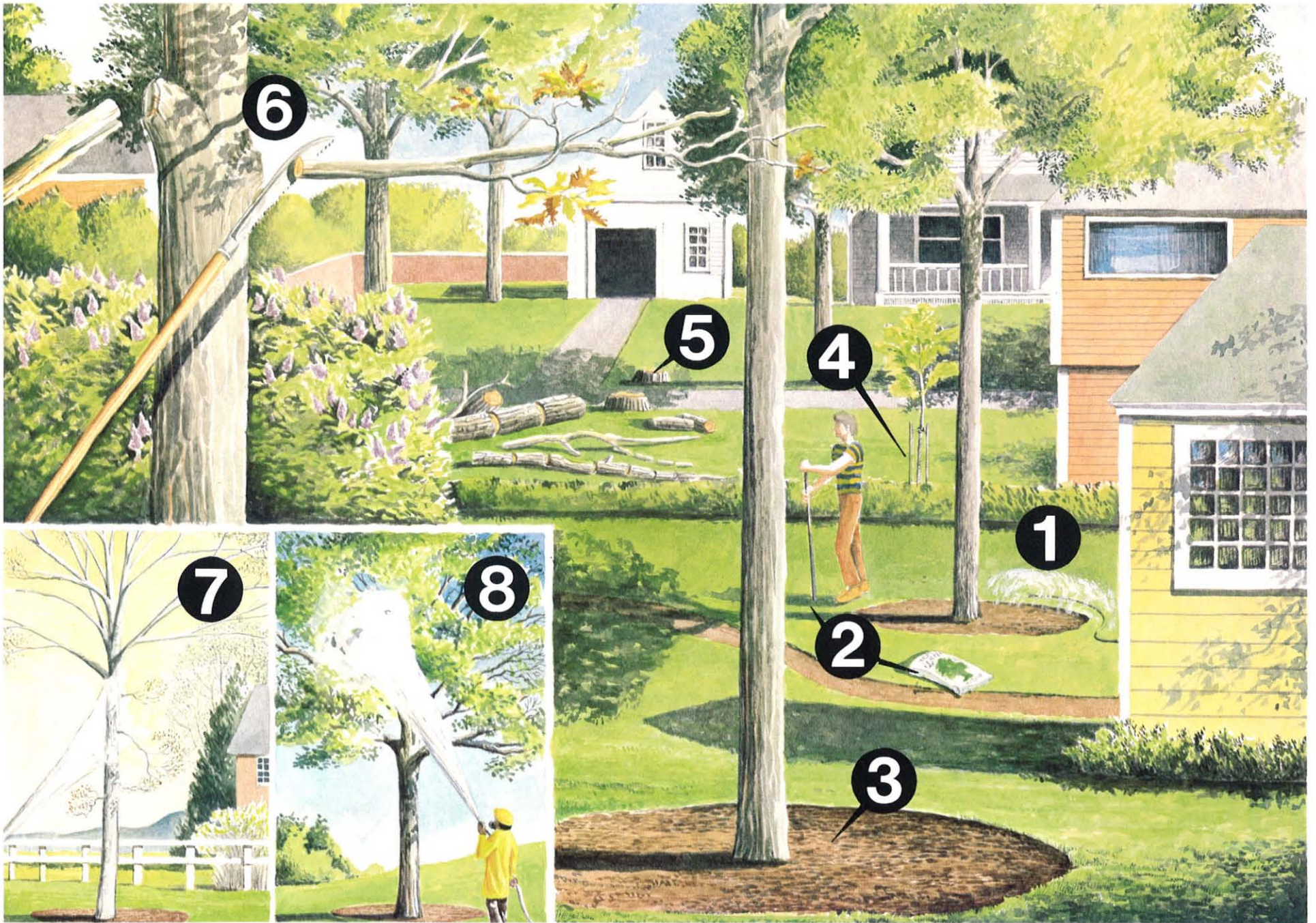
It is often possible to do more to alleviate the effects of stress in urban areas (Fig. 9) than in the forest. Moisture shortages can be prevented or alleviated by watering and fertilizing, by reducing competition from sod by placing mulch over the root zones of yard trees, and by avoiding soil compaction by covering walkways with wood chips or other organic mulches. Timely and judicious pruning of tree crowns will help trees in times of moisture stress, and removing weak or dead branches will help promote rapid wound closure and reduce the chance of decay. Planting new trees away from road-sides will avoid many severe stresses of the urban environment. Spraying to control sucking and defoliating insects when necessary and feasible will help prevent dieback and decline diseases of specimen trees.

Since diebacks and declines are initiated by stress and disturbance, it can only be concluded that these diseases will continue to proliferate as the number and diversity of stress factors increase with expanding urbanization.

The foregoing sections describe the general nature of dieback and decline diseases and the ways to reduce their significance. In the following sections, oak decline and mortality, a dieback-decline that has followed the widespread outbreaks of gypsy moth in the Northeast, is examined in detail.

Figure 9

Ways to prevent or reduce diebacks and declines in urban areas include watering (1) and fertilizing (2); covering tree root zones (3) and walkways with organic residues to alleviate water shortages and soil compaction; planting new trees (4) to avoid roadside stresses (5); pruning weak and dead branches to promote rapid closure and discourage decay (6); and spraying when necessary and feasible to control insects such as scales (7) and defoliators (8).



Oak Decline and Mortality Initiated by Gypsy Moth Defoliation: A Case Study

The Process of Oak Decline

Diebacks and declines of oaks are not new to forests of the East. Numerous instances of severe problems have been associated with stress factors such as late spring frost, drought, and insect defoliation, singly and in concert. In recent years, severe defoliation by gypsy moths in New England, New York, New Jersey, and Pennsylvania has triggered the decline and death of millions of oaks (Fig. 10). Regardless of the predisposing factors involved, the death of trees is primarily associated with the lethal attacks by *Armillaria mellea*, by *Agrilus bilineatus*, the twolined chestnut borer, or both.

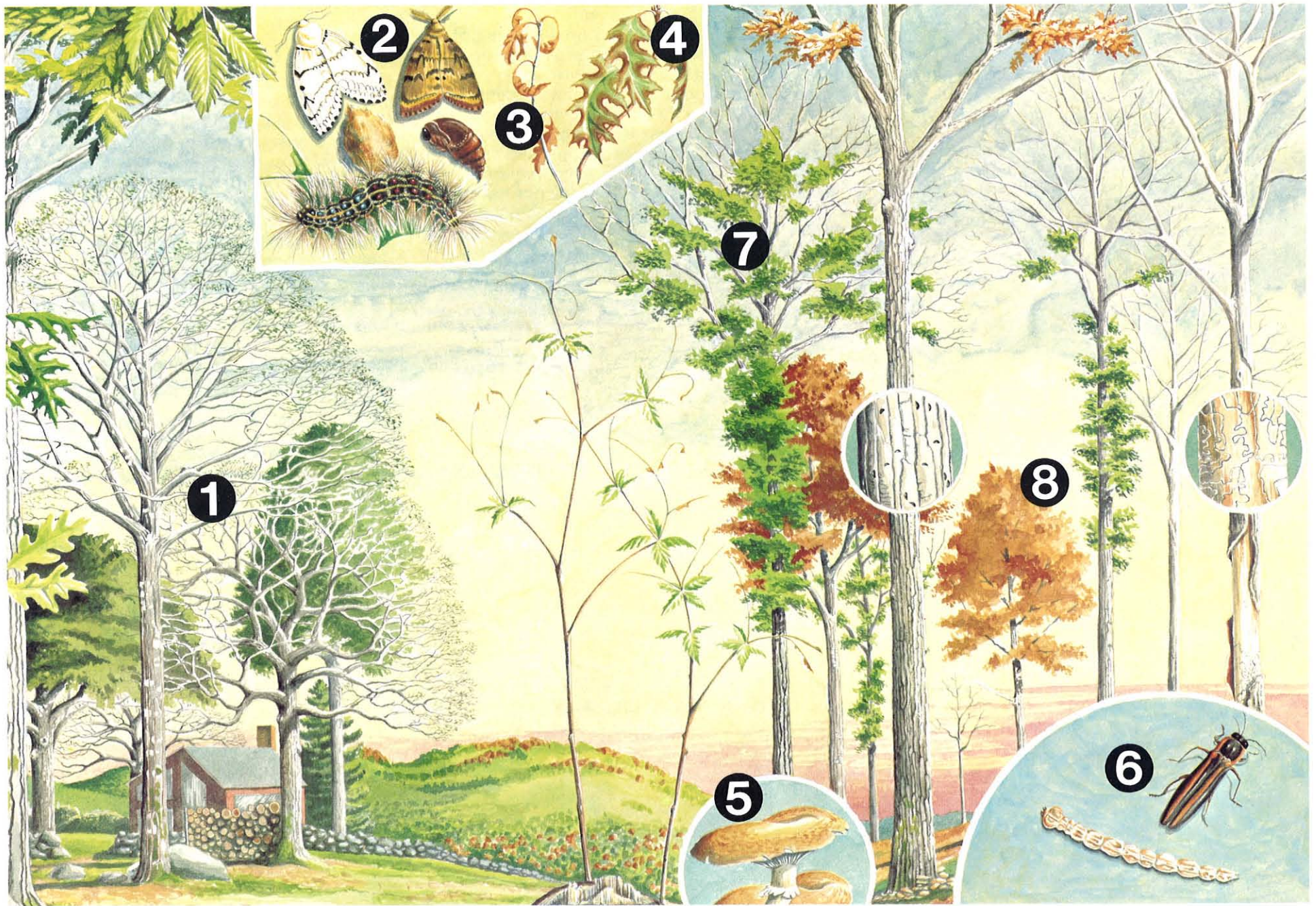
We can describe the system of defoliation-initiated oak decline by these equations:



In the following sections we will examine how defoliation affects trees, and how these effects render them susceptible to attack by *A. mellea* and *A. bilineatus*.

Figure 10

Oak decline occurs when healthy oaks (1), predisposed by the effects of defoliation by insects such as the gypsy moth (2), frost (3), or drought (4) are attacked and killed by the shoe-string fungus, *Armillaria mellea* (5) and the twolined chestnut borer, *Agrilus bilineatus* (6). Trees on ridge tops and in wet areas suffer most severely from drought, and frost often affects trees growing in valleys and frost pockets (center background). Trees defoliated sufficiently to be re-foliated the same season (center foreground) may show symptoms the next year (7). Repeated defoliations can result in tree death as weakened trees succumb, sometimes suddenly, (8) to the girdling actions of the borer above ground, and of the fungus below.



The Defoliation Stress

The function of leaves is to convert sunlight energy into chemical food energy needed by the tree for maintenance, growth, and reproduction. Defoliation, therefore, adversely affects the tree by interfering with its energy regimen. Fewer leaves mean less food produced and less growth. While this direct relationship exists for any level of defoliation, low levels usually are not harmful aside from reducing radial and terminal growth. But the removal of 50 to 60 percent or more of a tree's leaves can be very serious because such levels trigger major responses by the tree that can be deleterious to its function or form.

Refoliation-Dieback: Responses of Individual Trees to Defoliation and Their Consequences

Severe defoliation can cause trees to refoliate, an event that places them in an "out of phase" condition with respect to the growing season (Fig. 11). Buds formed for the next year are forced to break one season too soon, and the new leaves must produce food and new buds in a shortened growing season. Sometimes new leaves are immature when fall arrives and new buds have not been formed. Even when defoliation occurs early enough in the season for the new foliage to grow and mature, the new small terminal buds may not be winter hardy. When the terminal buds are killed or injured, or do not have time to form, twigs die back to the point where there are sound lateral buds.

Adverse changes are also occurring inside the tree. Sugars produced by the leaves usually are moved to the roots where they are stored as starch food reserves. Normally, food reserves are highest in the fall after a full summer's production. But defoliation and refoliation can change all of this. When buds break and leaves start to grow, starch is converted to sugars and sent to the growing areas to maintain the tree until there is new foliage. Often, tree roots are completely depleted of their starch by this process and little is replaced before the end of the growing season.

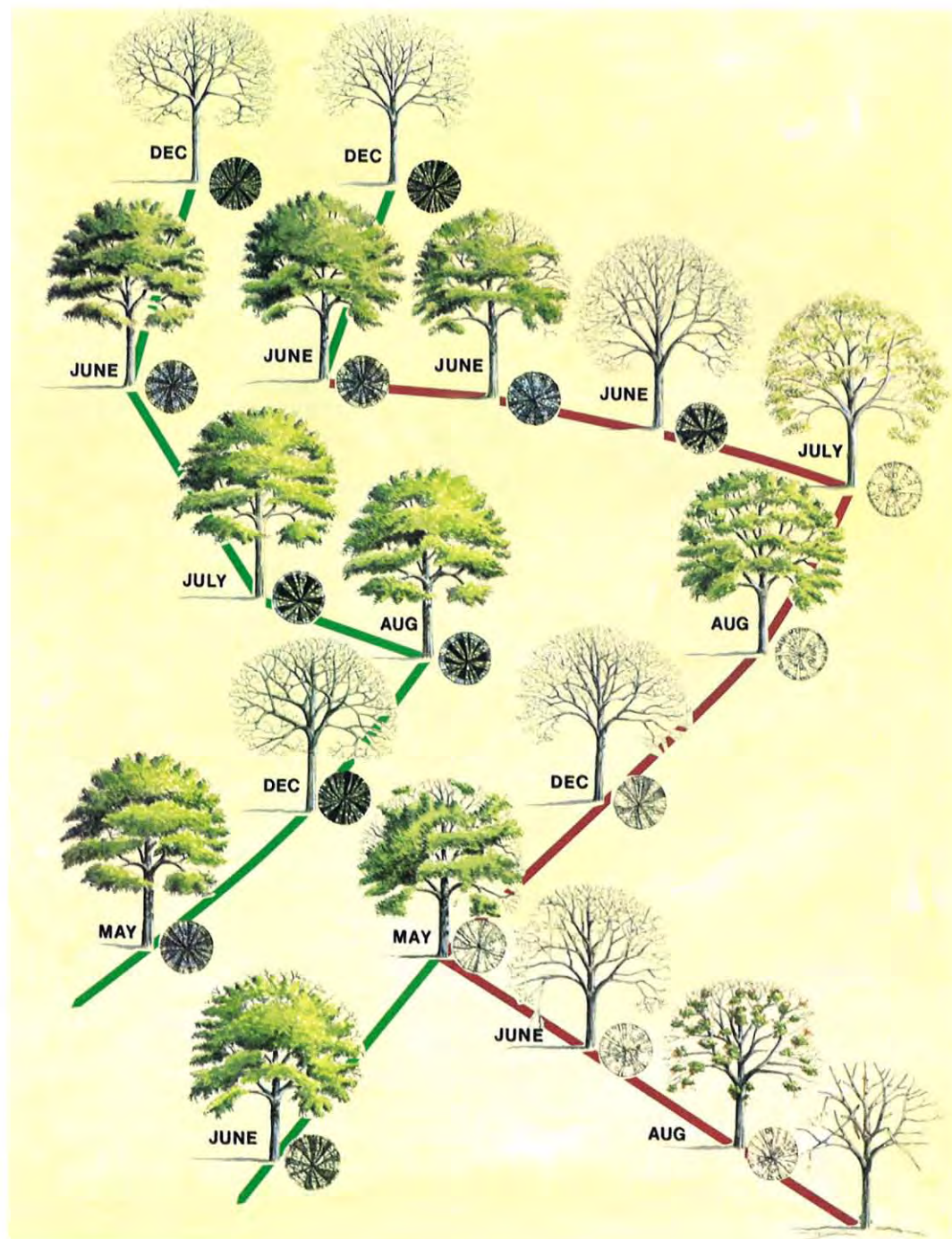
The effects of defoliation are most serious when it occurs just after "normal" leaves are produced in late spring-early summer but before starch reserves have been replenished. With such low food supplies, the energy demands of all the branch and root tissues cannot be met until new leaves are formed and some tissues die back.

The dieback process, which may be repeated again and again as the defoliation stress continues, serves as a survival mechanism. By reducing the amount of energy-requiring branch and stem tissues, dieback "fine tunes" the tree's energy balance to its adverse environment.

With abatement of the defoliation stress, even if it has occurred for more than one season, trees can recover providing growing conditions are favorable and providing they have not been lethally invaded by opportunistic organisms that can attack them in their weakened state.

Figure 11

Crown symptoms and root starch content (food energy reserves) in a nondefoliated oak tree (green track, left) compared with a defoliated tree (red track, right) over two growing seasons. Severe gypsy moth defoliation in June triggers refoleation. Food reserves stored as starch in roots (dark color of cross sections) are converted to sugars to provide energy needed until there are new leaves. New leaves produce insufficient food to replace that used, and trees enter the next winter with low or depleted starch reserves. Branch dieback may result from winter desiccation of buds, and from lack of food reserves; in the season after defoliation, leaves often are small, off color, and "clumped." A second defoliation further depletes starch reserves, the decline continues, and the trees may die. If defoliation is not repeated and growing conditions are favorable, the trees may recover (green track, right).



Organisms of Secondary Action: *Armillaria mellea* and *Agrilus bilineatus* and the coup de grace

Defoliation causes starch to be converted primarily to simple sugars such as glucose and fructose that occur in relatively low quantities in nonstressed trees. This is important because *Armillaria mellea*, the shoestring root attacking fungus (Fig. 12), uses these sugars as energy sources for its growth. Thus, the shift in energy within the tree initiated by defoliation favors the fungus and stimulates its rapid growth between the bark and wood of roots and root collar. This girdling action by the fungus sounds the death knell for many stressed trees.

Within individual trees, therefore, the defoliation process not only interrupts the conversion (flow) of sunlight energy to chemical food energy, but also triggers the shift of chemical food energy from one form to another (starch to sugars)—and ultimately from one organism to another (tree to fungus).

Although these energy relationships are probably most significant, defoliation does trigger other biochemical changes—as yet not thoroughly understood—that may serve to reduce a tree's resistance to attack, or increase an organism's pathogenicity. There is increasing evidence that the likelihood of a defoliated tree being attacked and killed is influenced strongly both by tree condition and by complex interactions between species of tree, strains of the fungus, and conditions of the site.



Figure 12

The fungus *Armillaria mellea* is an organism of secondary action important in many dieback-decline diseases. It can be recognized by the characteristic shoestring-like rhizomorphs in the soil or attached to roots, the white sheet-like fans of fungus mycelium between the bark and wood, and the clusters of honey-colored mushrooms that appear near the base of trees in the fall.

The twolined chestnut borer *Agrilus bilineatus* also has long been associated with dying oak trees (Fig. 13). Indeed, the obvious and characteristic galleries created by the borer as it tunnels between bark and wood of main stems have led many to conclude that it is a much more important mortality-causing agent than *Armillaria*—whose activity is mostly hidden below ground. Research has shown that either organism in its respective arena can deliver the *coup de grace* and that extreme mortality can result when they operate together.

It is not known if *A. bilineatus* is affected by the same changes in trees that trigger attack by *A. mellea*. Borers are attracted to trees under stress—probably by the release from such trees of a volatile chemical produced in response to the stress. Trees that have been girdled, injured by lightning or wind, droughted, or defoliated are attacked selectively.

The ability of a tree to withstand attack by the borer seems related to its physiological condition since trees growing slowly before they are attacked are more likely to succumb than trees with good growth. Thus, the tree's response to gypsy moth defoliation not only serves to attract this organism of secondary action and to stimulate its attack, but also seems to reduce the tree's resistance to that attack.

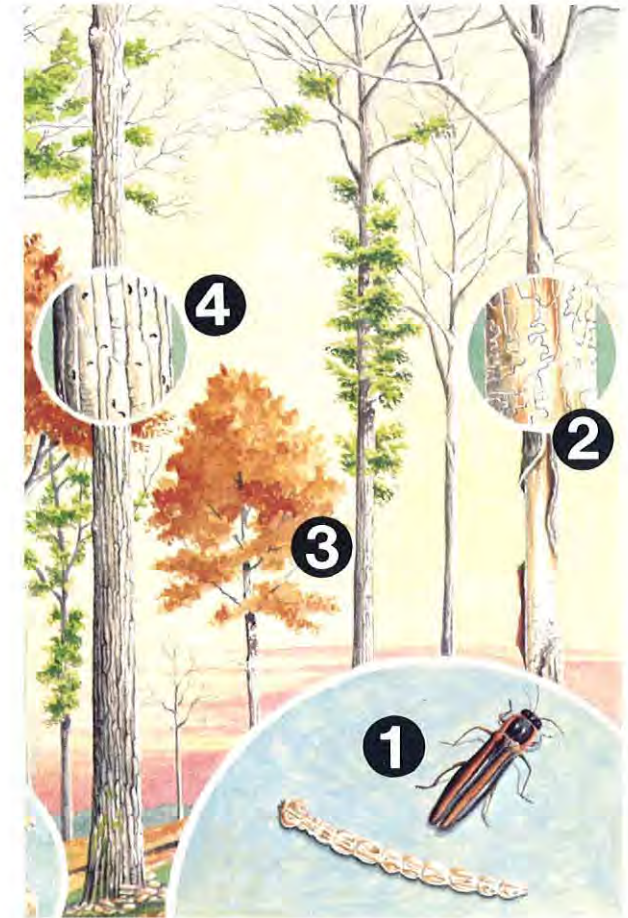


Figure 13

The twolined chestnut borer *Agrilus bilineatus* (1) also is an important organism of secondary action, responsible for the death of many oak trees weakened by stress. Often, trees girdled by the meandering galleries of the borer (2) die quickly and retain their brown foliage for some time (3). Borer damage can often be detected by the presence of D-shaped exit holes (4).

Some Ecological Relationships

Effects of Oak Decline on Energy Flow and Material Cycling in the Forest

Energy flows but one way through a forest ecosystem. It enters the system as light, is transferred within the system as chemical food, and exits the system as heat. It does not recycle. Essential nutrients, on the other hand, cycle continually within the ecosystem.

The defoliation process results directly in the shunting of the normal flow of energy from leaves to tree cells to soil microorganisms (the “detrital circuit”), to a flow from tree leaves to gypsy moth (the “grazing circuit”) (Fig. 14). The shunted energy continues its one-way flow through a number of gypsy moth-initiated food chains.

Since all materials essential for growth cycle within the ecosystem, defoliation, though it temporarily interferes with normal pathways, probably affects relationships of nutrients less seriously than those of energy. Significant amounts of nutrient-rich insect frass and leaf fragments could be washed from watersheds (Fig. 14), but such an event is probably rare and of little long-range consequence.

Some Forest Influences

Energy flow and nutrient cycling are the driving forces behind the relatively orderly biological development of a forest. Ecologists call this development “succession.” Stresses such as those that initiate oak decline—together with the tree mortality that follows—can materially alter the course of forest succession.

In the moderately moist northern states of New England, the development of hardwood forest, following agriculture or disturbance by heavy logging or fire, often begins with stands rich in such short-lived pioneers as gray or

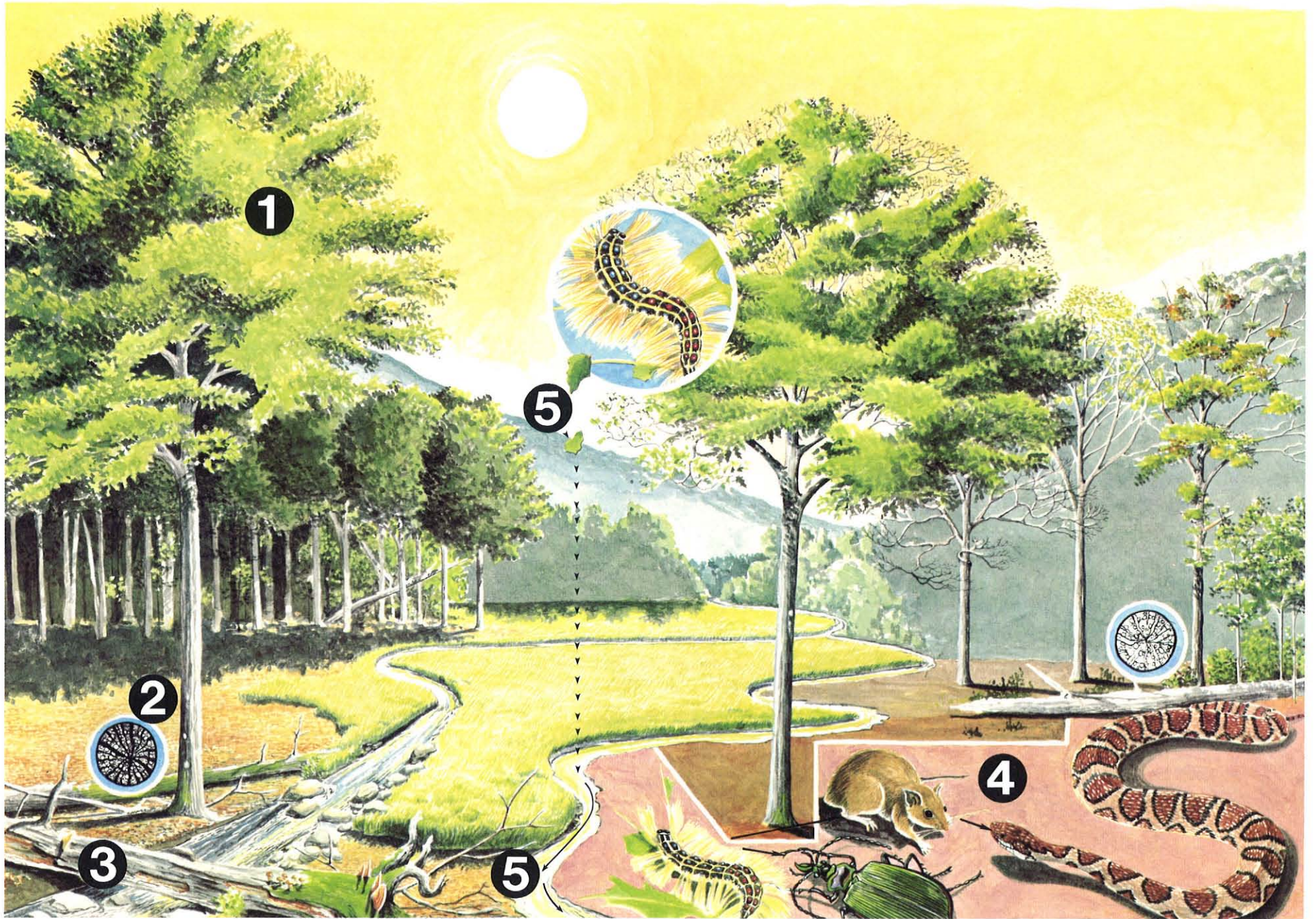
white birch and aspen. Later, these species are replaced, first with early-stage, longer lived oaks and eventually by more shade-tolerant species such as red oak, sugar maple, beech, and hemlock. Most oaks in these forests are relatively transient, and their dominance of the site is usually for short periods.

Moderately heavy defoliation of these forests by the gypsy moth often serves to accomplish in a short time what succession would do eventually, especially if forest development is well advanced. The reason for this is that gypsy moths prefer the early-stage species. In mixed forests, preferential defoliation tends to reduce the relative proportion of these early-stage species, leaving forests richer in species characteristic of more successional mature forests. Severe, repeated defoliation, however, can result in considerable tree mortality, even among species that are generally less favored by the gypsy moth.

In some southern New England states, oaks tend to be more numerous and to dominate the forest for longer periods. In such situations, most of the trees were eliminated from the stand.

Figure 14

In the nondefoliated forest (left), sunlight energy is converted by tree leaves to chemical food energy. This energy is used in tree growth and maintenance (1) and is stored in roots as starch (2), and finally flows through a “detritus circuit” as microorganisms decompose fallen leaves and other dead plant parts (3). When gypsy moth defoliates the forest (right), the energy flow is shunted into a “grazing circuit” and passes through a number of food chains that begin with the gypsy moth (4). Some potential chemical food energy and nutrients may pass out of the ecosystem in leaf fragments and insect frass (5) but this probably is of little importance.



Susceptible vs. Resistant Forests

Site conditions strongly influence where gypsy moth defoliation will occur. In New England, where gypsy moths and forests have interacted for over a century, some forests have had a history of repeated defoliation while others have been defoliated only rarely (Fig. 15). The often defoliated or susceptible forests characteristically grow on dry sites such as rocky ridges or deep sands. In many cases, they have been disturbed—sometimes frequently—by fire, wind, snow, or ice storms. The trees in these forests, mainly dry-site oaks, often are highly favored as food by gypsy moths, are slow growing, small, and scrubby, and have abundant structural features such as bark flaps, deep bark fissures, and holes or wounds that are used as resting sites by gypsy moths.

The open nature of susceptible forests encourages the growth of plants such as blueberry, huckleberry, bracken, sweetfern, grasses, and sedges. Leaf litter usually is shallow or lacking; on ridge stands, surface rocks or exposed ledges are common.

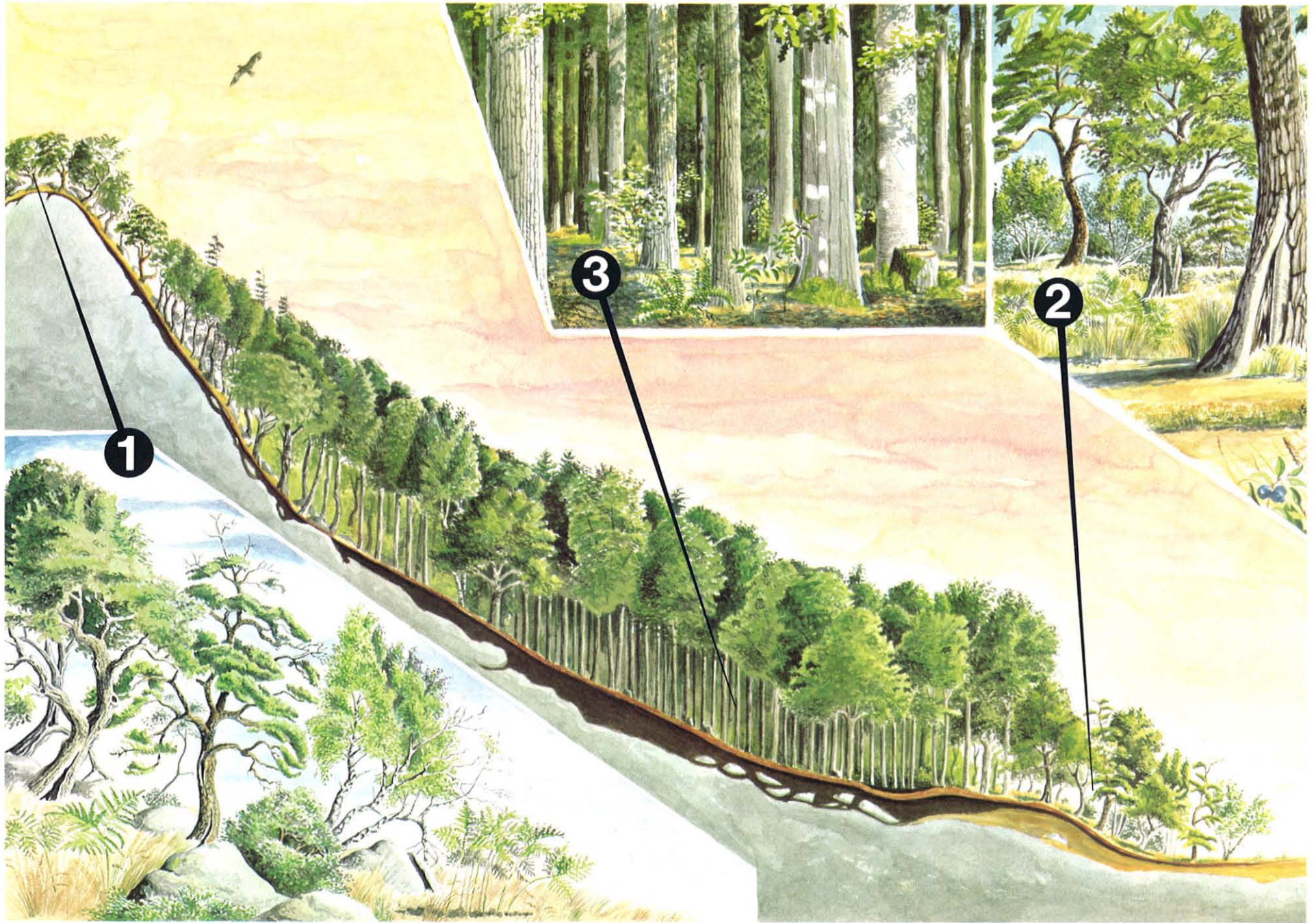
Resistant forests where defoliation is rare characteristically grow on relatively undisturbed sites with well-drained, deep loam soils where moisture is not limiting. They usually are well stocked and contain mixture of species, including some that are highly preferred. Trees on these sites have good growth rates and relatively few structural features used by gypsy moths.

Understory plants in New England's resistant forests include such species as wild sarsaparilla, maple-leaved viburnum, and woodland ferns. Resistant stands have deep litter layers that are favorable habitat for many predators of gypsy moth.

It is not axiomatic that trees growing on susceptible sites are more apt to succumb to a given defoliation regimen than trees on resistant sites. Studies suggest that trees on adverse sites may be no more—indeed, may even be less vulnerable—than trees on good sites. Perhaps this reflects the fact that trees on poor sites represent the survivors of an exceptionally intense and continual selection process.

Figure 15

Susceptible forests of New England characteristically grow on disturbed sites such as rocky ridges (1) or deep sands (2). The trees in these forests often are highly preferred as food by gypsy moths, slow growing, small, and scrubby, and have many structural features that serve as refuges for the insect. The resistant forests of this region (3) characteristically grow on relatively undisturbed sites with well-drained, deep loam soils where moisture is not limiting. Resistant stands contain mixtures of species including highly preferred ones, but they have relatively few structural features used by gypsy moths.



Physiological Performance and Condition: Reflections of the Past

Oaks growing on a good site may look quite different from those of the same species growing on a poor one (Fig. 16). These differences reflect the responses of trees to site-related limitations in soil moisture and nutrients, or to site-related disturbances.

Site-Related Characteristics

Chestnut oaks on adverse sites (left) grow more slowly than on good ones (right). This is reflected externally by smaller, shorter crowns, smaller stem diameters, and deeper bark fissures, and internally by narrow annual growth rings of stems and roots and a relatively narrow band of light-colored sapwood. Because slow-growing trees do not close wounds rapidly, trees on adverse sites often bear open wounds from branch stubs or injuries caused by storms or fire. Even on good sites some trees appear poorer than others. Often, this is a reflection of the inherently different capabilities of individual trees to grow and to compete for light, moisture, and nutrients. On good sites, these trees will drop by the wayside as the stand develops. These internal and external characteristics constitute a tree's record of **physiological performance**; that is, how well it has performed in response to intrinsic site factors.

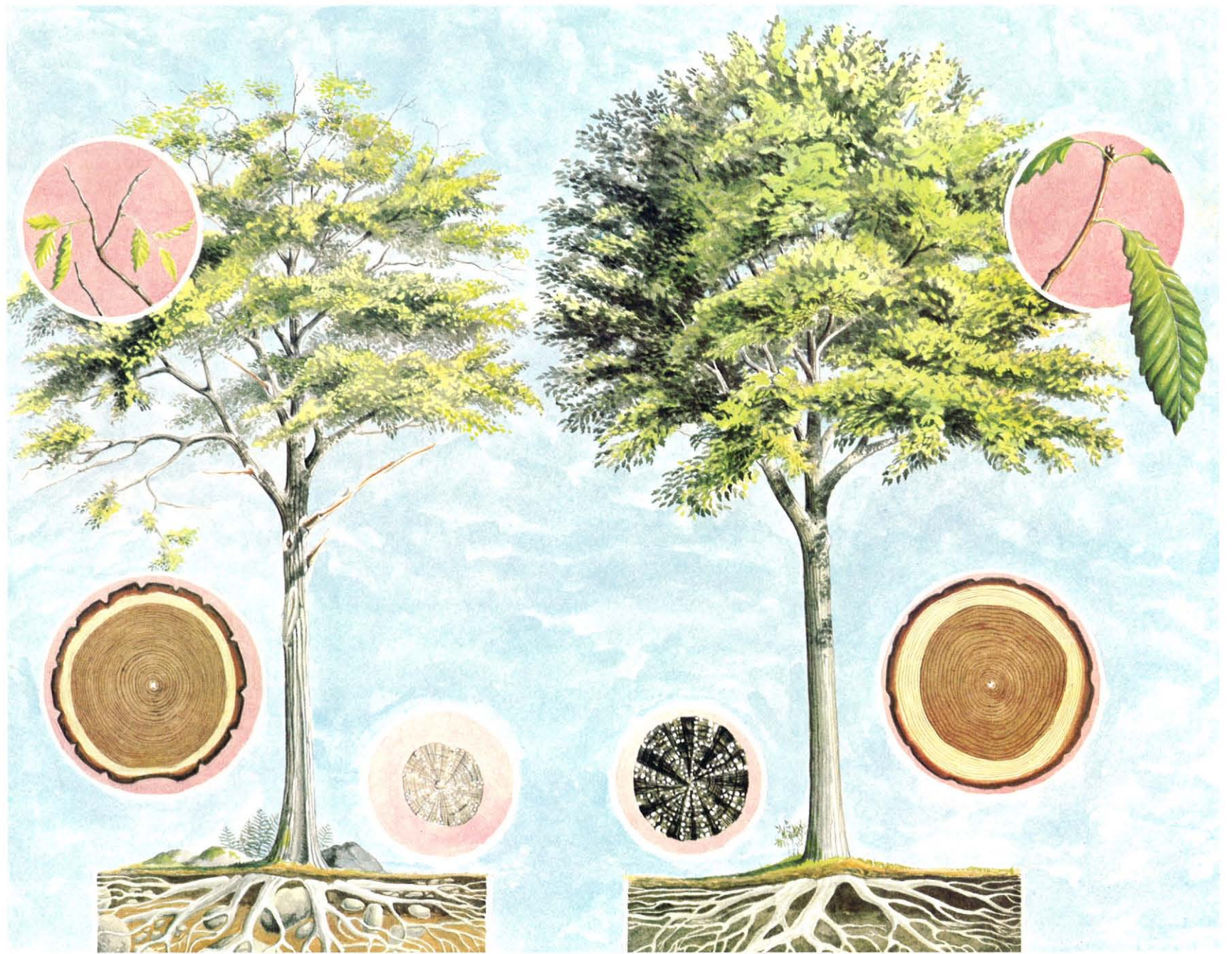
Disturbance-Related Characteristics

Extrinsic disturbances such as storms, fire, drought, frost, or defoliation occur on good sites as well as bad, but these disturbances are more frequent and severe on exposed sites. The poor appearance of oaks on adverse sites, therefore, reflects the response of these trees to a greater frequency and intensity of both internal and external factors on those sites. The small inserts in Figure 16 (crown and roots) depict external and internal responses of trees, regardless of site, to

disturbances such as severe late spring frost, drought, and especially insect defoliation (see also Fig. 11). Dieback of twigs and branches, small, sparse, off-color leaves, and low or depleted root starch content in the fall are indications that trees have been subjected to one or more of these severe stress factors. Because active dieback symptoms—and especially root starch content—reflect tree responses to recent events, they are better measures of current **physiological condition** than general records of physiological performance. Taken together, these measurements can be used as an index of tree condition.

Figure 16

The appearance of trees reflects their response to site quality or disturbance. Compared with the undisturbed chestnut oak on the good site (right), the tree of the same age on the poor site (left) has a smaller, shorter crown, a thinner stem with narrow growth rings, a narrow band of sapwood, deeper bark fissures, and a smaller root system. Wounds often remain open longer on slow-growing trees. Severe disturbances such as drought, frost, or insect defoliation can occur on any site. Tree responses to these external disturbances include dieback of buds, twigs, and branches, and small, sparse, off-color foliage, and low or depleted root starch content in the fall.



Indexing Tree Condition

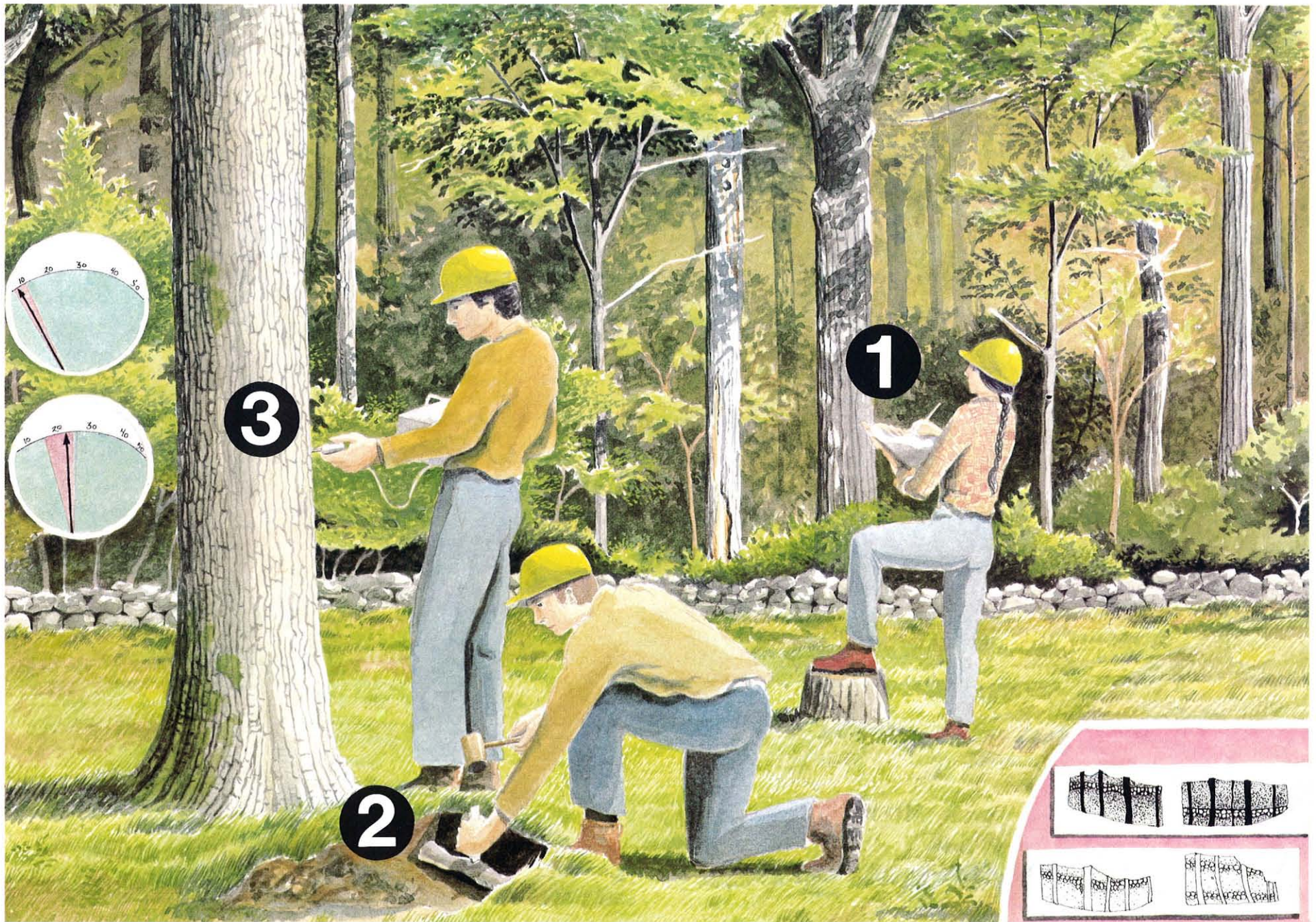
Several methods of assessing tree condition are shown in Figure 17. A general assessment is made of a tree's condition based on the relative position of the crown in the canopy, evidence of poor growth, injuries, dieback, etc. Not illustrated, but of value, is an increment core to determine patterns of annual growth rate. Root starch content is determined by removing a sample of wood from a large root with a hammer and chisel, sectioning this with a microtome, and staining the thin sections with a solution of potassium iodide. In this solution the starch turns purple, and sections rich in starch will be dark compared with those with little or no starch.

The use of an electronic method for measuring tree condition is shown in Figure 17. Although still experimental, readings of the electrical resistance of tissues near the cambial zone show promise of providing another measure of tree condition. Readings of low electrical resistance are associated with trees in good condition.

Root starch content not only reveals that trees have been stressed, but also may be of value in predicting the consequences of additional stress. As shown in Figure 11, white oaks with little or no root starch are more apt to die after defoliation than trees high in root starch. Knowing which trees or stands are the greatest "risk" can help in planning actions to reduce losses of valuable trees.

Figure 17

Evaluating tree vigor or physiological condition can entail several steps. An assessment is made of features that reflect general condition (1). Such features include relative size and position of tree crowns in the forest canopy, the size and color of leaves, the relative amounts of live and dead branches, and the relative rates of wound closure. Root starch content is determined from a sample cut from a large root (2). Thin sections are stained with potassium iodide (insert, right). Starch can be classed as high (dark sections), medium, and low to depleted (light sections). Low starch reveals trees in poor condition (high risk), high starch reveals trees in good condition (low risk). Measurements of electrical resistance (3) may someday be useful in determining tree vigor. Studies have shown that cambial zone tissues in high-vigor trees have a lower resistance to pulsed electric current than those in low-vigor trees.



Preventing and Reducing Oak Decline

Preventing gypsy moth-initiated oak decline entails, as with other dieback and decline diseases, actions designed to maintain trees in good physiological condition, and to reduce the stress agent. In the following sections, actions that can be performed in forest, campground, and urban environments to prevent oak decline are discussed.

In Forests and Campgrounds

Actions in the forest are general ones, designed primarily to enhance the conditions of trees growing there (Fig. 18). Silvicultural thinnings to remove trees in poor condition will reduce the numbers of trees most vulnerable to the effects of stress, and will enhance growing conditions for the residual trees. And, although not demonstrated, it is possible that removing weak and dying trees and the populations of twolined chestnut borers associated with them will reduce mortality attributable to those organisms. Weak and dying trees should be removed from campgrounds for the same reasons and also because they can be hazardous. Removing weak and defective trees will eliminate many refuges for the gypsy moth.

Monitoring gypsy moth populations will aid in determining when direct preventative actions must be taken. Within a forest, stands known to be outbreak foci, or stands identified as potentially susceptible—such as the oak-covered rocky ridge top in figure 18—would be good candidates for monitoring sites.

Traps baited with the female sex pheromone attract adult male moths and are especially useful in assessing insect populations in remote areas. In more accessible places such as campgrounds, burlap “skirts” tied around favored host trees also can be used. These skirts provide a favorable resting site

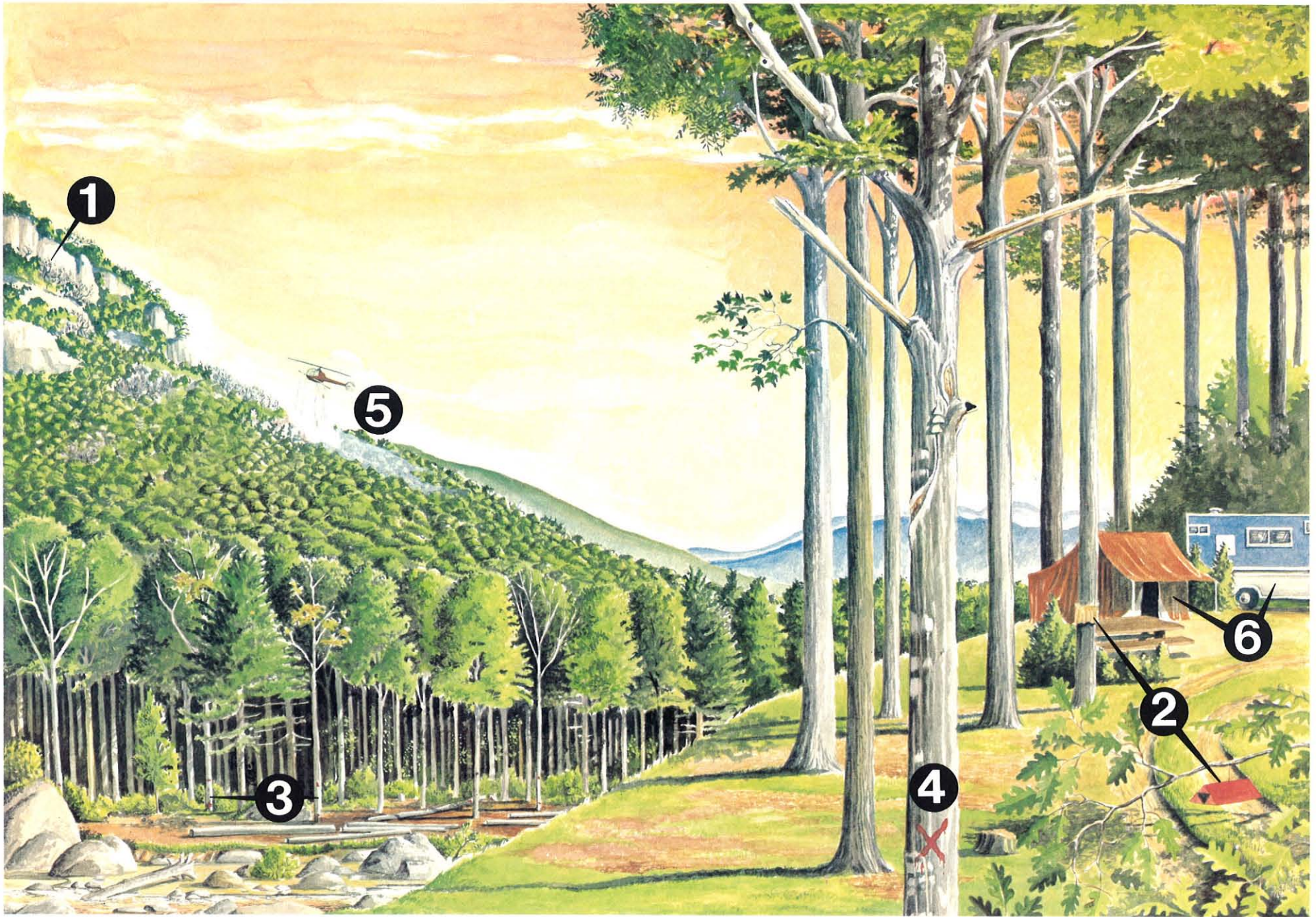
for gypsy moth larvae, and they can be easily checked for numbers of larvae.

It is especially important to monitor gypsy moth populations in campgrounds within the generally infested region to reduce the numbers of instances where insects on automobiles and camping vehicles and equipment are transported into uninfested areas.

Spraying with approved insecticides may be required when severe defoliation is inevitable, and especially if indexes of tree condition, such as low starch content, indicate that defoliation will trigger significant losses of valuable trees. It may be more important to protect foliage in the campground than in the forest.

Figure 18

Preventing gypsy moth-initiated oak decline in the forest and campground includes such diverse actions as monitoring populations in known outbreak foci (1) and in campgrounds (2) with pheromone traps or burlap “skirts”; removing vulnerable, weak, or dying trees and thinning to improve growing conditions for residual trees (3); eliminating from campgrounds trees that provide refuges for gypsy moths (4); spraying with approved insecticides where severe defoliation is eminent and where measurements of tree vigor indicate defoliation will result in high tree losses (5); and inspecting camping vehicles and equipment in infested campgrounds to reduce the numbers of insects being transported into uninfested regions (6).



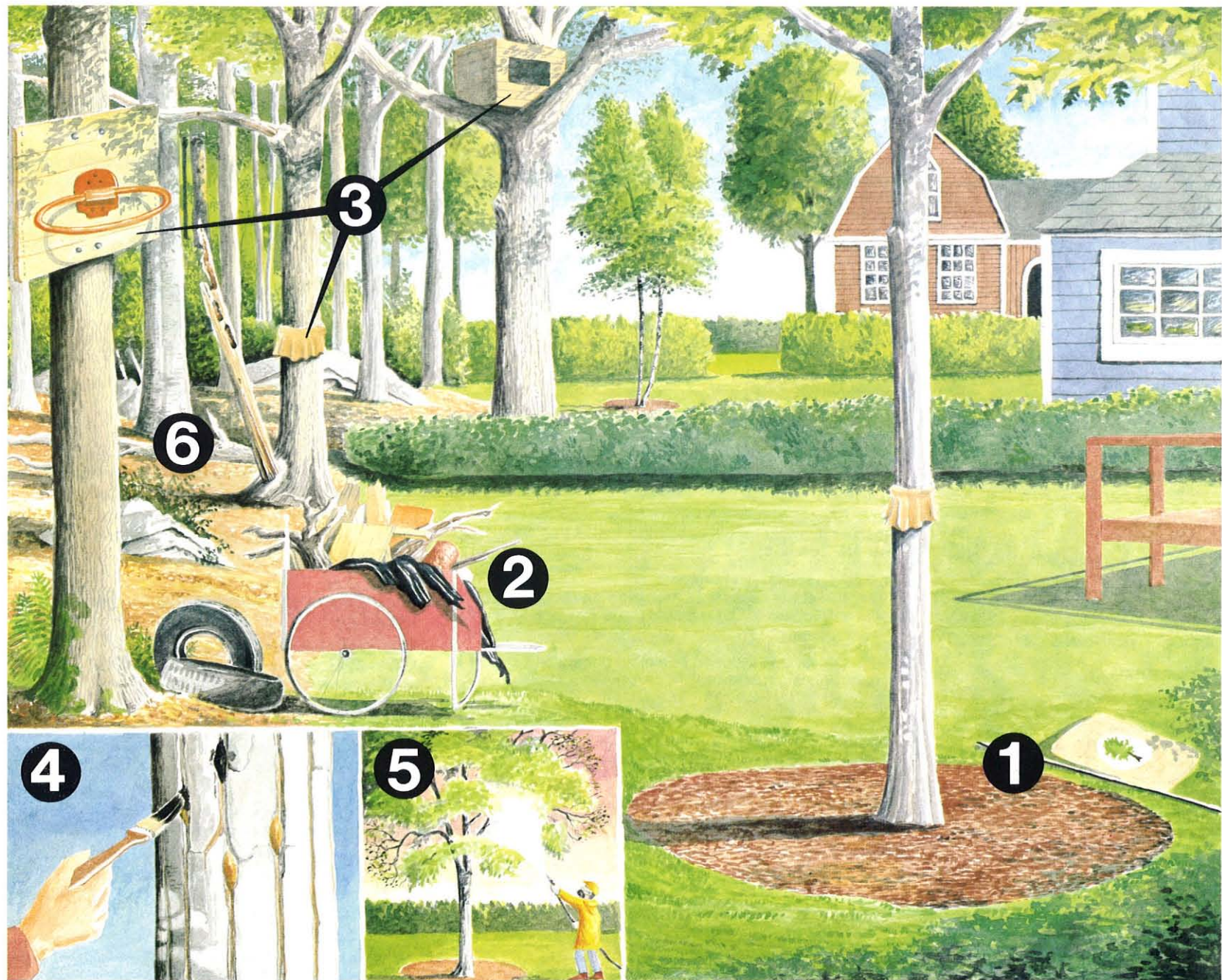
In Urban Areas

Preventing gypsy moth-related oak decline in the urban backyard (Fig. 19) can include several practices not feasible in the forest. Keeping valuable specimen trees healthy by watering, fertilizing, and mulching is as important for preventing oak decline as it is for other dieback-decline diseases. In addition, several activities will help keep insect populations low, especially where backyards and forest join. Removing rubbish from yards, especially near the forest edge, will eliminate many favorite gypsy moth refuges. Signs, old tires, tree houses, and wood piles are particularly favored places and should be inspected carefully, and large, dead branches and other tree features that provide habitat for gypsy moths should be removed.

Burlap skirts tied around preferred food trees are effective for both monitoring insect populations and collecting insects for destruction. Egg masses can be removed and destroyed or treated in place with creosote; when populations are high, trees can be sprayed with approved insecticides. Whenever possible, layers of forest litter, home of many ground-inhabiting predators of gypsy moth, should be maintained. Keeping humus layers intact also will help prevent the drying out of soil layers.

Figure 19

Preventing gypsy moth-initiated oak decline in the backyard requires that trees be kept healthy by fertilizing and mulching specimen trees (1); removing rubbish and natural refuges from backyards and forest edges (2); inspecting and, when necessary, destroying insects occupying objects such as tree houses, signs, picnic tables, and burlap skirts tied around trees to attract larvae (3); destroying egg masses (4); spraying when necessary (5); and keeping layers of forest litter as undisturbed as possible to encourage natural ground-inhabiting predators and to conserve soil moisture (6).



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