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A. F. Verrall
*Stephen F. Austin State University*

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# DISEASES OF FOREST TREES AND FOREST PRODUCTS

## A TEXT AND REFERENCE FOR GENERAL FORESTERS

A. F. VERRALL

**Stephen F. Austin State University**
SCHOOL OF FORESTRY
NACOGDOCHES, TEXAS

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# DISEASES OF FOREST TREES AND FOREST PRODUCTS

## A TEXT AND REFERENCE FOR GENERAL FORESTERS

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**A list of useful references follows each of the subject sections.**

# PREFACE

This text is primarily for foresters, not pathologists. It is intended to furnish foresters the information necessary to:

(a) Appreciate the role of diseases in the forest and of fungus defects in forest products.

(b) Recognize different types of diseases and some important diseases of these types.

(c) Understand the principles of disease prevention and control by direct and indirect methods.

(d) Know when to seek the advice of a trained forest pathologist.

To accomplish these purposes, emphasis is placed on the tree and wood product rather than on the pathogen. To understand diseases, however, the forester must learn the essentials about fungi, bacteria, viruses, nematodes, and higher plants that cause disease. Some scientific names of pathogens and the specialized terminology of mycology and pathology are introduced, but these are kept to a minimum.

Because the South is the most important timber producing region in the United States, expected to produce more than half of the nation's commercial wood products in the future, and in so doing, to employ a large proportion of future foresters, this text emphasizes disease problems of southern forestry. Coverage of diseases important to other regions is in some degree related to the importance of the resources involved.

ARTHUR F. VERRALL

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*A graduate of the University of Minnesota, where he received the BSF, MS, and PhD degrees in 1927, 1928, and 1934, Dr. Verrall for many years conducted research in forest pathology with the Bureau of Plant Industry and the Forest Service of the U. S. Department of Agriculture. He is author of more than 120 publications on tree diseases and fungus defects of wood products, including some of the most important research in these fields.*

*From 1965 to 1970, Dr. Verrall served as Professor of Forest Pathology in the School of Forestry, Stephen F. Austin State University.*

# INTRODUCTION[1]

The forester must realize that most forest disease problems result from a complex interaction of pathogen, tree, and environment. Usually control must be attained by such practices as selecting the proper tree for each site and regulating density rather than by the use of fungicides or other direct controls. This explains why ecology plays such a vital role in forest pathology and is stressed in this text.

## DISEASE LOSSES

Only occasionally are forest diseases spectacular and obvious. For this reason, losses frequently are not appreciated by foresters. Unlike bark beetle attacks, which cause extensive mortality during infrequent epidemics, most forest diseases cause less spectacular losses but are likely to persist for long periods so that the total loss is higher. Some types of disease loss are:

**Mortality, i.e.,** trees are killed.

**Reduced growth.** The infected tree survives but decreased height or diameter growth reduces volume increment.

**Delayed regeneration.** Diseases which kill seedlings may delay regeneration for important periods of time.

**Inadequate stocking.** Mortality may result in too few stems, poor spacing, and holes in stands. The remaining trees may become limby and produce lower quality wood.

**Change of species.** Mortality among preferred species may permit inferior or weed species to take over a site or require the substitution of less desirable species. Chestnut[2] blight essentially eleminated one of America's most valued timber trees. In parts of East Africa the slower-growing but resistant Jelecote pine was substituted for the fast-growing Monterey pine as a plantation species because of dothistroma needle blight.

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[1]No attempt was made to correlate the information presented in the text with specific published reports. In the author's longtime association with tree disease research he is indebted to many co-workers for information presented here. Some of the information is original but much is from the work of others. The references at the ends of chapters are intended for additional reading and are not necessarily the sources of information presented.

[2]In this text plant diseases and tree species are identified by common names. Common and scientific names of trees are listed in Appendix II, those of plant pathogens in Appendix III.

**Destruction of merchantable wood.** Heart rots usually do not kill but decay the merchantable part of the stem.

**Reduced wood quality.** Incipient decay, stain, pitch streak, etc. lower the quality of wood but not the volume.

**Site deterioration.** This can happen through soil erosion or the buildup of soil-borne pathogens.

The latest estimates of mortality in the forests of the United States were made in 1962. These showed annual mortality in trees 5.0 inches in diameter and larger to be:

| *Cause* | *Billions of Cubic Feet*[3] |
|---|---|
| Diseases | 1.2 |
| Insects | 1.2 |
| Fire | 0.3 |
| Weather and Other | 1.8 |
| Unknown | 1.1 |

Earlier reports included estimates of growth losses as well as mortality. These showed annual losses in trees 5.0 inches in diameter and over to be:

| *Cause* | *Growth Loss* | *Mortality*[4] |
|---|---|---|
| | *Billions of Cubic Feet* | |
| Diseases | 4.3 | 0.8 |
| Insects | 0.8 | 1.0 |
| Fire | 1.5 | 0.2 |
| Weather | 0.1 | 0.8 |
| Other | 1.1 | 0.7 |

Losses may, of course, be associated with two or more agencies. For example heart rots are caused by fungi entering trees through fire wounds made possible by dry weather. Trees weakened by a disease or fire may be attacked by bark beetles.

Some important losses were not included in the above estimates:

**Cone rust** frequently causes 30 to 90% loss of slash and longleaf cone crops in some areas.

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[3]Timber Trends in the United States. U. S. Forest Service. Forest Resource Report No. 17 Feb. 1965.

[4]Timber Resources for America's Future. U. S. Forest Service. Resource Report No. 14 Jan. 1958.

**Fusiform rust** has caused up to 90% cull in some nurseries and even with intensive control practices, losses of 5% are common.

**Black root rot,** when uncontrolled, becomes a limiting factor in most southern pine nurseries.

**Damping-off** and **heat injury** occasionally seriously reduce nursery stands.

**Fungus attack** on **wood products** in storage and use causes widespread damage, and necessitates expensive prevention measures. Examples:

> In a single 3 to 4 month rotation of stored pulpwood, loss from decay at a medium-sized mill can amount to 2000 cords. Countrywide, rot of wood in buildings amounts to 10 billion board feet annually. In the South, where conditions are favorable for rapid decay, annual losses are particularly high, despite heavy cost for control by the use of wood preservatives.

Thus losses due to diseases importantly increase the cost of growing timber, and shorten the service life of wood products. Contrary to general belief, many diseases can be controlled and controls are practical and economical.

## TYPES OF DISEASES

A tree **disease** is any variation from the normal, either in physiology or structure, which is sufficiently permanent to check development, cause abnormal formations, or lead to the death of part or all of the tree. This is a very broad definition which would include at least some insect attacks. Here, however, insects will be excluded except as they are part of a disease complex, where the direct pathogen is a higher plant, bacterium, virus, or fungus.

Diseases are of two general types:

> **Non-parasitic** diseases such as injuries due to heat, cold, and noxious gases. The factor inciting the disease is a **pathogen**—in this case an inanimate pathogen. The tree attacked is the host.
>
> **Parasitic** diseases, or those caused by living pathogens, **i.e.,** parasites. A parasite is merely an organism that lives in or on another organism and derives all or part of its food therefrom.

Not all parasites are pathogenic. Forest pathology is concerned mainly with harmful parasites (**i.e.,** pathogens) but also covers beneficial parasites or symbionts as mycorrhizal fungi and root nodule bacteria.

There are five main groups of animate pathogens: Bacteria, viruses, fungi, nematodes, and mistletoes. These animate pathogens can be conveniently divided into two groups:

**Native pathogens.** In undisturbed native forests these usually remain in an endemic state, **i.e.,** they are present but not causing significant damage. The reason for this is that under natural forest conditions, the higher plants and animals, the insects, and micro-organisms live in a harmonious and dynamic balance. When some factor, such as drouth, fire, or logging, disturbs this balance, a pathogen may increase sufficiently in numbers and virulence to cause an epidemic. Thus native pathogens play a major role in forest pathology.

Most forestry, of course, requires the establishment of artificial conditions. Too frequently, this has been done without regard to possible disease consequences. For example, fusiform rust caused very little damage until slash and loblolly pines were extensively planted on longleaf pine sites. Slash and loblolly pine are susceptible; longleaf is resistant. Pathology is strongly ecological, **i.e.,** diseases result from the mutual reaction of pathogen and host to a particular set of environmental conditions. Perhaps the most basic control for forest diseases will be the favoring of the right tree on each site.

**Introduced pathogens.** A fungus or other pathogen, when brought from one continent to another or even to a new region in a continent, usually arrives without its natural enemies. Also, the native trees which it encounters may have no inherent resistance to the new parasite. Devastating epidemics can result. This happened when the chestnut blight fungus came to the United States on imported nursery stock. In Asia, it was an inocuous canker fungus; here it eliminated the American chestnut as a forest tree. Other examples of devastating introduced pathogens are white pine blister rust and the Dutch elm disease fungus.

Microorganisms, including pathogens, fall into three groups:

> **Obligate saprophytes**—those capable of living only on dead material. Most fungi causing wood decay in buildings cannot attack living trees.
>
> **Obligate parasites**—those which can live only on live tissue. The rusts are all in this class.
>
> **Facultative organisms**—those which can live either as saprophytes or parasites. Many forest pathogens only attack trees weakened by drouths or other unfavorable conditions; at other times they live on dead branches, leaf litter, etc. Some of the most damaging pathogenic organisms can exist as saprophytes if necessary.

## SIGNS AND SYMPTOMS OF DISEASE

Diseased conditions are recognized and diagnosed by various characteristics known as signs and symptoms. When these are inadequate to irentify a specific disease, the causal pathogen may have to be isolated from the diseased tissue and identified. If the disease is non-parasitic, identification of the specific cause may be very difficult.

Diagnostic characteristics are of two types:

> **Signs,** consisting of some part of the pathogen, such as a bacterium or a fruiting body or mycelium of a fungus. For example, the presence of a conk of *Fomes pini* on the trunk of a pine is proof of heart rot.
>
> **Symptoms,** or some change in the host as a response to a pathogen.

Symptoms are of many types, most common being:

> **Necrosis, i.e.,** presence of dead or disintegrated tissue. "Die-back" is the death of terminal growth, "cankers" are localized dead areas of bark, "leaf spots" are dead areas in leaves, "root rot" is marked by dead roots, and "saprot" or "heart rot" is destruction of wood.
>
> **Hypotrophy, i.e.,** underdevelopment, dwarfing, or atrophy. Hypotrophy is expressed as undersized leaves or fruits, or underdevelopment of the whole plant. If chloroplasts fail to develop, "chlorosis" results, leaving a yellowish color.

**Hypertrophy,** or localized overgrowths. If the overgrowths are swellings, they are termed galls; if prolific branching, they are witches' brooms (in crowns) or hairy root (in root systems). Overgrowths can result from an increase in the number or the size of cells. Sometimes these are termed respectively, hypertrophy and hyperplasia. Usually both types are present and are commonly referred to as hypertrophy.

**Miscellaneous symptoms** include wilting (drooping or lack of turgidity), color changes, and crinkling or curling of leaves.

Signs obviously are available for diagnosis only when the disease is parasitic. Many symptoms may result from either parasitic or non-parasitic pathogens. Thus some necrotic symptoms, such as dieback of twigs or dead roots, most symptoms of hypotrophy, and miscellaneous symptoms such as wilting, color changes, or curling of leaves, can result from either type. Hypertrophy rarely results from non-parasitic causes.

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# NON-PARASITIC DISEASES

Non-parasitic, or non-infectious, diseases cause important damage at times, particularly in localized areas. Foresters should be able to identify non-infectious troubles and to separate those of importance from the more wide-spread troubles causing insignificant damage. Oftentimes, the exact cause is difficult to determine and one must be satisfied with such a diagnosis as "a soil factor" or "fume damage" until a specialist can be consulted. An important point to remember is that a tree weakened by a non-infectious disease may be attacked by a fungus or insect incapable of attacking healthy trees. The literature contains many references to fungi causing twig cankers and root rots without reference to the really important factor—drouth, soil compaction, etc.

Among the non-infectious diseases, those due to adverse weather are likely to affect broad areas. Air pollution damages trees in more limited, but expanding zones, while herbicides, soil compaction, and salt spray may be serious problems in some localized situations.

## ADVERSE WEATHER

Modern man has never experienced a period of the "normal" climate that probably prevailed through most of the Earth's history, when its surface was more level, there was fairly uniform weather over the entire Earth, with little variation between winter and summer, or between day and night, and when there were no violent storms. What we know and must contend with is the tail end of the last glacial period. Rather than "normal" uniformity we have dry and wet areas, polar ice caps and hot equatorial regions. Interactions of air masses from these extremes result in violent storms, and marked variations of temperature and rainfall over periods long enough to importantly affect vegetation. These climatic variations are not cyclic but seem to be random. For example, the 7th century was warm and dry, permitting heavy traffic over the Alps through passes now closed with ice. The 9th century was again wet; the 10th and 11th were warm and dry — so much so that the polar ice caps may have greatly diminished. The duration of such climatic periods usually is from 100 to 300 years. During the last 50 to 60 years the average summer temperatures in the United States have risen 1°F and winter temperatures 2 to 4°F, equivalent to about 100 miles reduction in latitude. There is some evidence that a reverse trend may have started.

In addition to these general climatic periods, there are important variations, from year to year, in rainfall and temperature. We may have a dry month or a dry summer, an unusually late or early frost, or a hot or cold summer. Both the climatic periods and weather irregularities have important effects on forest diseases, either as direct causes of non-infectious diseases or as predisposing factors for the parasitic diseases later discussed.

### Important Direct Factors

**High temperatures.** The most common damage due to high temperature is marked by heat lesions that kill very young pine seedlings. This will be discussed under nursery diseases. Sunscald also may cause cankers on the boles of larger trees, although this is not very important. Sunscald may occur during summer or winter. In the latter case, direct sunshine on dark-colored bark during unseasonably warm days may heat the cambial cells sufficiently to break their dormancy; a subsequent freeze can kill these active parts of the cambium.

**Low temperatures.** Low temperatures can result in frost killing or frost cracks in boles of trees. Frost killing results from freezing of actively growing tissues, caused usually by early freezes before trees have hardened for the winter or late freezes after spring growth has started. In 1962, thousands of exotic trees were frost-killed in New Orleans. Native trees, better adapted to the variable climate, were unharmed. Non-infectious diseases often are most serious on trees growing out of their natural range.

When large masses of arctic air move into an area, frost damage may be general. Localized damage can result from heat radiation during still, clear nights, when freezing often occurs in low areas, called "frost pockets." Radiation creates inversions with coldest air near the ground. This causes downhill movement of cold air and frost damage in valleys.

Frost cracks (**i.e.,** radial splits in trunks) can occur in either hardwoods or conifers when the temperature drops suddenly. They appear to result when the inner wood remains warmer and expanded while falling temperature shrinks the outer wood until it splits because of internal stress. Frost cracks create wounds through which heart rot fungi may enter. Sudden warming of frozen stems can lead to a reverse effect and peripheral shakes (separations of growth rings). Shakes do not expose heartwood and, therefore, do not create a decay hazard, but they are defects in themselves. Frost cracks and shakes are common in northern hardwoods and cause considerable degrade in lumber.

**Water deficiency.** Drouth or excessive soil drainage can deprive roots of sufficient water to meet the demands of the tree's life processes, leading to top dieback or mortality. This is a common trouble in East Texas and eastern Oklahoma, which are transition zones between forest and prairie, and on deep, coarse sands in many regions. Greatest damage, however, occurs during drouths in areas where rainfall is normally high. During the early 1950's prolonged drouth caused widespread dieback and mortality of sweetgum and other hardwoods throughout the southeastern United States. Frequently, the first and most severe damage occurred to shallow-rooted trees in swales that normally are wet. Deep rooted trees on drier sites were noticeably less affected.

Insufficient water may result not only from inadequate rainfall or its poor distribution, but also from unusual transpiration. The latter occurs mainly in winter while the soil is frozen. Warm winds can increase transpiration sufficiently to cause wilting while the frozen soil prevents replenishment. Such winter wilting is, of course, mainly a problem with conifers in the North. Sometimes only the needles are killed, and the trees survive; when the buds also are killed, the tree may die.

**Water excesses.** Too much water can be as deleterious as too little. Whole stands have been killed in areas flooded by the construction of dams or dykes. Temporary flooding frequently occurs in bottomland forests, with no or little deleterious effect. Tree species vary in the length of time they can withstand flooding. Some species, as baldcypress, survive long periods of flooding, albeit with slow growth. Among hardwoods, willow and cottonwood are least affected. Damage is less from winter flooding than from that during the growing season; and fresh water is less damaging than stagnant water.

With high water tables, root systems are shallow, predisposing trees to uprooting by wind and to drouth damage. In some relatively flat, low-lying areas, such as the coastal slash pine belt, a hardpan develops. This restricts water percolation, maintaining high surface moisture contents which restrict root development.

Loss of growth and mortality due to adverse weather is no longer accepted as inevitable in all cases. Because moisture stress is very important in Texas tree economy, the Texas Forest Service's tree improvement program is concerned primarily with the development of pine strains that are drouth resistant. Considerable research is being conducted on the effects of tree stand density and ground cover on soil moisture during drouths. Before many years we should have drouth-resistant trees and silvicultural systems to minimize soil moisture stresses.

The bottomland-hardwood forester already practices some soil-water conservation. Dykes are built to impound water over wide areas during the winter. If the water is drained off in early spring, the trees are not harmed and a good supply of water is stored in the soil. During most years there is an overabundance of water in many bottomland forests. Drainage ditches commonly are constructed to remove excess water. If ditches are provided with locks, depth of flowage can be regulated to prevent excessive water loss in dry years.

## AIR POLLUTION

Industrial plants, household furnaces, and automobiles account for most air pollution. Long-burning city dumps and trash burners are other sources. Bog and forest fires and prescribed burning add particulate pollution (smoke particles) to the air, but most of the chemicals they release are non-toxic.

Oxides of sulfur and fluorines are the oldest known air pollutants, and are among the most damaging to trees and other vegetation. Before there was any regulation of industrial by-products, smelter fumes killed thousands of acres of forest in North America. These areas of devastation were mainly around copper smelters at Trail, B. C.; several areas in Ontario; Anaconda, Montana; Spokane, Washington; and the "copper basin" in Tennessee.

Many of the acute cases of smelter-fume damage have been abated by engineering devices and the recovery of by-products. Nonetheless, fluorides and oxides of sulfur still cause damage around many industrial plants.

Several factors are increasing the importance of air pollution.

(1) Greatly increased emissions of stack gases come from huge soft-coal and oil-burning power plants and from other industries. These unidentified gases appear to be generated in the stacks after the smoke has passed through abatement devices to remove the common sulfur and fluorine compounds. Stack gases from power plants in eastern Tennessee are damaging white pines at least 20 miles away.

(2) The volume of urban photochemical smog is ever increasing. Many hydrocarbons and nitrogen oxides get into the air from combustion in open fires, home furnaces, and automobiles. These materials mix in the atmosphere and, in the presence of sunlight's ultraviolet rays, produce oxidizing substances, including ozone and peroxyacyl nitrate, highly deleterious to trees. The amount of damage depends on the concentra-

tion of the toxicant in the air and the duration of exposure to it. Color changes of foliage (often a reddish brown), general unhealthy appearance, leaf cast, and finally mortality, are usual symptoms.

(3) New industrial processes often produce new waste gases, some of them damaging. Their potential effects are rarely known until widespread damage has occurred.

Gases damage plants mainly after they have been absorbed through plant leaves. Pollutants may be concentrated near the ground, accentuating damage during temperature inversions, when the coolest air is at the surface; the incidence of such inversions is highest in winter. Foliage of pines and other conifers, being retained overwinter, is exposed to more prolonged and more severe pollution. Both here and in Europe, the serious forest air-pollution problems concern conifers rather than deciduous hardwoods.

Some specific instances of pollution damage are:

**Oxidant damage** to ponderosa pine from Los Angeles smog.

**Pollutants from automobiles** cause severe damage to Italian stone pine around Rome, Italy.

**Air pollution** near London has necessitated the removal of the British National Pinetum from Kew, near London, to Kent.

**Fluoride** and **$SO_2$** injury to spruce and fir in some areas of Germany has caused foresters to avoid these desirable but susceptible species.

**Creosote fumes** emitted when the cylinder doors were open damaged pines up to a half mile from a creosoting plant in south Louisiana. This is one of the many cases of forest damage being found around industrial plants located in rural areas. The general trend for industry to move from crowded urban to rural areas will tend to increase such damage as more industry locates nearer to our forests.

**Post emergence chronic tipburn** (PECT) is one of several manifestations of the sensitivity of eastern white pine to pollutants. Others, occurring throughout its range are chlorosis, decline in vigor, and even mortality. Damage is most severe in eastern Tennessee, where power plants of the Tennessee Valley Authority (TVA) burn thousands of tons of coal per day. Since these modern plants recover most of the $SO_2$ and other common toxicants, damage is attributed to unidentified gases formed in the stacks after the cleaning process. PECT first shows up in winter, when needles turn brown at the tip, shading gradually to a normal green at the base. Similar damage occurs around a ferro-alloy plant, a pulp mill, and an iron smelter.

**Emergence tipburn** (ET), a second white pine trouble, is more widespread, particularly further north in the eastern white pine range. ET first appears in the summer and there is a sharp demarcation between brown tips and the green bases of needles. It is caused by ozone which can damage white pine at concentrations of 7 pphm. Since ET occurs over wide areas remote from industry, it is doubtful that all or even a major part of the causal ozone results from man's activities.

What can we do about air-pollutant damage to forest trees? First, we can reduce the amount of air pollution. This is mainly an engineering and chemistry problem—and it won't be an easy task. Auto exhaust pollution will have to be reduced by better muffler systems, different fuels, or different types of motors. We will have to find ways to dispose of trash that produce less smoke than current city dumps and trash burners.

While the chemists and engineers are working on this problem, forest geneticists and pathologists have been busy looking into the possibility of tree strains resistant to damage by air pollutants. Several promising leads have been uncovered. Strains showing resistance to damage by specific air pollutants have been noted:

| | |
|---|---|
| Ponderosa pine | resistant to fluorides |
| Ponderosa pine | resistant to ozone |
| Eastern white pine | resistant to ozone |
| Eastern white pine | resistant to PECT |

## HERBICIDES

Large amounts of 2,4,5-T, 2,4-D, and other plant-killing or defoliating chemicals are used annually to kill weeds and unwanted trees and shrubs, to defoliate crop plants before harvest, or to sterilize soil. In application, however, drift often carries damaging amounts of chemical to nearby valuable trees. The following cases illustrate what is happening:

In a pine plantation at Bessmay, Texas, next to a railroad right-of-way recently sprayed with herbicide, terminal shoots were deformed, and some trees were killed.

## SALT SPRAY

During storm, salt spray can burn the foliage on trees near salt-water coasts. Browning, yellowing, or dying of foliage of trees in coastal areas usually can be attributed to salt spray if it occurs shortly after off-water winds.

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# PARASITIC TREE-DISEASE PATHOGENS

Viruses and bacteria play only minor roles in forest tree pathology; fungi and mistletoes are by far more important. In the future we undoubtedly will find many more viruses and bacteria in our forests but, unless there is a change in conditions, it is doubtful that they will cause major damage. The role of nematodes remains largely unknown.

## VIRUSES

Viruses are submicroscopic infective particles that can pass through filters fine enough to screen out bacteria. They are invisible under the highest power light microscope and consequently we had no idea what they looked like until the electron microscope was developed. When purified, some are spherical particles; others are elongate either as rigid rods or as flexible filaments.

Several viruses have been purified and chemically analyzed and found to contain only protein and nucleic acid. The composition of the nucleic acid and the amino acids of the protein vary with different viruses. Once within a living cell, a virus particle interferes with normal cell functions and induces the host protoplasm to produce new virus particles. This explains why viruses cannot reproduce outside living cells. Virus multiplication is very rapid. A single particle can increase to thousands within a few hours. Virus particles eventually may constitute up to 10% of the weight of a diseased leaf.

The interruption of normal cell functions results in the development of one or more of the symptoms shown by virus-infected plants. The most common symptoms of virus diseases appear in leaves. These include **chlorotic** (yellow or blanched) spots, mottling, curling, crinkling, and striping; these may be associated with small-sized leaves and proliferation of branches **(brooming).** Not all virus infections are destructive. Some varieties of tulips with variegated flowers, and other ornamentals with whitish or yellowish variegations in leaves, are common varieties infected with a virus.

Viruses cause such important human diseases as smallpox, measles, mumps, and rabies. Destructive plant diseases of virus origin cause heavy economic losses in sugar beets, sugarcane, tomato, and tobacco.

The most common means of transmission of plant viruses is by sucking insects. Some viruses can be transmitted in no other way.

There are only a few known virus diseases of forest trees and only one of these is important.

**Elm phloem necrosis** has killed large numbers of American elms in the Central States. The causal virus is spread from tree to tree by leaf hoppers and through root grafts. Infected trees have small chlorotic leaves and necrosis of the cambium. The cambium of the larger roots and lower trunk turns yellow and has a faint odor of wintergreen. Only the American and winged elms are susceptible. No effective control is known.

**Systemic brooming** of **black locust.** A virus causes extensive proliferation of buds and branches and also of roots. Some mortality results but the disease is of minor importance.

Viruses also cause a **zonate canker** of **elms** and a mottling and crinkling of elm leaves. These are of little consequence.

## BACTERIA

Bacteria are microscopic organisms sometimes classified as plants, sometimes placed in a separate kingdom. They are essentially unicellular but sometimes are loosely connected into chains of several cells. Most reproduction seems to be by simple fission of vegetative cells but there is some evidence that a sexual process takes place. If true, details are yet to be worked out.

Bacteria are extremely important to man. They cause such important diseases as tuberculosis, typhoid fever, and diphtheria in humans and anthrax and brucellosis in farm animals. They also cause many important diseases of economic plants. However, not all bacteria are harmful; many play useful roles such as the flavoring of Swiss cheese, production of organic acids, and the biological reduction of sewage as a pollution control measure. Bacteria also causes nodules on the roots of clover, locust, and some other plants, which fix atmospheric nitrogen, making it available to plants. This explains why legumes are good soil builders.

Some common symptoms of bacterial infections are galls, wilting, dwarfing, rotting, cankering, and brooming.

Bacterial diseases are mainly of importance in truck and farm crops. Perhaps the most important tree disease incited by a bacterium is fire flight of pear. The bacterium causes cankers which kill twigs, branches, and finally the entire tree.

In forest pathology bacteria are relatively unimportant and only a few instances need mention.

**Wetwood.** When an increment borer is used on hardwoods, water sometimes flows out increment borer holes. This indicates a bacterial infection, mainly in the heartwood. which appears water soaked, has foul odor, and may contain methane gas under pressure. In the last case, the gas can be lighted by holding a match to the hole.

At least in aspen, lumber cut from wetwood may develop appreciable collapse during seasoning.

Sometimes wetwood bacteria work into the outer growth rings of Lombardy poplar and elm, and are suspected of contributing to decline and death. The slime of wetwood frequently discharges through branch-stub wounds or splits in crotches and runs down the bole. Slime-flux disfigurement is particularly common in elm.

**Water-stored logs.** Logs stored in ponds or under water sprays frequently become contaminated with anaerobic bacteria. These do not attack such highly lignified elements as tracheids and, therefore, cause no appreciable loss in strength. However, by producing pectinase, they do deteriorate epithelial and ray parenchyma and pit membranes. This greatly increases the permeability of lumber cut from such logs. Porous wood is unsuited for such uses as siding because it absorbs more rainwater than normal wood. This accentuates paint deterioration, decay, and warping. If given a dip treatment in a water-repellent preservative, such wood may absorb excessive amounts of oil, increasing the cost of treatment and interfering with subsequent painting. The high porosity also may affect veneer cutting but the importance of this has not been determined.

Wood long exposed to water, such as untreated bridge piling, may be appreciably weakened by bacterial attack. In a Washington, D. C., bridge, strength loss amounted to as much as 50% in 60 years.

**Slime in pulp mills.** Bacteria, along with fungi, form slime in the closed water systems in pulp mills. Water is used over and over, concentrating sufficient dissolved nutrients from the pulp to support dense populations of micro-organisms. Slime coats rollers and paper surfaces and may become so thick that pieces break off and form blemishes in the paper.

Slimes are controlled by adding toxic chemicals to the slurry water. Periodically the type of chemical used is changed: for example, a chlorinated phenol and a mercurial will be alternated. Without such change, either bacteria or fungi commonly develop resistant strains which are not easily controlled.

## FUNGI

Fungi (singular, fungus) are plants without chlorophyl; their vegetative structure consists of microscopic filaments. Being without chlorophyl, fungi cannot synthesize their own food from inorganic materials but must depend on carbohydrates elaborated by other plants. By utilizing the energy of such carbohydrates, however, they can synthesize their own proteins.

The **mycelium** (plural, mycelia) or vegetative structure of a fungus may be visible to the naked eye, at least when grown in culture. The mycelium is composed of microscopic threads called **hyphae** (singular, hypha). Fungi reproduce by means of **spores,** both sexual and asexual. Asexual spores merely carry the genetic makeup of the hyphae which bore them. Sexual sporulation is preceeded by sexual fusion to form a diploid cell and a reduction division to form haploid spores.

Fungi are important for several reasons.

(1) Fungi are soil improvers. They are the most important agents for breaking down dead organic material so that it is again available to higher plants. This is particularly true of ligneous materials.

(2) Some antibiotics, as penicillin, are produced by fungi.

(3) Fungi are used to process most cheeses, to make beer, and to raise bread.

(4) In several parts of the world, primitive peoples use fungi as narcotics. Certain poisonous mushrooms are used for this purpose.

(5) Fungi are associated with tree roots to form mycorrhizae, by means of which most trees absorb materials from the soil.

(6) Some fungi are used as food, i.e., mushrooms. Mushrooms are related to the common wood decayers.

(7) Fungi cause plant diseases, including the most important tree diseases.

(8) Fungi cause some human diseases, such as ringworm and some lung infections.

Like other plants, fungi require certain environmental conditions to thrive.

Temperature: mostly between 60 and 95°F; most optima between 70 and 85°F; most maxima between 85 and 95° F. Most fungi will survive severe cold, down to —32°F but temperatures above 130 to 140°F usually kill them in a few hours.

Oxygen: required but usually only in small amounts.

Water: free water is required but not so much that oxygen is excluded. The oxygen-water balance is particularly important for wood decayers. Most parasitic fungi seem able to stand a higher water-to-oxygen ratio.

Food: some fungi are omniverous and will grow on almost any organic material. Others are specific and will grow on one host species only.

Light: fungi will grow in the dark but some require light to sporulate.

These requirements form the basis for much fungus control. For example, wood will not decay so long as it is kept air dry, because it contains no free water. Or we can cross different species of pine to make hybrids that are resistant to specific diseases. Or logs can be stored under water to reduce oxygen and thus limit fungus deterioration.

Classification of fungi is based on hyphal and fruiting characteristics. There are five main classes of fungi.

**Phycomycetes**

The hyphae of these are **coenocytic** and contain many nuclei, **i.e.,** there are no cross walls except at fruiting structures (Fig. 1A).

The asexual spores are borne in **sporangia,** or bulbous swellings on hyphae (Fig. 1G). In aquatic forms, swarm spores develop in sporangia. These are ciliate and motile. In other cases, the spores are non-motile or the sporangium may germinate directly to form a germ tube (incipient hypha) rather than forming internal spores.

Sexual spores are formed after the fusion of male and female elements (Fig. 1D). The resulting diploid cell becomes thick walled and is the resting or overwintering spore **(zygospore).** Reduction division occurs on germination to form haploid swarm spores or germ tubes. Sexual elements may be similar or differentiated into distinct male (+) and female (—) structures. A mycelium may be hermaphroditic, **i.e.,** have + and — elements on the same plant or it may be dioecious, i.e., have + and — elements on separate plants.

We will meet Phycomycetes again as causes of nursery diseases and general declines in the forest.

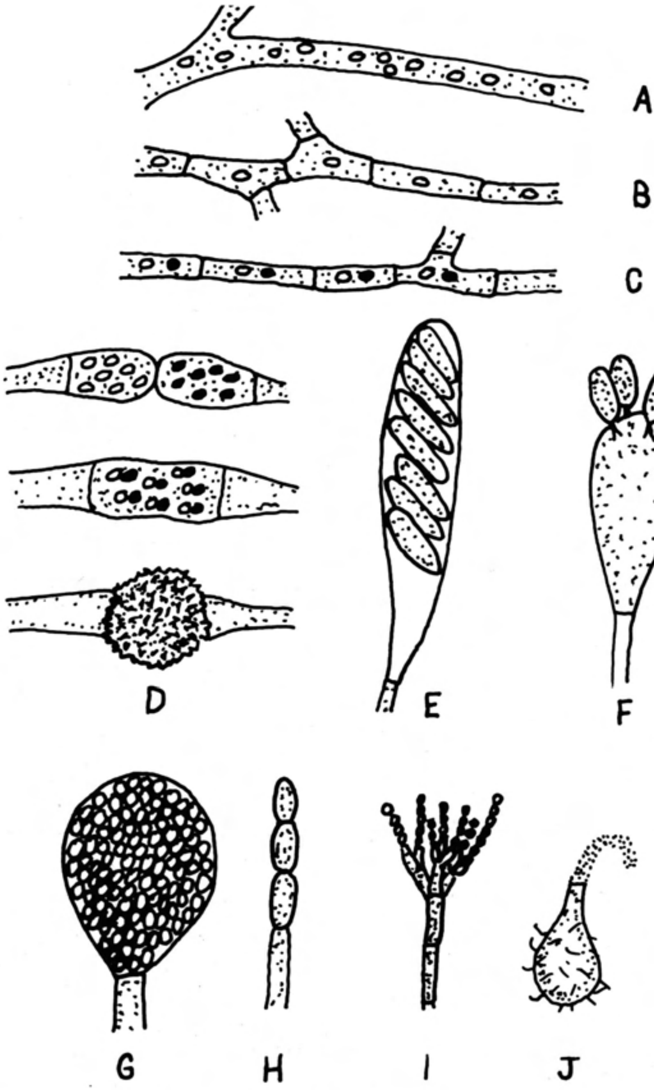


FIGURE 1. *Fungus characteristics. Hyphae are: (A) coenocytic (non-septate) in the Phycomycetes, (B) septate and uninucleate in the Ascomycetes, and (C) septate and dikaryotic (+ and — nuclei in in each cell) in the Basidiomycetes. Typical sexual spores are: (D) zygospores or resting spores (shown in 3 stages of development) in the Phycomycetes, (E) ascospores borne in an ascus in the Ascomycetes, and (F)basidiospores borne on a basidium in the Basidiomycetes. Asexual fruiting consists of sporangiospores in a sporangium in the Phycomycetes (G) and conidia (H, I, J) in the other orders of the fungi. The shape of fruiting bodies and spores varies considerably among different families, genera, and species.*

**Ascomycetes**

The hyphae of Ascomycetes are **septate** (partitioned) and usually have one nucleus per cell (Fig. 1B). The sexual spores are **ascospores** borne in asci (singular, ascus) or sacs (Fig. 1E). The formation of ascospores involves fusion of nuclei of opposite sex and reduction division, usually resulting in 8 haploid ascospores in each ascus. Ascospores may be 1-celled or 2 or more celled; they germinate by producing a germ tube. In most cases asci are aggregated in special fruiting structures, or **ascocarps,** which usually are bulbous and sunken in bark or leaf tissue.

Asexual spores are **conidia,** or specialized cells of vegetative hyphae. They vary enormously in shape among different species. Conidia are borne singly, in chains, or in heads; they are free on hyphae or in special structures resembling ascocarps (Fig. 1H, I, J).

The Ascomycetes include many important forest tree pathogens—particularly those causing leaf diseases, cankers, and wood stains.

**Basidiomycetes**

The hyphae of the Basidiomycetes are septate and usually **dikaryotic, i.e.,** each cell contains two nuclei of opposite sex (Fig. 1C). Sexual spores, called **basidiospores,** are borne on **basidia** which are club-shaped modified hyphae (Fig. 1F). Their formation is preceded by sexual fusion, i.e., dikaryotic cells become diploid, and by reduction division form haploid basidiospores. In the lower forms basidia form free on the mycelium but usually they are in complex **basidiocarps**—flat crusts, rigid mats, clubs, toothed surfaces, pored brackets, gilled mushrooms, or puffballs.

Some Basidiomycetes produce asexual spores (conidia) or, in the rusts, several distinct spore forms.

Basidiomycetes cause rusts, root rots, and wood rots and, therefore, are extremely important in forestry.

**Fungi Imperfecti**

These are fungi known to reproduce only asexually (Fig. 1H, I, J). Many undoubtedly have sexual stages which have not yet been found; some have lost their sexual stage. Many fungi originally placed in this class have proven to be Ascomycetes. In fact the imperfect or asexual stages of Ascomycetes are commonly referred to by names assigned them as Fungi Imperfecti. Species of Fungi Imperfecti cause the same types of diseases as do the Ascomycetes.

**Mycelia Sterilia**

Some fungi are known only by their mycelia, and therefore, cannot be accurately placed taxonomically. Some damping-off and root rot fungi are in this group.

In the above classes there are at least 133 families in 52 orders. It is estimated that these contain:

| | | |
|---|---|---|
| Phycomycetes | 245 genera | 1,300 species |
| Ascomycetes | 1700 genera | 15,000 species |
| Basidiomycetes | 550 genera | 15,000 species |
| Fungi Imperfecti | 1350 genera | 11,000 species |

The number of families, orders, genera, and species varies according to the taxonomist writing about them. The main point to remember is that there are many different fungi and in many cases identification even to genus may be difficult.

## NEMATODES

Nematodes or eelworms are small roundworms which are common in the soil. They also occur in aboveground parts of plants and frequently are found in moist, stained lumber. Most nematodes are microscopic, but some females are just visible to the unaided eye. They reproduce by producing eggs. Both ecto- and endoparasitic nematodes, **i.e.,** those living outside and inside host plants, are known.

The role of nematodes in forest pathology is imperfectly known. There is considerable evidence that several types can parasitize the roots of conifers and hardwoods, producing symptoms resembling root rot. These are mainly ectoparasites, puncturing fine roots with their stylets, which are protrusible, needle-like structures. Damage has been observed both in nurseries and young plantations. Also, by puncturing rootlets, nematodes may create infection courts through which pathogenic fungi may enter. Many nematodes, however, are undoubtedly scavengers in tissue killed by other organisms or by adverse environmnt.

## MISTLETOES

Mistletoes are seed plants that are parasitic, or semiparasitic, on other seed plants. The roots are replaced by **haustoria** and **sinkers** that penetrate the bark of trees and secure nourishment from the host. Mistletoes reproduce by seeds.

FIGURE 2. *American mistletoes on a dormant water oak.*

**American Mistletoes**

The American mistletoes have evergreen leaves and may grow to several feet in height (Fig. 2). They are disseminated by birds, the sticky seeds adhering to their beaks or feet, or carried in their excrement. Eastern mistletoe **(Phoradendron flavescens)** is abundant on many hardwoods, including oak, yellow-poplar, and black locust. Other species of **Phoradendron** occur on hardwoods or conifers (fir, juniper, and cypress) in the west and southwest. **Phoradendron** does not seem to seriously harm vigorous hardwoods, but under moisture-stress, may cause decline or even death; it appears to damage conifers more than hardwoods. The common Christmas decorations are American mistletoes.

Mistletoes can be controlled by pruning off infected small branches, or in some cases, by a winter application of 2,4-D (see Boyce). On large branches, infections can be excised. In commercial forests, no control is necessary.

**Dwarf Mistletoes**

Dwarf mistletoes (5 species in the genus **Arceuthobium)** are serious pests on conifers in the West and Southwest. Douglas-fir, lodgepole pine, ponderosa pine, western hemlock, and western larch are most severely damaged (Fig. 3). Dwarf mistletoe also occurs across the northern tier of states, but is less serious there than further west.

Dwarf mistletoes are smaller than the American and are leafless (Fig. 4). They appear as short protuberances from twigs and branches. Infected trees of any age may be deformed or killed. Oftentimes, htey develop large witches' brooms, resulting in enlarged branch knots which seriously lower wood values. Trunk infections can result in conspicuous swelling and cankers.

The sticky seeds of dwarf mistletoes are forcibly ejected for horizontal distances up to 33 feet, adhering to plants they hit. Thus, a relatively few infected trees in the overstory can scatter seeds to much of the reproduction.

FIGURE 3. *A dwarf-mistletoe infection center in a stand of ponderosa pine. The mature trees have been killed and much of the reproduction is heavily infected.* Photo by U. S. Forest Service.

In the West, dwarf mistletoe control often is the most important management problem in coniferous forests. Badly infected stands may require clear-cutting and artificial regeneration. Sometimes, removal of

FIGURE 4. *Dwarf mistletoe plants on ponderosa pine.*
A. *Female plant with fruits approaching maturity.*
B. *Male plant showing flowers producing pollen.*
Photos by U. S. Forest Service

infected overstory trees will give adequate control for a considerable number of years. A second cutting a few years later may be necessary to remove trees which had latent infections.

## VARIABILITY OF PATHOGENS

We are all familiar with differences among human beings, due to genetic, nutritional, environmental, and other factors. Variability is even greater in microorganisms. A variant may differ from its parents in morphology (color, size, shape, etc.) or in physiology (rate of growth, ability to cause disease, host range, tolerance to chemicals, rate of reproduction, etc.). The variation among biotypes, strains, or races of microorganisms is extremely important in plant pathology.

Variation may be associated with or independent of the sexual process. Variants with new characteristics that are advantageous to life processes are those most likely to persist; many others undoubtedly disappear shortly after their creation because some desirable characteristic is lost.

Variability can arise through the action of several mechanisms.

**Hybridization.** When haploid nuclei of different genetic makeup are combined in a sexual process, the resulting diploid progeny differ from the parents. Frequently, as the chromosomes of the two parents align themselves into homologous pairs, some genetic material may crossover from chromosome to chromosome, resulting in a recombination of genes of the parent nuclei. In this case, the resulting offspring, either diploid or haploid, differ from the parents and among themselves.

Hybridization is most common between races and varieties of microorganisms. Experimentally, hybrids between species and genera have been made but the frequence and significance of this in nature are unknown.

**Heterokaryosis.** Single vegetative cells may contain nuclei of different genetic makeup and of different sex. In the wood-rotting and rust fungi, most vegetative cells contain two nuclei of opposite sex. Instead of fusing into a single diploid nucleus, they remain separate during most of the life of the fungus. Such a dikaryotic mycelium has different properties than the two haploid mycelia from which it originated. Thus, the dikaryotic spores of fusiform rust can infect only the alternate host (oak); haploid spores can infect only pine. Among wood rotters, the dikaryotic mycelium usually rots wood faster than either of its haploid components.

Another type of heterokaryosis results from the asexual anastomosis of hyphae of different strains. The nuclei of one mycelium may migrate into the other so that cells then contain genetically, but not necessarily sexually, different nuclei. During cell division of a heterokaryotic mycelium the possibilities of creating variants of different nuclear makeup are enormous.

**Mutation.** During cell division, occasionally an accident occurs, resulting in a change of the genetic makeup which can be passed on to future generations. Mutants have been found in fungi, bacteria, and viruses. Very likely most mutants have lost a characteristic and are less able to survive than the "parents." But mutants with increased virulence are known.

**Educatability.** A microorganism constantly exposed to unfavorable but non-lethal changes in an environment, sometimes can adjust to the change. Thus, fungi gradually exposed to increasing concentrations of a toxicant, can "learn" to tolerate concentrations, much higher than are normally lethal. Characteristics acquired through educatability are not genetically controlled and are quickly lost when grown under a normal environment. The actual mechanism involved in educatability is not known but it is suspected to be related to changes in the organism's enzyme system.

**Selection.** Microorganisms frequently occur in nature as mixtures of strains rather than as genetically pure species. Strains differ mainly in physiology. Should a strain be resistant to a toxicant, it will become dominant when the species is continually exposed to that toxicant.

A lumber company in Alabama was one of the first to use ethyl mercury anti-stain chemicals to protect lumber during air seasoning. After 15 years of continuous use, their lumber started to stain severely, due to a fungus usually of minor importance. A strain resistant to mercury had been selected and multiplied into the dominant fungus in the seasoning yard. A switch to another type of treatment, **i.e.,** a chlorinated phenol, corrected the trouble. It is fortunate that organisms tolerant of one type of toxicant are seldom tolerant of toxicants of different chemical makeup.

## DISEASE ESTABLISHMENT

Before a parasitic disease can be understood, or prevention and control measures intelligently carried out, one must have clearly in mind the series of processes required for establishment of the parasite.

**Inoculum production.** Inoculum is the principle that reproduces the pathogen and initiates infection. The inoculum of most fungi is a spore, although fragments of the hyphae can grow and reproduce; that of bacteria and viruses is the entire organism; that of nematodes is an egg; that of higher plants, as mistletoes, is a seed. Inoculum frequently is produced on diseased plants, but in the case of facultative parasites it may originate on dead plant material or in the soil. Fungi frequently exhibit a delicately balanced mechanism which insures that spores are discharged from fruiting bodies under conditions needed for survival. These mechanisms may be regulated by gravity, light, moisture, etc.

**Dissemination** or the transporting of the inoculum to a susceptible host. Wind, insects, and rain splash are the most important disseminators of forest tree parasites. Spores of a few root-rot organisms are motile and disseminate themselves by swimming in wet soil. The placing of inoculum on or in the host is termed **inoculation.**

**Host penetration.** After the inoculum arrives on a host tree, it must penetrate the protective layers of the tree (bark, cuticle, or epidermis). Some pathogens can enter only through such natural openings as stomata; others only through wounds such as those caused by insects, logging operations, or fire. Some pathogens can directly penetrate the cuticle and epidermis by mechanical growth pressure or the production of suitable enzymes.

**Infection.** This involves the establishment of parasitic relations and invasion of the host tissue by a vegetative structure. The interval between infection and the expression of disease symptoms is termed the **incubation period.** Sometimes, a pathogen can penetrate a tree which is not suspectible to the disease it causes; then penetration is not followed by infection and no disease results.

**Surviving unfavorable periods.** Many pathogens causing tree diseases overwinter in a vegetative form in perennial host tissue. Such pathogens as those causing bark cankers, twig die-back, and heart rot overwinter this way. If the disease is in annual tissue, such as deciduous leaves, special provisions are needed to insure survival during the dormant season or periods of unfavorable weather. Resistant spores, seeds, or eggs in the soil or in dead host tissue are common means of surviving.

Each of these processes requires specific environmental conditions which vary with different pathogens. Should the correct conditions not exist for any of the processes, the pathogen will die and the disease will not develop. Disease prevention and control consist of making conditions unfavorable for one or more of the five processes.

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# NURSERY DISEASES

Artificial regeneration is increasingly important in forestry in the United States and in most foreign countries. A number of diseases which attack seedling trees present serious problems in tree nurseries. Fortunately, values per acre in nurseries are high, making intensive controls feasible.

The recent trend toward direct seeding rather than the planting of nursery-grown seedlings transfers the seedling problem to the forest where intensive controls are seldom practical. The few that are economical will be discussed later. In most direct seeding operations it is necessary to use sufficient seed per acre to insure a fully stocked stand, after allowing for expected losses.

The following discussion refers primarily to seedling diseases in nurseries. While examples from southern nurseries are described, the same types of diseases occur in other regions, though causal organisms and control details may differ.

## DAMPING-OFF

Damping-off is a general term for the rotting of very young seedlings. It probably occurs to some extent in all nurseries, both coniferous and hardwood. When severs it can destroy entire seedbeds. There are three types of damping-off.

**Pre-emergence damping-off.** The seed itself or the seedling is killed before it emerges from the soil. Often poor seed is blamed. The presence of germinated seed with decayed radicles is good evidence of pre-emergence damping-off. When the seed is killed before germination, diagnosis is difficult.

FIGURE 5. *Post-emergence damping off of southern pine seedlings.*

**Post-emergence damping-off.** Here the seedling is attacked after emergence (Fig. 5). A brown lesion appears just above the groundline, the stem is rapidly girded, and the seedling topples over.

**Top damping-off.** This usually occurs with older seedlings during periods of high humidity. Usually only the new terminal growth is killed.

All the southern pines are subject to damping-off. Recent research indicates that among hardwoods, elms, black locust, mulberry, willow, sweetgum, and tupelo are susceptible and that green ash, catalpa, hackberry, most oaks, and black walnut show high resistance.

Damping-off is caused by a number of fungi including species of *Fusarium* (Fungi Imperfecti), *Rhizoctonia* (Mycelia Sterilia), and *Pythium* (Phycomycetes). Many damping-off fungi are common soil saprophytes, able to survive in the soil without the host plant, and cause appreciable damage to seedlings only when conditions permit them to multiply excessively. Damping-off can usually be kept at low levels of the seedling environment is manipulated by:

(1) Choosing a well-drained nursery site. Wet soils favor the development of pathogenic fungi, particularly those, like *Pythium*, that have motile spores.

(2) Sowing seed only after the soil temperature rises to about 60°F at a depth of 6 inches. Many damping-off fungi are moderately low-temperature organisms; above 60°F some of the antagonistic fungi, such as *Trichoderma* (Fungi Imperfecti), develop rapidly.

(3) Keeping the soil pH at 6 or below. Since many pine nursery soils in the South have a pH of 5.5 or lower, damping-off is rarely serious in them. Most of the causal fungi grow best at pH 6 or above.

(4) Avoiding dense stands, which may maintain moisture conditions suitable for the build-up of pathogen populations.

(5) Maintaining a low level of nitrogen until seedlings are at least 6 weeks old, **i.e.,** are past the damping-off stage. High available nitrogen favors damping-off. Sawdust as a soil amendment tends to make nitrogen less available. Nitrogen fertilizers may be applied before cover crops are planted, **i.e.,** a year before pine seed is sown, and again as a side dressing after seedlings are at least 6 weeks old.

(6) Turning cover crops under at least 2 months before seeding.

(7) Using only enough mulch to conserve moisture.

Since damping-off usually appears and runs its course in a very short time, chemical controls applied after the disease appears are rarely worthwhile. Nonetheless, thiram, captan, and PCNB sometimes are used as soil drenches on pine (see Control Techniques).

When damping-off consistently causes losses in pine nurseries over a period of years, treating the seed with thiram or captan (1 pound per 100 pounds of seed) will pay. The seed treatment may reduce germination 5 to 15%, but the overall effect will be beneficial. Damping-off also can be controlled by soil fumigation prior to seeding, but this usually is too costly unless other problems, such as root rot, nematodes, or weeds also are present.

## ROOT ROT

After seedlings are too old for damping-off their roots still may be attacked by fungi. In mild cases only a few small roots are killed and no top symptoms will show. If soil moisture is particularly favorable for the seedlings, a large part of the root system may be killed before stunting and chlorosis are evident. Badly root-rotted seedlings have low survival on out-planting, particularly during periods of moisture stress.

FIGURE 6. *Black root rot of southern pine seedlings. The two outer stunted, infected seedlings have few lateral roots and thickened, corky tap roots. Normal seedling in center.*

Photo by U. S. Forest Service

The most serious root rot in solthern pine nurseries is black root rot. Infected seedlings have few small lateral roots while the larger laterals and taproot are swollen, corky, and reddish-black (Fig. 6). The seedlings are stunted and chlorotic (Fig. 7). The disease is most severe during late summer when temperatures are high. New lateral roots may develop just below the groundline in early fall, but survival of such seedlings on out-planting often is poor.

The cause of black root rot is complex; several fungi and nematodes commonly are pres-

FIGURE 7. *Soil fumigation effectively prevents black root rot. In the foreground, where the plastic used in fumigation did not cover the ends of the beds, fungi have stunted or killed seedlings.* Photo by U. S. Forest Service

ent. The most important fungi appear to be a *Fusarium* and *Sclerotium bataticola* (Mycelia sterilia). The former causes most rot of rootlets; the latter, the swelling of the large roots. The role of nematodes still is uncertain; some may be pathogenic or cause feeding wounds through which pathogenic fungi enter, some probably are harmless scavengers on dead roots.

The best control for black root rot is a fumigation with a complete soil fumigant before planting (see Control Techniques). Methyl bromide (at a rate of 1 pound per 150 square feet of bed) is best, and if properly applied will prevent serious root rot for 3 to 5 years. Seedlings from fumigated beds are larger and survive better when outplanted than those from unfumigated beds (Fig. 7). If the seedlings are too large, withholding water and reducing fertilization will keep them smaller.

Sooner or later black root rot occurs in most southern pine nurseries and must be controlled.

## NEMATODES

Parasitic nematodes may build up gradually in nurseries over a period of years until severe damage occurs. Because the symptoms are similar to those of root rot (death of fine roots, chlorosis, and stunting) it is often difficult to determine which is involved. In fact, fungi may enter roots through nematode feeding wounds. Unless a careful diagnosis is made by a pathologist, it is best to treat the disease as a root rot. Nematodes are controlled by preplant fumigation (see Control Techniques). If only nematodes are involved, a cheaper fumigant like EDB (at a rate of 15 gallons of 85% concentrate per acre) can be used before planting or DBCP as a drench after planting.

## FUSIFORM RUST

Fusiform rust, caused by *Cronartium fusiforme* (Basidiomycetes), is a serious disease of loblolly and slash pine seedlings and also in forest trees up to sawlog size. Shortleaf and longleaf pines are resistant. The disease will be discussed in detail in the section on plant rusts. It invades nurseries when it spreads from oak to pine during March through June, with most infection occurring in April and early May. The first symptoms are tiny purple spots on needles or stems of small seedlings, indicating the points where the fungus entered the host. The typical spindle-shaped galls on stems are not evident until late summer (Fig. 8), and 10 to 20% of the infections may be latent and not evident at lifting time the following winter. Infected seedlings should be culled at the grading table before trees are packed for shipment.

Without control, losses from fusiform rust commonly are 10 to 20 percent and, when weather is favorable for infection, may be up to 90 percent. Losses are most severe within 150 miles of the Gulf of Mexico.

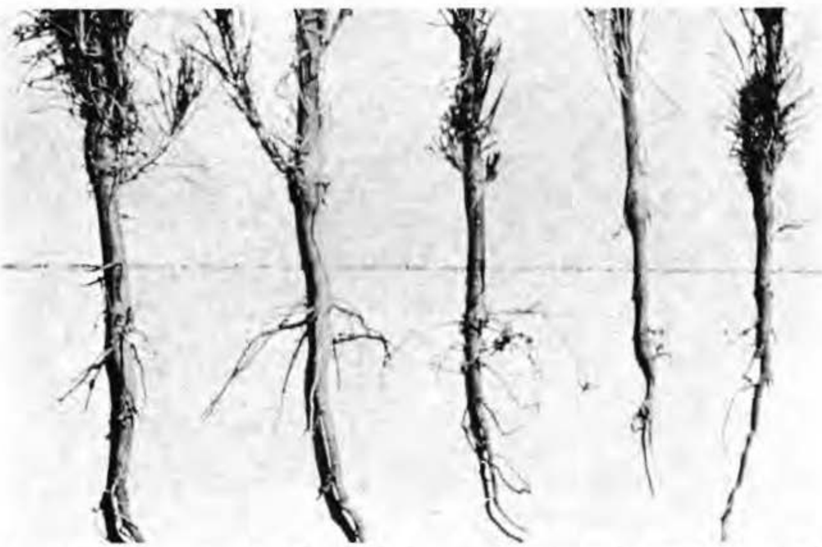

FIGURE 8. *Fusiform-rust infected slash pine seedlings with typical galls and adventitious branching.*

Fusiform rust is controlled by spraying nursery beds with ferbam at the rate of 2 pounds per 75 gallons of water per acre (see Control Techniques). One or two sprays a week are needed throughout the infection period. It is particularly important to watch weather predictions for hazardous weather, **i.e.,** periods of 18 hours or more with saturated atmosphere and temperature between 60 ond 80°F. Sprays must be on before rainy or foggy weather sets in; it will be too late to spray after a 24-hour rainy spell.

## BROWN SPOT

Brown spot, caused by *Scirrhia acicola* (Ascomycetes), is a serious disease of longleaf pine. It is discussed in detail in the section on leaf diseases. The fungus causes needle spots with intervening live tissue (Fig. 9). As the spots coalesce, the needles die back from the tips. If uncontrolled, it defoliates seedlings and so weakens them that many die after outplanting. Even when not killed, brown-spotted seedlings may remain in the grass stage for years. The disease usually appears in nurseries about June but is most severe in late summer and fall.

Brown spot is controlled by spraying with 4-4-50 bordeaux mixture (see Control Techniques). Four to 6 applications (at a rate of 60 gallons per acre) from June through October usually are sufficient. Since brown spot also occurs after outplanting, a final spray just before lifting affords an extra period of protection after outplanting. Seedlings are resistant after they reach a height of 5 to 6 feet.

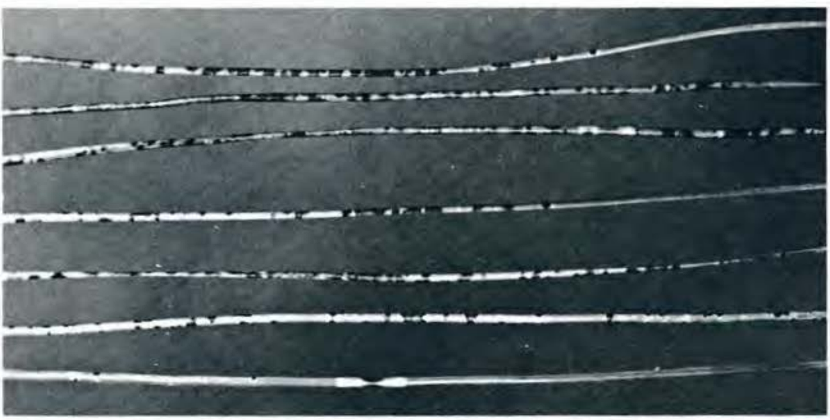

FIGURE 9. *Lesions on longleaf pine needles caused by* Scirrhia acicola. *Green tissue persists between spots for several months before the spots coalesce and cause dieback. Lesions with yellow margins indicate resistance.*

Photo by U. S. Forest Service.

## NON-PARASITIC TROUBLES

**Heat lesions.** Young seedlings exposed to excessive heat before the stem tissues have hardened, develop lesions near the ground line. Affected seedlings usually drop over and often are diagnosed as having damping-off. Heat injury is most common in loose, sandy, light-colored soils; it is less common in southern-pine nurseries than in the North and West.

Heat lesions can be prevented by sprinkling during the heat of the day when weather is unseasonably hot early in the nursery season.

**Sand splash.** Rain or irrigation water may splash soil onto the needles and stems of seedlings. If the silt or clay content is high, the soil may adhere tightly and build up coatings 1/4 inch or more thick. This reduces photosynthesis, lowers growth rate, and favors fungus attack. An adequate mulch will prevent sand splash. A soft rake or flap can be pulled over beds to dislodge soil from seedlings.

**Chlorosis** is a general term for yellowing foliage. Much chlorosis is due to iron deficiency and is characterized by creamy-yellow new needles; older needles may have normal color. In severe cases, however, the older needles also become chlorotic. This may happen when iron in the soil is adequate but unavailable to the seedlings because of high soil pH (above pH 7 iron is bound to soil minerals). In this case an acid-forming fertilizer, such as ammonium or ferrous sulfate, will lower the pH and make the Fe available. High phosphate content of the soil coupled with low pH also will bind Fe. Liming will correct this.

Where there is an iron deficiency, the application of an iron chelate is the quickest way to correct chlorosis. Three pounds of actual Fe per acre usually is sufficient.

If the needles of pine turn a light green color and root rot is not present, the normal green color frequently can be restored by a top dressing of urea, ammonium nitrate, or diammonium phosphate at the rate of 50 pounds of nitrogen per acre. The final correction for chlorosis due to soil deficiencies should be based on adequate analysis of the soil and seedlings.

Chlorosis also may be caused by hot weather during July and August, by root rot, or by chemical injury. The cause of chlorosis frequently is difficult to determine. When an expert is not available, control usually must be by trial and error.

## CONTROL TECHNIQUES[5]

The common fungicides, fumigants, and other chemicals used in nurseries, and methods of their application are discussed briefly below. More detailed information is included in Hodges' "Diseases in southeastern forest nurseries and their control" and other literature listed at the end of this chapter. Instructions and precautions given by distributors of chemicals should be followed. Some chemicals, as methyl bromide, are extremely dangerous and should be used only by experienced personnel.

### Fungicidal Sprays

To be effective, fungicides must be properly chosen, correctly mixed, and applied in the correct amount at the correct time. After the correct fungicide and time of application have been determined, proper methods of application are essential.

In nurseries, fungicides are applied mostly by tractor-drawn power sprayers (Fig. 10). The plants must be uniformly covered with very small droplets. This requires nozzle orifices not larger than 1/32 inch

FIGURE 10. *Applying a fungicidal spray. Spray rig treating three nursery beds For seedlings as tall as these, spray coverage would be better if the boom were set higher.* Photo by U. S. Forest Service

[5]Trade names of commonly used and widely available commercial preparations are listed for the convenience of users of this text. Such listing does not imply that the listed products are superior to comparable products which are not listed.

and a pressure of at least 300 pounds per square inch. The alternative is to apply the fungicide with a mist blower. Large drops, resulting from large orifices or low pressure, give poor protection, even when excessive quantities are applied.

Nozzles must be at a height and spacing which causes the cones of spray to overlap slightly above the seedlings. The amount of spray applied depends on orifice size, pressure, and tractor speed. A rig must be calibrated and the tractor speed adjusted to deliver the proper amount of spray per acre.

Small areas can be effectively sprayed with a hand sprayer, provided it has an adequate nozzle and pressure pump to deliver a fine spray.

A spreader-sticker must be added to most fungicides to insure that the spray droplets spread over and stick to the waxy leaf surfaces. The commonly used spreader-stickers include Santomerse S, Triton B 1956, Ortho Spray Sticker, and DuPont Spreader-Sticker. These should be used as directed on the labels.

The fungicides commonly used in forest tree nurseries are:

**Bordeaux Mixture.** A homemade solution, mixed only as needed, is far superior to the prepared products on the market. A 4-4-50 mixture is prepared by dissolving 4 pounds of $CuSO_4$ in 50 gallons of water. Four pounds of hydrated lime are stirred into a bucket of water and this suspension slowly stirred into the $CuSO_4$ solution. It is usually applied as a spray at the rate of 60 gallons per acre.

**Ferbam** (ferric dimethyldithicarbamate sold as Fermate, Ferrodow, NuLeaf, Karbam Black, and other proprietaries). Usually applied as a spray at 2 pounds per acre, mixed with 75 gallons of water.

**Ziram** and **zineb.** Like ferbam, these are dithiocarbamates; they are mixed and applied at the same rates.

**Soil Drenches**

These are pesticides applied to the soil with large volumes of water mainly for the control of damping-off and nematodes. The chemical can be applied dry or in a small amount of water and then watered-in by using the overhead irrigation system. About 3/4 inch of water will distribute the chemical through the upper 6 inches of the average nursery soil. The chemical can be applied with a watering can, hand sprayer, power sprayer, or through the overhead irrigation system.

**Thiram** (tetramethylthiuram disulphide, sold as Arasan 75, Tersan 75, Thiram 75W), **captan** (N-trichloromethyl-4-cyclohexene-1,2-dicarboximide, sold as Captan-50 and Orthocide 50), and **PCNB** (pentachloronitrobenzene, sold as Terrachlor) are used as soil drenches to control damping-off. Thiram also is used as a seed treatment. **DBCP** is used as a drench to control nematodes (see Soil Fumigants).

**Soil Fumigants**

To fumigate, a volatile chemical releasing toxic vapors is introduced into the soil. Fumigants are used to control weeds, nematodes, insects, and fungi. Some are specific for one class of pests; some are effective against all four. Success depends on:

(1) Soil temperatures between 50 and 80°F are best. Usually the lower the temperature, the longer it takes to fumigate.

(2) Soil moisture near field capacity is best. Higher moisture contents result in poor soil penetration and slow escape of the gas.

(3) Discing or plowing to a depth of 6 to 8 inches before fumigating will loosen the soil and expedite gas penetration and escape.

(4) Most recommendations are for a light-textured soil with little organic material. On heavy soils or those with high organic content, the rate of application must be increased by 25 to 50% and more time allowed between fumigation and planting. Cover crops should be turned under two months before fumigating.

(5) Covering treated beds with a 4-mil polyethylene film increases effectiveness in most cases. Covers are essential for highly volatile chemicals and with some, as methyl bromide, for the safety of workmen.

Commonly-used fumigants are discussed below. The first three are all-purpose preplant fumigants effective against fungi, nematodes, weeds, and insects. The others are preplant fumigants used against nematodes only. One (DBCP) can be used as a post-planting soil drench also.

**Methyl bromide** (Dowfume MC-2, Brozone, Pestmaster, and other proprietaries). Those used in forest nurseries usually consist of 98% methyl bromide and 2% chloropicrin as a tear-gas warning agent. Methyl bromide is extremely toxic and should be used only by experienced personnel. It must be applied under a polyethylene film with the edges sealed with a layer of soil. It can be applied three ways, at a rate of about 250 pounds per acre:

(1) The gas, dissolved in a solvent, is injected into the soil with a special power injector and simultaneously covered with a plastic film.

(2) A 20 x 100 foot plastic film is laid down over sacks filled with straw to permit gas distribution; the edges are sealed with soil. The fumigant is fed under the film through a plastic tube from small cans of compressed methyl bromide. Special clamps are provided to easily release the gas from the can.

(3) The gas is applied hot and the plastic is laid by a special machine (Fig. 11). This is the cheapest method of treating large areas but restricts treatment to the actual bed area and not the lanes between beds.

FIGURE 11. *Soil fumigation. The fumigant is released under the polyethylene film and the film edges sealed with soil. Later the film is removed to permit escape of the gas prior to seeding.* Photo by U. S. Forest Service

The cover can be removed after 48 hours if the chemical was applied cold, or after 12 to 18 hours if applied hot. Seed may be planted 48 hours after the cover is removed.

**Vapam** (sodium N-methyldithiocarbamate). This is effective when injected into the soil with special power equipment at the rate of 50 gallons per acre and covered with a polyethylene film for 48 hours. The soil should be disced at least once after removing the cover and seeding delayed two weeks to permit escape of the gas.

**Mylone** (3,5 dimethyltetrahydro—1,3,5,2H—thiadiazine-2-thione). This is applied as a powder (300 pounds per acre) to the surface, either alone or with a fertilizer, and is then disced in to a depth of 6 inches. No cover is needed. Seed may be planted 2 to 3 weeks after treatment.

**DD** (dichloropropane—dichloropropene mixture). This is injected into the soil at a rate of 20 to 25 pounds per acre. Planting can be done 2 to 3 weeks after treatment.

**EDB** (ethylene dibromide sold as Dowfume W-80, Soilfume 85). Ten to 15 gallons per acre are injected into the soil. No cover is needed and the area can be seeded after 2 weeks.

**DBCP** (dibromochloropropane sold as Nemagon, Fumizone). Twenty to 35 pounds per acre are spread on the surface (granular form) or injected into the soil (liquid form). No cover is needed and seed can be sown in 2 to 3 weeks.

DBCP is also used as a drench after seedlings are up. A dilute solution (4 gallons per 100 gallons of water) can be injected into the overhead irrigation system. It must be followed by additional watering to prevent damage to the seedlings.

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# ROOT DISEASES

In addition to the root troubles encountered in nurseries, root diseases present some serious problems in the forest.

Forest soils are biologically complex, containing multitudes of bacteria, nematodes, fungi, insects, and such small animals as earthworms. Also living in the soil are the roots of plants, including the trees in which foresters are primarily interested. Normally, all these organisms are in a dynamic natural balance which changes with season and gradually over a period of years with the ecological succession.

Under the best forest conditions, probably every tree has some minor root rot, because fungi capable of attacking roots usually are present; the main problem is to determine and prevent conditions under which root-rot fungi become destructive. Trouble starts when some change in the environment permits a pathogen to gain the upper hand. Flooding, drouth, or fire can radically change an environment; forest management and harvesting operations also change the soil. Perhaps the most drastic changes come with arable agriculture; the effects of cultivation may persist for years after land reverts to forest. Mismanagement in either forestry or agriculture which permits erosion, compaction, etc., is particularly destructive.

## SWEETGUM BLIGHT

In the 1950's, which included several drouth years, a serious decline of sweetgum appeared from Texas to Delaware. First marked by death of a few small twigs, this "dieback" killed progressively larger branches until trees became stagheaded or dead (Figure 12). Dieback was found in 67 percent of 1298 plots examined in 1954. In the 9 states surveyed, 2 to 40% of the sweetgum trees were affected and 6% of all sweeegums had over 50% of their tops dead. These top symptoms were the result of root damage. Diseased trees had a greatly reduced number of fine

FIGURE 12. *Young sweetgum trees showing several stages of dieback due to sweetgum blight.*

Photo by U. S. Forest Service

feeder roots. Dead roots contained many common soil fungi, with no single species consistently predominant.

More roots died on poor sites with heavy soils, particularly where high contents of sodium and potassium reduced the amount of available water. On better sites where sweetgum is more vigorous, dieback was less common. With the return of normal rainfall, symptoms rapidly disappeared.

Sweetgum blight is typical of many hardwood diebacks. It is immaterial whether facultative parasites play a major or a minor role in the death of roots. The important point is that for most tree species, damages associated with adverse weather are lowest on the sites to which the species is best adapted. Foresters should encourage the economic species best suited to each site, unless they are willing to gamble on periodic losses due to environmental factors and facultative parasites.

## LITTLELEAF

**Littleleaf** is primarily a disease of shortleaf pine, although other southern pines may be affected to a lesser extent and similar troubles have been reported on red pine in the North and western white pine in the West. Like sweetgum blight, littleleaf is a general decline resulting from a reduction of the feeder root system. Above-ground symptoms seldom develop on trees less than 20 years old. They include sparse crowns of short chlorotic needles, abrupt reduction in diameter growth, dead branches, and large crops of undersized cones (Fig. 13). Death follows 1 to 12 years after symptoms first appear.

FIGURE 13. *This shortleaf pine stand contains healthy trees and others in various stages of decline from littleleaf disease.* Photo by U. S. Forest Service

About 35% of the commercial area of shortleaf pine east of the Mississippi River is affected. In 18 South Carolina Piedmont counties, 13% of all shortleaf pines over 6" in diameter were diseased in 1950. Thus littleleaf is one of the most serious diseases of southern pines.

Littleleaf is primarily a disease of the Piedmont region, where the original stands were hardwoods with a scattering of pine, growing in deep, rich, friable soil. The settlers cleared much of this forest for agriculture and erosion soon removed much of the topsoil. Now little topsoil remains in much of the Piedmont, and in many places the poor clay B horizons are exposed. Shortleaf pine invaded much of this agricultural land when it was abandoned 50 to 100 years ago.

The etiology of littleleaf is complex. The trees are weakened by unfavorable soil conditions such as low fertility, poor internal drainage and aeration, low organic content, and a restricted fungus flora. Littleleaf develops when root tips are killed by the common soil watermold, *Phytophthora cinnamomi* (Phycomycetes) and, as a result, the tree is starved, particularly for nitrogen.

There are two longtime approaches to reduction of littleleaf damage:

(1) Breeding for resistance to *P. cinnamomi.* Some selections of shortleaf pine have been found which have a practical level of resistance and eventually can be used on littleleaf sites.

(2) Soil rehabilitation. By encouraging such soil-building species as dogwood, redbud, yellow-poplar, hickory, and redcedar, soils eventually could be improved to a point where littleleaf would be unimportant.

In the meantime two practices are available to reduce losses.

(1) In stands with few diseased trees, light cuts at 10-year intervals permit salvage of trees in an early stage of decline. Where 10 to 25% of the trees are affected, removal at 6-year intervals of all trees showing symptoms is advisable. If over 25% of the trees are diseased, it is best to cut all shortleaf as soon as it is merchantable. Short pulpwood rotations are safest on high-hazard sites. These recommendations are based on observations of the rate of stand degeneration after different degrees of infection.

(2) Favoring loblolly and other pines relatively resistant to littleleaf and encouraging those hardwoods which are merchantable.

Ornamental or other stands of high value can be protected against littleleaf, or trees showing early symptoms can be improved by fertilizing with one ton per acre of 5-10-5 commercial fertilizer plus ½ ton per acre of ammonium sulfate.

Recently Monterey pine, which was introduced and extensively planted in New Zealand, is being attacked by *P. cinnamomi* and its close relative, *P. cactorum.* Decline is more rapid than with shortleaf in this country.

## ANNOSUS ROOT ROT

*Fomes annosus* (Basidiomycetes) causes a root and butt rot of conifers in many temperate parts of the world. Mortality from annosus root rot is increasing in the United States, especially in young planted stands following thinning. Heavy losses in some plantations are of increasing concern to foresters, in view of the large acreages of plantations currently approaching thinning age.

### Distribution

*F. annosus* is prevalent throughout the North Temperate Zone and also is found in some tropical and subtropical areas. The fungus is native to the United States and can be found wherever conifers grow. Killing by annosus root rot has been reported in all the states where southern pines are native, as well as in many northern, eastern, and western states. The highest mortality is in the coastal states from Virginia to Texas. Although damage has been high in some individual plantings, severe losses have not occurred over wide areas.

In 1961, 476 plots in thinned stands were examined from Virginia to Texas. Considering all plots, overall infection was low:

2.8% of trees in planted loblolly pine stands
2.2% of trees in planted slash pine stands
0.07% of trees in natural slash pine stands.

Another survey of slash and loblolly pines in the Southeast showed that infection was higher in thinned stands and that damage was greatest in planted stands. Probably most of the planted stands were on former agricultural land.

| *Type of Stand* | *With F. annosus* | *Mortality lacking* | *Mortality occasional* | *Mortality general* |
|---|---|---|---|---|
| | *- - - - - - - - - - Percent of all stands - - - - - - - - - -* | | | |
| Planted, thinned | 82 | 27 | 47 | 26 |
| Planted, unthinned | 9 | 91 | 9 | 0 |
| Natural, thinned | 70 | 43 | 52 | 5 |
| Natural, unthinned | 13 | 87 | 13 | 0 |

### Hosts

Most conifers probably are susceptible to annosus root rot, and it has been reported on 20 species of hardwood in Europe. Although *F. annosus* fruits on hardwoods in the United States, it is not known to have killed any. In the Placerville genetics arboretum in California, the fungus has killed 24 species of pine. A report from Denmark lists 26 species of conifers as susceptible. All the southern pines are attacked and, contrary to the belief of many, loblolly pine is just as susceptible as slash. The disease is particularly severe on eastern redcedar; this root rot is the major cause of mortality in the species.

**Signs and Symptoms**

Infected southern pines usually die before there are clear aboveground symptoms, but a slight thinning of the crown is often evident (Fig. 14).

The main signs and symptoms are at or below ground level.

**Fruiting bodies.** These start as small mycelial buttons, often no more than an inch across. Developed conks are a few inches to a foot across (Fig. 15). Usually they are attached to the base of the tree or stump but sometimes occur several feet from the bole, presumably attached to roots. Conks are irregularly shaped with a gray to brown upper surface and a creamy white pore surface underneath, which darkens with age. Conks may be perennial but with age weather or are eaten by insects. Consequently, they may be difficult to find except in cooler

FIGURE 14. *Mortality in a slash pine plantation due to annosus root rot following thinning.* Photo by U. S. Forest Service

FIGURE 15. *Fruiting bodies of the root rotting fungus,* Fomes annosus, *form at the bases of stumps or trees; they aften are hidden under the duff.*

weather when fresh fruiting surfaces are present. Conks frequently are covered by leaf litter and are easily overlooked unless the needles are scraped from the base of the tree.

In Europe, Canada, and northern United States, basidiospores are produced during all seasons. In southern United States, however, spores are produced in the fall, winter, and spring, with practically none produced during the summer. As pointed out later, this has an important bearing on control in the South.

**Light yellowish stringy rot** of the roots and butt (Fig. 16). Initial stages may be irregular pinkish to dull violet stain of the wood. Later, whitish pockets of rot develop, sometimes with black spots or

FIGURE 16. *A white pine wind-thrown following attack by* Fomes annosus, *showing the typical stringy yellowish-white rot.* Photo by U. S. Forest Service

flecks in them. These pockets finally merge, producing the typical yellowish stringy rot.

**Resin infiltrated roots.** Resin may ooze out and mix with soil to form incrustations on the root surface.

**Mycelial mats.** As the root dies these form between the bark and wood.

**Disease Development**

When residual conifers die within a few years after a stand is thinned, annosus root rot should be suspected. The pattern of killing is similar to that caused by bark beetles or turpentine beetles. Since trees weakened by *F. annosus* are attractive to bark beetles, some annosus root rot mortality undoubtedly has been diagnosed as beetle attack. Whether insects are present or not, dead trees in thinned stands should be examined for root rot.

There is considerable evidence that *F. annosus* will not grow in the soil and can survive there only in or on roots and butts of trees. Because annosus root rot is essentially a disease of thinned stands, it appears that most infection is by wind-borne spores infecting fresh stumps. Other wounds probably account for the limited infection which occurs in unthinned stands. From the fresh stump the mycelium spreads out through roots, at a rate of 3 to 6 feet per year, into the roots of adjacent residual trees. When it reaches the bases of these trees, it girdles them. Once started, the process may be repeated through interconnected root systems until large openings result.

Some stumps become infected without infecting residual trees; conks sometimes develop on stumps in healthy stands. Such stumps apparently are not directly connected with the roots of adjacent trees, or stump infections are prevented from reaching the roots of residuals by intervening infections of stump roots by other fungi with which *F. annosus* cannot compete.

Several site and stand factors influence the severity of annosus root rot:

(1) Severe mortality is essentially limited to thinned stands, presumably because most infections occur through fresh stumps. Infection, however, can occur through any fresh wound, and by spores washed through the soil to wounds in stump roots. The effectiveness of stump treatments indicates that the latter rarely occurs.

(2) Low organic content in the soil favors attack, probably because such soils have fewer competing organisms. This explains why damage is greater on deep sand or clay sites, which are usually low in organic matter.

(3) Other factors being equal, dense needle litter favors attack.

(4) Damage has been greater on old agricultural sites. Such sites usually have a low organic content in the soil. Most plantations in the South have been on abandoned agricultural land.

(5) Damage increases with the number of years since thinning and with the number of thinnings, because the fungus continues to spread out from the original infection and each thinning may permit new infections.

In England, mortality is reported to occur mainly in young stands; in older stands mortality is lower and damage is mainly butt rot instead of root rot. There is some evidence that in southern pine stands, infection areas become stable when stands are about 35 years old. In western hemlock, *F. annosus* is a common butt-rotter in over-mature trees rather than a killing root-rotter.

**Control**

Once *F. annosus* is established in a stand, there is no known economical method of eradicating it.

One preventive usable under forest conditions is the treatment of stumps to prevent infection by *F. annosus* but to permit early infection by *Peniophora gigantea* (Basidiomycetes). This is the common initial decay fungus on pine stumps over the entire Northern Hemisphere and it is quite antagonistic to *F. annosus.*

The first stump treatment used in England, and later in America, was creosote, but this is no longer recommended. Technical grade borax, dusted onto the tops of stumps with a perforated can, is more effective. Application must be at the time the tree is felled. Since harvesting crews are prone to neglect this stump treatment, one company adds dye to borax to facilitate inspection and check-up.

Recently, Rishbeth in England has found that cultures or spore suspensions of *P. gigantea* can be used to inoculate fresh stumps, getting the competitor into the stump ahead of *F. annosus.*

A recent study by the International Paper Company in south Georgia showed little infection in slash pine thinned in June, July, and

August, even when the stumps were artificially inoculated with *F. annosus* spores. In fall and winter thinnings, infection rose sharply. Dry, hot summer weather probably reduces spore production and minimizes germination and infection should spores land on stumps. *F. annosus* is a moderate temperature organism. Studies in Pennsylvania and Europe showed little seasonal effect (Penn.) or greater infection in the summer (England). However, in the hot southern pine region, seasonal cutting may be a useful tool in annosus root rot control. If plantations on high-hazard sites were thinned exclusively in summer, infection might be low even without stump treatment. This certainly should be further investigated.

## OTHER ROOT ROTS

Laminated root rot, caused by *Poria weirii*, is a lethal disease of Douglas-fir in northwestern United States and adjacent Canada. Damage usually is greatest in stands 40 to 125 years old. No practical direct controls are known but losses can be reduced by such management practices as first logging areas where mortality is greatly reducing net increment, clear-cutting infection centers and border trees, and on heavily damaged sites favoring less susceptible species, as western hemlock.

In the South, the agaric *Clitocybe tabescens* has caused considerable damage to such introduced trees as Australian pine and peach in Florida; native trees are more resistant. This again illustrates the need for care in planting species out of their natural range or off site. Also, black root rot, the destructive nursery disease, has damaged a considerable acreage of slash pine plantations (2-7 years old) in the sand hills of western Florida. This sandy area, now mostly in scrub oak, was originally covered with the deep-rooted longleaf pine; damage by root rot seems to indicate that slash pine is not well adapted to this site.

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# LEAF DISEASES

A variety of fungi commonly attack the leaves of trees . Although most cause little or no economic loss in the forest, their disfigurement of shade and ornamental trees is important. Foresters frequently are asked about leaf diseases on non-forest trees. Furthermore, a few leaf diseases can become damaging to forest trees when epidemics last more than a year, particularly if leaves are lost early in the season. Late defoliation seldom affects growth, particularly of hardwoods, because they have good recuperative power, so that a single complete defoliation usually does not kill.

## LEAF DISEASES OF HARDWOODS

Four leaf diseases or types of diseases are common on southern hardwoods.

### Leaf Spots

Sweetgum and some other hardwoods are heavily leaf-spotted late in most summer seasons; this apparently causes leaf shedding perhaps a month earlier than would otherwise be normal. There is no noticeable effect on growth. Occasionally heavy infections of leaf-spotting fungi occur early in the spring; such early infections may seriously reduce the year's growth.

Necrosis from leaf spots varies from large general leaf areas to discrete spots, either large or small. Spots may be yellow, brown, or black; some have margins of other colors. The lesions of some spots drop out leaving characteristic "shot holes". Most forest tree leaf spots are caused by Ascomycetes and Fungi Imperfecti, but bacteria and viruses also may cause spots.

### Leaf Blister of Oaks

This disease is caused by *Taphrina caerulescens* (Ascomycetes). In the southern states it is most common during spring and early summer. Although not a major forest tree disease, it occasionally causes 50 to 85% defoliation by midsummer, which undoubtedly weakens trees and reduces increment. Many oak species are susceptible, but the disease is more severe on scarlet, southern red, water, shingle, and live oaks.

The fungus overwinters as spores lodged in bud scales or bark crevasses. After infection in early spring, the initial small light green spots enlarge to form blister-like areas on leaves. Blisters seldom are more than a half inch in diameter and may be yellow or light green with rose or purple tints. The convex upper surface usually is smooth; the lower concave surface is silvery gray with dense masses of asci. Later, the blisters turn brown. Heavy infections cause affected leaves to fall prematurely so that the foliage is sparse in late summer.

Direct control measures are not recommended for forest trees. On shade, ornamental, and nursery trees fungicidal sprays are feasible and afford effective control. An effective spray formulation is: 1.5 pints of Puratized Agricultural Spray and 3 pounds of ziram (Zerlate) in 100 gallons of water. The spray should be applied in late February and again in early March as buds start to swell. Sprays applied after buds have burst and leaves have emerged are not effective.

**Powdery Mildew**

The six genera of powdery mildew fungi (Ascomycetes) attack many species of hardwood trees and crop plants. The most common genera are *Uncinula,* particularly on elms, and *Microsphaera,* particularly on oaks. Infected leaves have a powdery appearance due to mycelium and conidia on the leaf surface.

The powdery mildew fungi are obligate parasites, **i.e.,** they live only on live tissue. They overwinter on fallen leaves as ascospores, which in the spring are wind disseminated and inoculate young leaves. Unlike those of most fungi, the spores need little moisture to germinate, and the mycelium develops rapidly even during relatively dry spring and summer weather.

The germinating ascospores form a superficial mycelium on the leaf surface, instead of the internal mycelium of most other leaf parasites. The mycelium sends haustoria into the leaf cells to extract food from the protoplasts and produces an abundance of conidia which can infect other leaves throughout the growing season. In the fall the sexual stage, **i.e.,** asci in perithecia, appears as minute black dots on the leaf surface. These overwinter. The visible surface mycelium and fruiting bodies make diagnosis easy. Control of powdery mildew in the forest is not practical.

For ornamentals, collection and burning of leaves in the fall is an effective control, because the fungus overwinters on fallen leaves. Since the mycelium is superficial, it can be killed by spraying or dusting after infection, in contrast to almost all other tree pathogens which must be prevented from causing infections. Sulfur dust applied early in the morning when the leaves are moist, or lime-sulfur spray are effective.

**Poplar Leaf Rust**

Poplar leaf rust is caused by several species of *Melampsora* (Basidiomycetes). While best known for disfigurement of ornamentals, the disease can severely damage cottonwoods and other species of the genus *Populus*. As plantings of cottonwood for pulpwood become more extensive there is a possibility that epidemics of rust may develop and cause important growth loss.

In the summer, golden-yellow to orange pustules develop on the undersides of leaves. The uredospores from these reinfect other poplar leaves. In late summer or fall, slightly raised crusty areas develop, which at first are orange but become brown or even black. These crusty areas contain the teliospores which overwinter on fallen leaves. In the spring, they germinate to form sporidia which are wind disseminated to inoculate the alternate host. One species infects hemlock, another tamarack. Aeciospores produced on the coniferous hosts reinfect the poplars. Since neither alternate host occurs in the South, it is assumed that southern poplars are infected by air-borne uredospores from northern poplars. The later appearance of rust on poplar in the South than in the North supports this assumption.

Individual cottonwoods have been found which are highly resistant to rust and have other desirable characteristics. Since cottonwood is propagated by cuttings, it will be economically feasible to multiply resistant stock rapidly for nursery use, and to use only rust-resistant cottonwoods in the planting program. Such a program has recently been initiated in Mississippi.

## LEAF DISEASES ON CONIFERS

Conifers, like hardwoods, are attacked by a number of leaf fungi. One of these, brown spot, needs detailed attention.

**Brown spot**

Brown spot, caused by *Scirrhia acicola* (Ascomycetes), is one of the four most important diseases of southern pines. It occurs in the coastal states from North Carolina to Texas, and in Arkansas, Tennessee, Wisconsin, Ohio, Oregon, and Canada. Very likely it occurs elsewhere but is not of sufficient importance to have been found. It is of primary importance on longleaf pine, but moderate to severe defoliation has been reported on ponderosa, white, and loblolly pines. It also has been found on seven other pines. Further discussion will be restricted to longleaf.

Although brown spot was described in 1876, it was not recognized as a serious disease until 1919. Prior to 1915, most longleaf pine stands were burned annually, ignited either by lightning or man. Both the Indians and white settlers made regular use of fire. This undoubtedly kept brown spot in control so that it was economically unimportant until fire control became a regular practice. Now it is a limiting factor in longleaf pine management. A 10% destruction of seedling foliage may reduce height growth 50% the next year; a 30% destruction virtually stops terminal growth.

Spots first appear when needles are only partially expanded. The fungus invades and kills the mesophyll cells but not the vascular system; thus green tissue may persist between spots (Fig. 9). Eventually, however, spots coalesce and the needles die back from the tips (Fig. 17). In late winter and early spring the fungus rapidly extends to the needle base without forming spots. Repeated defoliations of seedlings in early height growth result in strongly tapered stems.

Conidia are produced all year in black fruiting bodies on spots. The sexual spores (ascospores) are produced on dead needles and are

FIGURE 17. *A severely brown-spotted longleaf pine seedling. Dead extremities, 1/2 to 2/3 of the needle length, are brown, and show light in the photograph.* Photo by U. S. Forest Service

most prevalent in early spring. They are wind borne for long distances to start new infection centers. The conidia are exuded in a water-soluble matrix. At least 48 hours of rainy or wet weather are needed for abundant spore discharge. Conidia are disseminated mainly by rain splash and account for local intensification.

Longleaf pine is most susceptible while in the grass stage. When the seedlings begin active height growth, resistance starts, and at 5 feet in height plants are highly resistant. Longleaf normally remains in the susceptible grass stage for 3 to 5 years, but brown spot can extend this period indefinitely (Fig. 18).

Prescribed burning is the only economical control for brown spot under most forest conditions. Burning usually should be done in January or February but circumstances may dictate a slightly earlier or later date. It should be done only when brown spot becomes serious. Decisions should be made on the basis of foliage infection about December 1. Areas where more than 35 percent of the foliage is dead should be burned the following January or February. If dead leaf area is 12 to 20 percent

FIGURE 18. *Brown spot needle blight of longleaf pine. The white cards mark 10-year old seedlings held in the grass stage by brown spot. The background trees are the same age but were protected with a fungicide.*

**Photo by U. S. Forest Service**

of the total foliage, the area will probably need burning a year later. This advance warning permits preparation of firebreaks, planning for financing, etc.

Usually prescribed burning is first needed in the third year after longleaf seedlings are planted. If infection is heavy after the second summer, however, the plantation should be burned the following winter. Omission of a final bordeaux spray at lifting time, or direct seeding in areas where there are infected natural seedlings often makes early burning desirable.

Burning should be thorough enough to reach practically all infected seedlings and hot enough to brown all needles as high up as infection occurs. If the needle is browned, the fungus in it is killed. Actual consumption of needles on plants is not desirable, because this means there was sufficient heat to damage buds and stems. Longleaf 6 inches to 4½ or even 6 feet in height are more susceptible to fire damage than those in the grass stage, particularly if weakened by brown spot. Therefore, the best time for a control burn is before any large percentage of trees are in early height growth or are weakened by brown spot.

The larger the area burned, the slower brown spot will reinvade. Burns of 500 to 1000 acres are not too large, but if no infected seedlings are nearby, smaller burns are effective.

Sometimes, particularly where vigorous height growth is long delayed, a second or even third burn may be needed within two to five years.

Burning, however, may have an adverse effect. Seedlings having a genetic factor for early height growth or brown-spot resistance will tend to be in early height growth when a burn is needed. Fire may kill such seedlings and thus tend to perpetuate the more brown-spot-susceptible individuals rather than the resistant ones.

Fungicidal sprays, as used to control brown spot in nurseries, are used only occasionally in plantations. In some low flat areas, longleaf is direct seeded on plowed ridges to avoid excessive water damage to newly germinated seed. Not only does brown spot develop more rapidly on such exposed seedlings, but there may be insufficient grass to support a sterilizing burn when needed. In this situation, one company in Louisiana applies a bordeaux spray in May of the second year, with a spray rog mounted on a jeep. This has given many good stands, but tests indicate that really good control requires two sprays a year (May and October) during the second and third years, and sometimes the fourth year.

Another study indicates that a good control program would consist of a prescribed burn for the first sanitation followed by a bordeaux spray if brown spot builds up before sufficient numbers of seedlings are in vigorous height growth. This would permit the use of the cheaper fire before seedlings are in height growth, and the use of the spray after some trees are in height growth — thus saving from possible damage stock with any genetic factor for early height growth or brown-spot resistance.

The use of other species, such as slash or loblolly pine, on longleaf sites will reduce brown spot damage since these species seldom are seriously brown spotted. Slash and loblolly pines have been planted extensively on longleaf sites for this reason, but this has created another disease problem, fusiform rust.

Eventually, the use of longleaf pine strains genetically resistant to brown spot may be an important means of control. Individual longleaf pines have been found which have a genetic factor for brown-spot resistance, carried in both the male and female genes.

**Other Leaf Diseases of Conifers**

In the South, most leaf diseases other than brownspot usually are innocuous, despite occasional conspicuous flare-ups; some are important on ornamentals even though they have little effect on growth. One of the latter is hypoderma needle blight of pines caused by *Hypoderma lethale* (Ascomycetes). Some or all the needles on a branch turn yellow and die; damage usually is most prevalent in the lower third of the crowns of trees growing in the open. Because mainly the lower crown is involved, *Hypoderma* may not appreciably affect growth. This disease, however, has caused considerable concern by disfiguring pines, mainly loblolly, along highways and in parks and yards.

Several additional leaf diseases occur on conifers, some of them quite damaging in the West. Rhabdocline needle cast of Douglas-fir, caused by *Rhabdocline pseudotsugae* (Ascomycetes), is periodically epidemic in the Northwest. Elytroderma needle blight, caused by *Elytroderma deformans* (Ascomycetes), causes important amounts of defoliation of western conifers, particularly ponderosa pine.

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# CANKERS

A tree canker is a localized killing of bark on branches or trunks. Eventually it leads to a sunken area or to girdling and death.

Some parasitic cankers are annual; **i.e.,** the causal organism operates only during one season. Such wounds, if not too large, callus over in later years. Most annual cankers are probably caused by weak parasites attacking trees which are under moisture stress. Other annual cankers are caused by non-parasitic agents, such as frost and heat.

The cankers important to forestry are perennial and are caused by fungi, although bacteria cause serious cankers on some orchard trees. In many cases, the rate of development of cankers depends on the turgidity of bark cells; under moisture stress, the tree is less able to repel attack and the rate of canker spread increases. Many canker fungi are most active during the semidormant season. During the tree's active growing season, the advance of the fungus is stopped and the canker begins to callus over. In the exceptional cases where the canker spreads continuously, girdling and death may follow in a short time.

## CANKERS ON HARDWOOD

There are more described cankers on hardwoods than on conifers, but the general mode of action is the same, i.e localized areas of bark are killed. Some affect only the phloem, but the important ones also kill the cambium. Many are of minor importance and are believed to be caused by facultative parasites able to attack only trees weakended by moisture stress or some other unfavorable site factor.

Four cankers, or groups of similar cankers attacking hardwoods, are of economic importance.

FIGURE 19. *A typical canker on a hardwood stem. Fungi of various genera cause such cankers.*

Photo by U. S. Forest Service

**Typical Non-girdling Cankers**

Cankers caused by various species of ascomycetes in the genus *Nectria* and of the Fungi Imperfecti in the genera *Strumella, Cytospora,* and *Botryodiplodia* occur on all the commercial hardwoods (Fig. 19).

Cankers have increased in importance for three reasons:

(1) Repeated high-grading leaving unmerchantable low vigor trees, many with cankers.

(2) During the 1950's the South went through its most serious known drouth; there have been more severe individual drouth years, but because of the number of dry years involved the overall effect during this period was more pronounced. In the Mississippi River bottomlands, water tables fell as much as 9 feet. The weakening effect of these dry years caused a plethora of hardwood cankers all over the South. Many of the cankers described in the 1950's have essentially disappeared since more normal rainfalls have returned.

(3) Planting large acreages of such species as cottonwood on sites for which they were not well adapted. On the heavier clay soils cottonwood, and some other hardwoods, grow with low vigor and thus are susceptible to cankering.

Control of the typical hardwood canker consists of removal of badly cankered trees during improvement cuttings and encouraging each hardwood species only on suitable sites.

**Sweetgum Lesion**

Sweetgum lesion, caused by *Botryosphaeria ribis* (Fungi Imperfecti), occurs in the southern 100 miles of the sweetgum range. It does not kill, but seriously degrades lumber and veneer cut from affected trees.

The first evidence is a small spot of fresh storax or gum oozing through the bark. Later, a crack appears and the gum flows down the trunk, blackens, and hardens. These lesions, which eventually heal over forming a ridge or hump, occur mainly on the lower 8 feet of the trunk but have been found at a height of 28 feet. Many infections occur year after year until the lower bole becomes gnarled and deformed. As many as 28 healed cankers have been found in a single cross section (Fig. 20).

It is not known how the fungus spreads or how it enters the bark, but some wound must be necessary. Inoculation trials show that wounds need not extend into the cambium to establish infections.

FIGURE 20. *Sweetgum lesion. Cross-section of a stem showing multiple infections that have calloused over, resulting in a distorted stem of little value.*
Photo by U. S. Forest Service

### Canker Rots

A few of the heart rot fungi (Basidiomycetes) that attack southern hardwood work out through the bark and cause cankers (Fig. 21):

*Polyporus hispidus,* mostly on water and willow oaks.

*Poria spiculosa,* on water and willow oaks and honeylocust.

*Irpex mollis,* on red oaks.

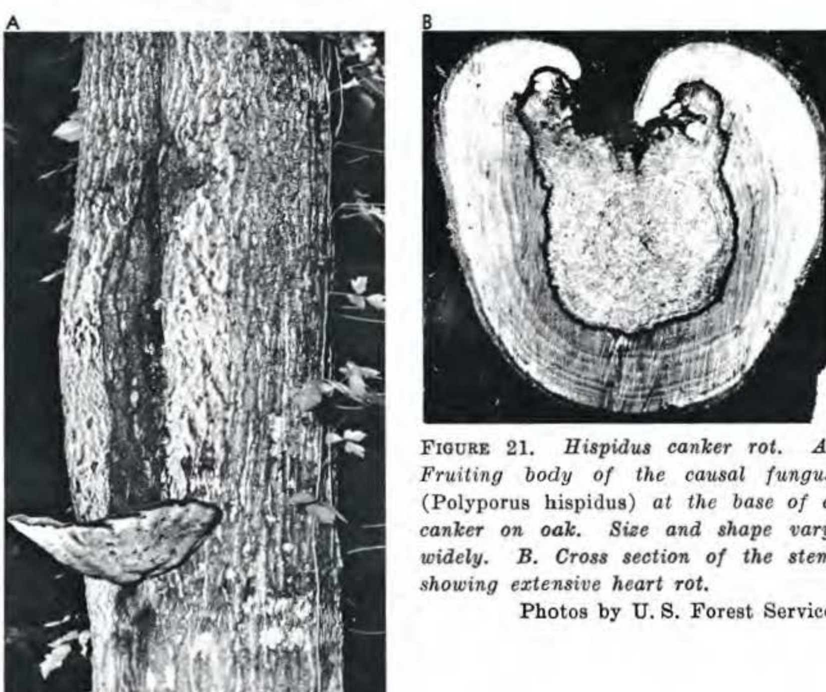

FIGURE 21. *Hispidus canker rot. A. Fruiting body of the causal fungus* (Polyporus hispidus) *at the base of a canker on oak. Size and shape vary widely. B. Cross section of the stem showing extensive heart rot.*
Photos by U. S. Forest Service

Other species, of course, also are attacked. In one study in the Piedmont, spiculosa cankers were found on 8.1% of hickories and 7.7% of red oaks. In a 2,000 acre Mississippi bottomland stand, the same canker was found on 13% of willow oaks and 3% of Nuttal oaks. The main loss is from the heart rot.

No practical controls are known. Because of rapid heart rot advance, infected trees quickly become culls, and consequently, cankered trees should be salvaged as soon as possible. Unmerchantable trees should be felled or otherwise killed.

**Chestnut Blight**

Chestnut blight, caused by *Endothia parasitica* (Ascomycetes), a native of Asia, was first found in the United States in 1904 and undoubtedly was introduced on nursery stock. By 1913, it was apparent that American chestnut was doomed as a commercial species. Chestnut was one of our most desirable timber trees: had high quality wood, grew rapidly, and was easily managed silviculturally. This is another example of the risk involved in introducing foreign tree species as seedlings.

American and European chestnuts are susceptible to blight; Asiatic chestnuts are resistant or immune. Allegheny chinquapin, several oaks, maple, hickory, and sumac will harbor the fungus but, of these, only chinquapin is seriously damaged.

Spores of the pathogen can be carried long distances by birds or wind, or by movement of infected material such as logs. Chestnut blight was an unusually fast spreading disease. The area of 80% infection spread across Virginia at a rate of 24 miles a year.

The only hope for the American chestnut is that a suitable resistant strain can be found. The resistant Asian species are suitable for nut production but not for timber. A promising hybrid suitable for timber production has recently been developed; its resistance to blight is under study. Some research is being directed toward creating resistant mutants by atomic irradiation.

## CANKERS ON CONIFERS

**Larch Canker**

This disease, caused by *Dasyscypha willkommii* (Ascomycetes), causes serious loss to larch in Europe. In 1927 it was found in two places in New England, on larch introduced from Great Britain. There happened to be no native larch nearby. All infected trees were destroyed but the fungus was again found in the same localities in 1935 and 1952. Tamarack, our eastern larch, is susceptible and there is no assurance the fungus can be eradicated from the United States, again illustrating the foolishness of importing stock from abroad. How much better it would be to import surface-sterilized seed.

**Pitch Canker**

Pitch canker, caused by *Fusarium lateritium* f. *pini* (Fungi Imperfecti), is a potentially serious disease of several southern pines and, therefore, foresters should be acquainted with it. The fungus occurs from northern Virginia to the tip of Florida and westward to Tennessee and Mississippi. It was first observed in 1945 and may have been introduced from Haiti, where it attacks West Indian pine. The causal *Fusarium* can attack any of the southern pines. It is the most damaging disease of South Florida slash pine and is one of the few fungi that can readily kill Virginia pine regardless of size. Pitch canker could became a major disease.

The main symptom is a copious flow of pitch from sunken cankers which retain the bark (Fig. 22). The wood beneath cankers is heavily pitch-soaked. No other southern pine canker has these extremely pitchy characteristics. Cankers may form on twigs where insects feed at the bases of needle clusters or at wounds on trunks. The fungus sometimes enters through fusiform rust galls. Cankers may girdle Virginia pine stems of any size; on other pines, stems over 5 inches DBH are seldom girdled. The copious pitch flow makes infected trees particularly prone to fire damage.

No control is known other than the systematic removal of infected trees. This at least will reduce fire hazard and make room for healthy trees. In south Florida removal of trees with pitch canker often is a main object of thinning operations.

FIGURE 22. *Pitch canker on the bole of a Virginia pine, showing heavy exudation of resin.* Photo by U. S. Forest Service


FIGURE 23. *Dry face of a naval-stores pine showing cessation of gum flow above points A and B.*
Photo by U. S. Forest Service

## Dry Face

Another canker-like disease of southern pine is dry face of naval-stores pines. It is characterized by a permanent cessation of gum flow from a portion or all of a turpentine face (Fig. 23). It may occur as early as the third year of work on a front face, but is more common on back faces. Affected trees produce little gum and are readily attacked by insects and stain or decay fungi. The trouble is more common on slash than longleaf pine.

The first symptom is a pitch-soaking of the inner bark and wood above the turpentine face. As chipping progresses, the dry areas develop on the faces. Internal lesions may occur as pitch streaks for many feet above the face.

Several fungi, including the common stainers *Diplodia pinea* (Fungi Imperfecti) and *Ceratocystis ips* (Ascomycetes), are associated with dry face. These fungi probably accelerate and aggravate the rate of dry face extension but are not the primary cause. Drouth appears to be the primary predisposing factor for dry face. In dry periods, greatest damage may occur at pond margins where roots are superficial. Mechanical damage associated with poor gum extraction techniques can aggravate drouth effects. Such techniques include: (1) making faces greater than one third of the tree circumference, (2) working two or more faces simultaneously, (3) chipping deeply into the wood, and (4) using broadaxe incisions for gutters.

Trees with crowns less than one third their height are more prone to dry face than those with longer crowns. Thinning stands well ahead of turpentining helps develop long crowns. In older stands having short crowns, turpentining should be avoided. Bark chipping with acid treattreatment instead of wood chipping, and the use of nailed instead of inserted gutters in recent years have reduced the incidence of dry face by 50%. Many operators limit naval stores work to three years per tree because dry face seldom appears in that time. If dry face occurs, prompt harvesting will prevent the spread of decay and stain. Should mild symptoms appear, stopping chipping until wet weather returns will help.

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# VASCULAR WILTS

Among the wilts are several important killers. The mode of action is essentially the same in each case. The organism infects the vascular system and produces toxins. The toxins cause wilting in either of two ways: (1) the toxin is transported in the sap stream to the twigs and leaves where it reduces cell turgidity, or (2) the toxin stimulates the production of tyloses or gums which occlude the vessels so that the sap flow to leaves is reduced. The latter seems to be the more common mode of action. Many wilts cause discolorations in the xylem or cambial region of stems and branches. Some of these are sufficiently characteristic to be of diagnostic value, but in many cases it is necessary to isolate and identify the pathogen for positive diagnosis.

At present, most tree wilts are of concern primarily to arboriculturists. The Dutch elm disease and phloem necrosis (see Viruses) have essentially eliminated the beautiful American elm from some cities in the Northeast, and Mimosa wilt raised havoc with mimosa in the Southeast. The elm diseases and other wilts, however, could also seriously affect the oaks and elms throughout the hardwood forests.

## PERSIMMON WILT

Persimmon wilt, caused by *Cephalosporium diospyri* (Fungi Imperfecti), occurs from North Carolina to Florida and westward to Texas and Oklahoma. It is fast acting and lethal, usually killing the host tree within two years. It has not been found in the bottomlands where persimmon reaches commercial timber size. In range country, where persimmon is a weed, the causal fungus has been used to artificially inoculate trees. No control is known.

## MIMOSA WILT

The causal fungus, *Fusarium oxysporum* f. *perniciosum* (Fungi Imperfecti), may have been introduced from Haiti. From North Carolina, where it was first found in 1930, it has gradually spread westward to the Louisiana border. Once the disease appears in an area, the common mimosa is eliminated (Fig. 24). The fungus spreads through the soil and can enter the host through roots. Resistant selections of mimosa have been found which can be planted with safety in infested soil.

## DOTHIORELLA WILT OF ELM

This wilt, caused by *Dothiorella ulmi* (Fungi Imperfecti), occurs throughout the range of American elm. It is common on American elm and occasionally attacks slippery and Siberian elms. Trees may live for several years after attack. This disease is more like die-back than a true wilt because it spreads slowly in the vascular system.

Sometimes pruning of infected branches for several successive years will eliminate infections. Pruning cuts must be at least a foot below the lowest point of discoloration in the wood.

FIGURE 24. *Mimosa trees infected with vascular wilt. Leaves on infected trees loose turgidity and droop before the tree dies.*

## DUTCH ELM DISEASE

Since the Asiatic elms are resistant, the causal fungus, *Ceratocystis ulmi* (Ascomycetes), probably originated in Asia and was carried to Europe by Chinese laborers during World War I. It first appeared in the United States in 1930 at Cleveland and Cincinnati. The fungus entered the United States on elm burl logs imported from France for the produc-States, the small European elm bark beetle *(Scolytus multistriatus)*, already had been introduced in shipping crates made of green elm and was well established in the Northeast and the Ohio River Valley. The pathogen and its vector now have spread over most of the ranges of the American elm in the United States and Canada.

The relationship between the pathogen and the vector is a beautiful example of coordination. The emerging adult beetles, contaminated with spores, feed in twig crotches of healthy elms, thus creating a wound and inoculating the tree with the pathogen. As the tree is weakened and dies from wilt, the adult beetles deposit their eggs under the bark. The developing larvae and next generation of adults become contaminated to repeat the process.

The native elm bark beetle *(Hylurgopinus rufipes)* also can spread the pathogen. It can also be spread by pruning equipment that is not sterilized after use on an infected tree, and by root grafts from tree to adjacent tree.

Susceptible elms can be protected by (1) sanitation against bark beetles by cutting and burning dead elms or by spraying all dead bark with DDT in oil. The spray will kill broods under the bark. (2) by spraying or misting live trees with DDT to prevent beetle feeding. These controls are effective only with a concerted effort by an entire community, and have aroused opposition because of adverse effects on song birds. Other insecticides are being developed. (3) spread through root grafts can be prevented by killing the roots in a limited zone between trees with a soil fumigant. Both Vapam and methyl bromide are effective.

A resistant selection of the European elm has been found, but it does not have the unique shape of the American elm. Search is continuing for a resistant strain of American elm for the hybrids between this and resistant Asian elms. Hybrids must wait the development of a mutant American elm with a chromosome number compatible with that of the Asian elms.

## OAK WILT

Oak wilt, caused by *Ceratocystis fagacearum* (Ascomycetes), is a puzzling disease. The pathogen is a very rapid and sure killer that lacks an efficient means of dissemination. The fungus is probably a native everywhere it has been found from Texas, Tennessee, and North Carolina northward. In a few areas it has caused extensive mortality, but in most places it kills only occasional trees. So far it has not been found in the highly productive bottomland oak stands along the major southern rivers.

The fungus spreads from tree to tree through root grafts or is carried by insects that visit infected trees and then fresh wounds on uninfected trees. Should an efficient insect vector ever be introduced, untold devastation could result because no native oak is known to be immune and 50 species are known to be susceptible. Red oaks are particularly susceptible and often die within a few weeks.

Several states have control programs consisting of the destruction of all diseased trees found and all healthy oaks within root grafting distance. There is considerable experimental evidence that such practices are not effective; one would expect this to be true of a native pathogen.

Some foreign countries will not accept oak lumber or logs from states known to have oak wilt. Thus many oak-producing states are excluded from the foreign market. The effectiveness of such a quarantine is questionable. For example, oak can be shipped from an Alabama mill located within a few miles of infected oaks in Tennessee. Yet oak lumber from east Texas is excluded even though the oak-producing parts of Texas are at least a hundred miles from the Dallas infections and have non-oak land in between. More recently some countries have made the logical change to exclude oak products produced within a given distance of known infections rather than on a state-wide basis.

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# PLANT RUSTS

Economically, the rusts constitute one of the most important groups of the Basidiomycetes — in fact of all fungi. Black stemrust of wheat and white pine blister rust are well known examples causing enormous damage. Other rusts seriously attack coffee, asparagus, beans, juniper, snapdragon, carnation, and many other crops. Cereal rusts were recogniged by the ancient Romans who believed that the gods were responsible for them. Rust epidemics have caused serious food shortages and famines over the ages.

Although some rusts have recently been grown in articifial culture during part of their life cycle, most pathologists still consider them to be obligate parasites because in nature they are known to develop only on living tissue. They live congenially with their host until ready to sporulate. The mycelium is intercellular and obtains food from the host by means of haustoria extending into the protoplasts.

The typical rust has a complex life cycle of five stages:

| *Stage* | *Spore* | *Nuclear Condition* | *Produced On Host* | *Spore Function* |
|---|---|---|---|---|
| 0 Spermagonial | Spermatium | Haploid | 1 | Sexual reproduction only |
| I Aecial | Aeciospore | Dicaryotic | 1 | Infects host 2 |
| II Uredial | Uredospore | Dicaryotic | 2 | Infects host 2 |
| III Telial | Teliospore | Dicaryotic-Diploid | 2 | Germinates to produce IV |
| IV Sporidial | Sporidium | Haploid | 2 | Infects host I |

Certain rusts apparently have lost some stages. Several races of *Peridermium harknessi* undoubtedly belond in *Cronartium,* but regularly produce only stage I, which reinfects pines instead of an alternate host as with a typical rust. This rust is important in the West on ponderosa, Jeffery, and lodgepole pines, and is the East on Scotch pine. Other races of this or similar rusts produce all five stages and have an alternate host (paintbrush), but since the aeciospores can reinfect pine, they also can exist as stage I only.

Each section of the northern hemisphere has at least one important forest tree rust.

## WHITE PINE BLISTER RUST

White pine blister rust, caused by *Cronartium ribicola,* attacks most of the five-needle pines and has been particularly destructive on eastern white pine and sugar pine. It must be considered in the management of these species. The alternate hosts, the gooseberries and currents of the genus *Ribes*, occur wild almost everywhere white pines are native.

Blister rust was first known as a relatively inocuous Asian rust on Swiss stone pine. When our eastern white pine was introduced and extensively planted in Europe during the 1700's and 1800's, the rust gradually spread over most of Europe as a pest on this species. When Americans started serious forest management in the early 1900's, they had little experience in nursery management. Consequently, they imported the cheaper white pine seedlings from nurseries in Germany and France. These were widely planted in the Northeast and white pine blister rust was introduced on them. The rust quickly spread over the entire range of eastern white pine and by 1921 had appeared in the western pine forests.

Blister rust causes cankers on the branches and stems of trees. Seedlings and small saplings are killed quickly. Death of successive crops of seedlings eventually eliminates white pine from the stand unless control measures are used. Larger trees die more slowly, living for 10 to 20 years. The first symptom is a small golden-yellow leaf spot at the point of infection. As the mycelium spreads into the adjacent twig, the bark becomes yellow to orange as spindle shaped or sunken cankers form. Honey-yellow to brownish spermatial pustules appear on the cankers late in the first summer after infection. Early the following summer white aecial pustules appear; the pustules quickly rupture, discharging masses of orange-yellow aeciospores.

The primary control of blister rust is eradication of the alternate host. Since the sporidia are very delicate and quickly lose viability, the effective distance of sporidial dissemination from native *Ribes* usually is less than 900 feet. Spread from the European black currant, which is extensively planted in this country, can be as much as a mile.. Normally, removal of *Ribes* within 900 feet of white pine stands gives adequate protection, provided no European black currants are grown within a mile. At first, hand pulling and grubbing were the principle methods of eradication, but now 2,4-D and 2,4,5-T are used, applied in oil mainly to the bases of *Ribes* stems, or in water to the foliage where the plant is abundant.

In the West, antibiotics (Actidione and Phytoactin) have been used to treat infected pines. At first, they were applied as basal sprays in oil, but later as aerial foliar sprays. The effectiveness of the antibiotics for rust control is controversial. There is good evidence that they are ineffective on eastern white pine for blister rust control and on southern pines for fusiform rust control. Applied directly to cankers or galls, antibiotics certainly can inhibit sporulation for some time, but it has not been proven that the fungus is killed. Translocation of the antibiotic from the point of application appears to be very limited.

## FUSIFORM RUST

In 1930, fusiform rust, *Cronartium fusiforme,* was a minor problem in southern forests, but since then it has become the most destructive disease of slash and loblolly pines. Climatic conditions favoring rust infections and plentiful alternate hosts (oaks) are common in the natural range of longleaf pine which is fairly resistant to this rust. Because longleaf is susceptible to brown spot and its early height growth is delayed, slash and loblolly pines have been encouraged on longleaf sites. Since these are highly susceptible to fusiform rust, the change in pine species merely exchanges one problem for another. It is likely, too, that fire control has increased the abundance of the alternate host (oaks) in southern pine forests.

Fusiform rust occurs in the Southeast from Maryland to Tennessee, Arkansas, and Texas. The most severe attacks have been in the southern halves of Georgia, Alabama, Mississippi, and Louisiana. In 1940, the severe damage area terminated at the Mississippi River, but now it extends into the eastern tier of Texas counties. So far, however, fusiform rust is not severe in most of the Texas pine area.

Natural infections have been found on 12 pines: loblolly, longleaf, pitch, red, slash (typical and South Florida), Torrey, and four exotic pines (Caribbean, Cooper, Austrian, and Nicaraguan). Inoculations have shown that 13 other pines are susceptible, including Coulter, Jeffrey, lodgepole, Monterey, and ponderosa.

The important hosts are slash and loblolly pines. Longleaf pine has a practical degree of resistance. A few infections have been reported on shortleaf pine, but this species is essentially immune. One wonders if the few fusiform galls reported on shortleaf pine actually were not on natural shortleaf-loblolly hybrids.

Stages II and III have been found as natural infections on 14 oak species. Artificial inoculations show that many other oaks are susceptible, and also tanoak and several chestnuts and chinquapins.

FIGURE 25. *Telia of fusiform rust appear as hair-like structures on the under sides of young oak leaves. Telia illustrated are exceptionally long and were produced in a greenhouse.* Photo by U. S. Forest Service

A heteroecious, long cycle rust, *Cronartium fusiforme* requires two hosts and produces all five stages:

Spermatia are produced on pine in the fall.
Aeciospores are produced on pine from February through April.
Uredospores are produced on oak from February through May.
Telispores and sporidia form on oak from February to mid-June.

**Description of Damage**

On oak, fusiform rust usually causes only an inconspicuous leaf spot, but occasionally heavy infection leads to defoliation. The uredia appear as bright orange pustules and the telia as brownish hairs on the undersides of leaves or occasionally on succulent stem tissue (Fig. 25).

Pine infections occur on new needles or succulent stems. Penetration can be either through stomata or directly through the young epidermis. In the latter case, the fungus germ tube produces an **appressorium** which becomes attached to the plant surface so that growth pressure forces a chitinous peg through the leaf cuticle and epidermis. Purplish spots develop at the point of entry. Six to 12 months later, a spindle-shaped gall develops on the stem or branch adjacent to the infected

FIGURE 26. *Aecial fruiting, usually a bright orange, of fusiform rust on a gall on loblolly pine.*
Photo by U. S. Forest Service

FIGURE 27. *This slash pine, with fusiform rust, has multiple stems that will not yield usable products even if the tree survives.*

needle (Fig. 26). Galls elongate 75-125 mm per annum and may persist for many years. Parts of old galls may die or be killed by insects or by other fungi, resulting in sunken cankers. Such cankers are most common on slash pine and some have the pitch canker fungus in them. Infections on seedlings and small pines usually lead to death in a few years or to multiple branching and bushy growth (Fig. 27). Stem infections on older trees lead to weak, distorted boles that are easily windbroken (Fig. 28).

In high hazard areas, it is not uncommon to find slash and loblolly plantings below pulpwood size with 30% mortality and with 60 to 80% of the survivors infected. The most damaging infections are those sufficiently close to the stem to cause stem infections before natural pruning kills the branch. In some areas, cutting practices may be determined largely by the need for removal of badly rusted trees.

FIGURE 28. *Slash pines broken by wind where fusiform-rust cankers had weakned their stems.* Photo by U. S. Forest Service

Seedlings infected in the nursery seldom survive outplanting. Seedlings from four nurseries plant in south Mississippi showed the following survivals:

| *Condition at Nursery* | *Survival After Planting* | |
|---|---|---|
| | *10 Months* | *19 Months* |
| Non-infected | 78% | 76% |
| Infected | 29% | 16% |

**Conditions Necessary for Infection**

All spore forms will germinate at temperatures between 58° and 82°F, with an optimum around 68 to 72°F. Because spring temperatures usually range from 58 to 77°F, they seldom limit rust infection of either pine or oak.

Adequate moisture is the critical factor determining the amount of infection from a given amount of inoculum. A saturated atmosphere, due to either rain or fog, is necessary. In a saturated atmosphere telia germinate abundantly in 9 hours and sporidia germinate in an additional 6 hours. Thus, for heavy infection of pine, a saturated atmosphere for at least 18 hours is needed.

Since only new, succulent pine tissue is subject to infection the rust spores produced before pine buds open are harmless. Any factor which hastens opening of pine buds, however, will increase the danger of rust infection. Pine stands burned over during the winter, and those cultivated or fertilized, start growth earlier and thus are more subject to infection.

As many as 6 to 8 years may pass without serious infection in a given locality. This leads to carelessness in applying controls, and when a heavy infection year comes, the need for control is frequently ignored until it is too late.

**Control**

In **nurseries** and young **seed orchards,** fungicidal sprays (ferbam) are used. The same schedules are used for both (see Nursery Diseases).

In Georgia, it has been found possible to spray only to precede periods when 18 hours of wet weather are predicted. In Louisiana and Mississippi, there are many nights when fog persists for 8 to 12 hours. Even though these fogs seldom last for the 18 hours needed for maximum infection, they permit limited infection. Since there are many of these limited infection periods in a season, the total amount of infection may be high. Therefore, spraying at 3-day intervals is safer.

**Longleaf** and **shortleaf pines** should be encouraged on high-hazard sites. Where this is not feasible, loblolly is safer than slash because loblolly, although just as susceptible to infection as slash, survives somewhat better when infected.

**Closer planting** will encourage natural pruning of infected branches and lessen the chances of stem infections. Also closer planting permits more mortality without understocking.

In **high-hazard areas,** young pine stands should not be cultivated or fertilized.

**Periodic pruning** of branches with infections less than 15 inches from the stem will lessen the number of damaging stem infections. Pruning, of course, is useless on trees with stem infections except where the infection is on the terminal which can be cut off. Pruning should be done during the winter following a high-infection year. In pine, the rust mycelium extends only a half inch beyond visible swelling. Thus pruning may prevent stem infections even when the branch gall is quite close to the stem.

**Genetic resistance** will eventually play a major role in control. Some individual slash pines show some resistance, but the most promising strains are hybrids of shortleaf with slash or loblolly. With cereals, new rust-resistant plants must be developed constantly, because the cereal rusts are comprised of physiologic forms and eventually some form capable of attacking a resistant cereal builds up or is created by mutation, etc. So far, there is no evidence that this will happen with fusiform rust, but should it occur, the counter measures will be more difficult than with an annual farm crop, because of the long lifespan of pine trees.

**Local seed** is better than seed grown at a distance from the planting site. With loblolly pine, when local seed is not available, seed from west of the planting site is less rust-susceptible than that from the east.

## SOUTHERN CONE RUST

Twenty years ago, cone rust *(Cronartium storbilinum)* was only an oddity unknown to most foresters. Today it is an important disease in the Southeast. It became important because several expensive seed orchards were located in the rather restricted cone rust belt. Cone rust is important only in the range of the principle alternate host, live oak. This occurs in a narrow belt along the southern Atlantic and Gulf Coasts and across south Georgia and north Florida. In Texas, where the live oak belt widens, the pine hosts are not common.

Longleaf and slash are the only susceptible pines. The main alternate hosts are the evergreen oaks (life oaks, runner oak, and water oak where it retains its leaves over winter). The rust also attacks a number of other oaks but, being deciduous, these are inocuous because the fungus must overwinter on living oak leaves.

On oak, the symptoms and signs are the same as those of fusilform rust except for time of sporulation and inconspicuous

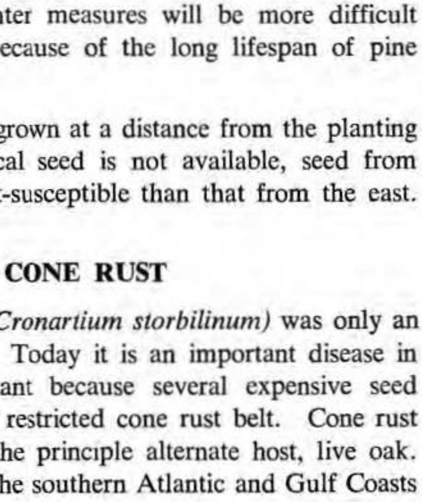

FIGURE 29. *Southern cone rust on slash pine, showing first-year cones: the enlarged one is rusted, the small one normal.* Photo by U. S. Forest Service

color differences. On pine, infected first-year conelets increase rapidly in size and by late spring are as large as normal second-year cones (Fig. 29). Yellow aeciospores are produced in late spring and the infected cones drop by late summer.

Telia, produced in late fall and winter, overwinter on oak leaves. Teliospores germinate at the same time pines are pollinated and the resulting sporidia infect the receptive strobili. Aeciospores infect young oak leaves. Uredospores produced on the oak leaves reinfect other oaks.

### Control

**Bagging female pine flowers** during the time they are receptive to pollen is used for controlled pollination in genetics work. This also effectively prevents rust infection.

**Locating seed orchards** and seed production areas outside the live-oak belt is the logical control. A 20-mile live-oak-free zone probably is adequate.

**Spraying with ferbam** is used in orchards already established in the high-hazard zone. This is cheaper than abandoning and relocating orchards. The first spray is applied when the strobili are just emerging from the bud scales, and continued at 5-day intervals until the conelet stage is reached, i.e. until all pollination has ceased. Usually five to six sprays are needed.

Only ferbam is recommended, because the spray, being applied during pollination, must be toxic to the rust spores but inocuous to pollen. Ferbam actually increases the percentage of pollen germination.

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# DECAY IN STANDING TREES

Most decay in living trees is heart rot because living sapwood has too high a moisture content for decay fungi to develop. Of course, at wounds or dead parts the sapwood dries sufficiently to decay.

Considering all factors (influding fire, insects, and diseases), heart rot is by far the most important cause of loss in the forest. Heart rots are particularly important because they destroy merchantable wood already accrued instead of delaying regeneration or reducing growth as many diseases do. It is estimated that heart rots in the South cause an annual loss of 5,500 million board feet and, in addition, reduce the quality of an additional volume. Foresters, therefore, must become acquainted with heart rots, the factors leading to their occurrence, and how loss from them can be minimized.

The fungi causing heart rots are mainly Basidiomycetes such as *Poria, Polyporus, Fomes,* and *Hydnum*. Some Ascomycetes also cause decay but usually at a slower rate. Decayers are known mostly by their fruiting bodies or the type of decay they cause. The destructive part, however, is their vegetative structure—the microscopic hyphae within the bole which secrete **enzymes** that dissolve the wood constituents. Every tree species, even those with so-called "decay resistant" heartwood, is attacked by at least one species of heart-rotting fungus.

Not all decayers are harmful. Without decay to remove dead branches there could be no continuous lengths of clear wood. Fungi which decay down and dead timber and logging slash are highly useful because they reduce fire hazard and, at the same time, break down the complex lignified wood and return the materials in it to the soil as simpler compounds reusable by higher plants. Decomposed plant material, particularly lignin, importantly improves the tilth of the soil.

Basidiomycete decay, both heart and sap rots, can be divided into brown rot or white rot. The brown-rot fungi cause a friable, brownish rot which on drying shrinks excessively and tends to check across the grain. These fungi live primarily on the cellulose constituents, removing little lignin. In contrast, the white rotters remove both celluloses and lignins, resulting in a lighter-colored rot with less tendency to shrink or check. Decays also are classified by the part of the tree attacked (as butt and top rots) or by some characteristic of the decayed wood (as pocket, stringy, mottled, and cubical rots).

Losses from heartrot can be minimized by:

**Short rotations;** harvesting trees before there is much heartwood to decay.

**Prevention of wounding** by controlling wildfires and by careful logging practices.

**Harvesting wounded trees** before the rate of decay exceeds growth. Recognizing **"pathological rotations", i.e.,** the age at which decay exceeds growth, in managing stands for large sawtimber. This is necessary because heart-rotters eventually enter most old trees, even when unwounded, and, in time, render them culls.

Selecting **optimum sites** for growing large saw-log trees.

## HEART ROT OF CONIFERS

### Annosus Butt Rot

The root-rot fungus, *Fomes annosus,* in Europe causes butt rot and rarely kills conifers older than 20 years on acid soils and 35 years on alkaline soils. In western United States, *F. annosus* causes the most important heart rot of overmature hemlock, usually of the butt log, but it has been found as high as 40 feet. Foresters hope older southern pines will survive *F. annosus* attack. Latest information suggests that infection areas do not increase in size after the stands are about 35 years old; but southern pines butt-rotted by *F. annosus* without mortality are rare.

### Red-brown Butt Rot

*Polyporus schweinitzii* causes red-brown butt rott in southern pines and other conifers elsewhere. Occasionally this velvet-top fungus attacks

A

B

FIGURE 30. *Red-brown butt rot caused by* Polyporus schweinitzii. A. *Fruiting bodies at the base of a Douglas fir.* B. *Rot at the end of the butt log.*
Photos by U. S. Forest Service

and kills small trees by rotting their roots, but it is most destructive as a butt rotter (Fig. 30). Rot usually is limited to the lower 2 to 8 feet of the butt log but in Douglas-fir it can reach heights of at least 90 feet. Frequently the only indication of rot before the tree is felled is the presence of fruiting bodies on the ground near the base of the tree. These bodies have central stipes like most mushrooms, are light brown, and hirsute or velvety on top.

The fungus can enter through basal wounds such as fire scars. When found on unwounded trees, it is assumed to have entered through a root.

**Red Heart**

Red heart or red ring rot, caused by *Fomes pini,* like other heart rots, is of declining importance in southern pine because of the increasing proportions of second-growth pine too young to contain much heartwood. It must be considered, however, in managing stands for sawtimber or veneer bolts since heartwood is often formed in trees of these sizes. Dead branch stubs become infected, and any factor which increases the amount of heartwood in smaller trees will lead to red heart. Pines on very poor sites tend to develop heartwood early, so that red heart can be an important source of cull in trees 6 to 10 inches in diameter.

The incipient decay is pinkish; advanced decay is a white pocket rot. Indicators of red heart are the perennial fruiting bodies at branch stubs and swollen knots, although the latter are less common in southern pine than in some western species. The fruiting bodies are moderately thin shelves when young but become hoof-shaped with succeeding annual layers of growth (Fig. 31). The tops are rough, zonate, and nearly black; the under-pore-surface and recent marginal growth are light to dark brown. Any fruiting bodies at branch stubs in southern pine usually are *F. pini.*

FIGURE 31. *The red-heart fungus,* Fomes pini, *fruiting at a branch scar on loblolly pine. This old conk indicates there is extensive heart rot present.*

Photo by U. S. Forest Service

Several practices will reduce losses from red heart. Infected trees can be salvaged; the longer they remain standing, the greater will be the proportion of heart rot. On poor sites, which favor early heartwood formation, short rotations for pulpwood, posts, etc., will reduce loss.

## ROTS OF HARDWOODS

Heart rot is extremely important in hardwoods due in part to the past practice of high-grading stands, **i.e.,** removing the sounder trees and leaving culls. Also, the high incidence of wildfires in the past created many wounds through which fungi could enter. Sap rot fungi usually precede heart rotters at wounds, but do not progress beyond the exposed dead sapwood.

There are three general types of heart rot in hardwood stands.

**Butt rot** mainly associated with fire wounds is a common source of cull (Fig. 32). Another type of butt rot occurs in sprout stands, by the rot fungus entering through the parent stump or through the stub of a harvested, fused companion sprout.


FIGURE 32. *Heart rot in a bottom-land oak associated with a fire wound.* A. *Fire-wounded tree.* B. *Extent of rot revealed by dissecting the tree.*

Photos by U. S. Forest Service

**Top rots** enter through dead branch stubs or stag-headed tops such as those due to die-back during drouths. Top rot is assuming more importance with the current tendency to salvage topwood for pulpwood and other uses.

**Canker rots** also enter through dead branch stubs in the lower and central bole, **i.e.,** the sawlog area. These not only cause heart rot but also kill the cambium, resulting in cankers (see section on cankers). The important canker rots are caused by *Polyporus hispidus, Poria spiculosa,* and *Irpex mollis*. Since these are among the fastest acting rots, infected trees should be salvaged promptly; otherwise they will soon become culls.

**Controlling butt rot associated with fire wounds.**

Control consists mainly of preventing fires and harvesting wounded trees before rot becomes excessive. Hard and fast rules cannot be given because the rate of deterioration varies with the rot fungus present, tree species, and the size of the wound. Rot tends to progress faster behind larger wounds. The indicators for the presence of rot are: open fire wounds, irregular bark indicating healed wounds, butt swell, and the presence of fruiting bodies of decay fungi.

In estimating the average rate at which rot can be expected to spread behind recent fire wounds the following can be used:

During the first 10 years

| | |
|---|---|
| Hickory and overcup oak: | Very little |
| Ash and red oak: | Same rate as later |
| Sweetgum and elm: | Twice later rate |

Rate per decade after first 10 years

| | |
|---|---|
| Overcup oak and sugarberry: | 2.0 ft. |
| Red oaks and green ash: | 1.3 ft. |
| Hickory: | 1.6 ft. |
| Sweetgum and elm: | 0.9 ft. |

The amount of rot behind old fire scars can be estimated from the height of hollow, height of butt swell, or rot diameter at the stump. The merchantable height is then reduced by the length of the rot column and D.b.h. reduced 1 inch for every 6 feet of rot, Also D.b.h must be corrected for any butt swell present. Details for making these estimations in southern bottomland hardwood stands are given in "Decay after fire injury" listed under "References" at the end of this section.

The above information can be used in routine timber marking as a guide in deciding what trees to leave. It should be remembered, however, that the most valuable part of the tree will rot, breakage may destroy the entire tree, and stain and insect damage, often associated with wounds, can increase the amount of degrade. For heavily fire-wounded stands complete harvesting, before decay becomes serious, and regeneration of a new stand should be considered. Cull trees should be felled or killed to make room for replacement trees.

**Lessening decay in sprout stands**

This type of decay enters through the parent stump or through the stub of a harvested, fused companion sprout.

In young stands the amount of decay can be minimized by (1) favoring seedlings or seedling sprouts as crop trees, (2) favoring sprouts from small stumps and those originating near or below the ground line, and (3) when thinning fused sprouts, cutting as nearly flush as possible without injuring the favored sprout.

In older stands (over about 20 years of age) single sprouts should be favored over fused sprouts. It is wise to discriminate against sprouts with unhealed stumps or with enlarged butts. Clumps of large sprouts that are fused for some distance above ground and have V crotches should be entirely cut or left unthinned. There is evidence that when a fused sprout of commercial size sweetgum is cut, little serious decay in the remaining sprout is likely within 10 years. Decay is present, however, and will develop rapidly thereafter.

**Scaling logs with branch stubs**

General rules have been devised for estimating loss of wood in top logs with rot (see references). The average length of the rot column in southern bottomland hardwoods is as follows:

| *Special and Scar Age* | *Length of Rot Column in Feet* | | |
|---|---|---|---|
| | *Branch Diameter* 1-3" | *Branch Diameter* 4-6" | *Branch Diameter* 7-10" |
| Oaks | | | |
| Scars less than 15 years old | 0.1 | 0.4 | 2.5 |
| Scars 15-30 years old | 0.2 | 1.0 | 4.7 |
| Diffuse-porous hardwoods | | | |
| Scars less than 15 years old | 0.2 | 0.9 | 3.6 |
| Scars 15-30 years old | 0.2 | 0.9 | 5.0 |

The following rules of thumb are sufficiently accurate for most purposes.

(1) Disregard scars less than six inches in diameter.

(2) For larger scars less than 15 years old, deduct ½ of the board foot volume for the part of the log with rot.

(3) For larger scars 15 to 30 years old, deduct all of the board foot volume for the part of the log with rot.

Probably the amount of rot associated with branch stubs could be lessened by maintaining dense stands to promote early natural pruning, favoring tree species best suited to each site so that fewer of the large final top branches would die during periods of adverse weather, and by breeding trees with small branches.

**Damage from Increment Borings**

Increment borer holes callus over rapidly, but in hardwoods this does not prevent the development of dark stains, or even decay, in the surrounding wood. If the borings are at breast height, the discolorations extend well up in the butt log and average 3 to 13 inches in length within two years. Some discoloration undoubtedly is physiological in origin, but stain and decay fungi have been isolated from an appreciable proportion of borings sampled. Even without decay, the stain associated with borings is a defect in factory or veneer logs. The number of borings, therefore, should be kept at a minimum, particularly in valuable hardwood trees.

## DETERIORATION OF LOGGING SLASH

This is important because it affects fire hazard and salvage possibilities. In the South the latter is more important, but elsewhere the reverse usually is true. In regions where slash decays slowly, special measures are required to reduce the fire hazard. Rapid decay in the South makes this unnecessary and slash is left where it falls. Generally, the rate of deterioration appears to be the same for southern pine and hardwood slash, except for cottonwood, which deteriorates more rapidly.

As slash deteriorates, fire hazard is reduced. Fall-cut slash retains a high fire hazard until spring and then decays to a low hazard only slightly sooner than spring-cut slash. Cottonwood slash reaches a medium fire hazard in two years and a low hazard in three years. Other species reach a medium hazard in four years and a low hazard in six years.

Salvage value of logging slash as pulpwood and dimension bolts rapidly declines with age. Usually in the South, fall cut sapwood is usable up to six months, while spring cut is cull after two months. Heartwood is usable for about two months longer than sapwood. Even for the lowest quality products, topwood is essentially valueless after one year.

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# FUNGI AND BACTERIA ATTACKING WOOD DURING SEASONING AND USE

The deteriorating agents of most importance to the life of wood are biological: insects, marine borers, and fungi. Accurate figures are not available, but there is little doubt that fungi cause more loss than any other agent. Fungi must be considered in all air-seasoning operations. They also have an important bearing on the uses for which wood is suitable, its protection in use, and its preservative treatment.

Because fungi are plants, their growth requires water, air, food, and suitable temperature. They lack chlorophyll needed to combine minerals, air, and water into complex organic substances; they live on foods already elaborated by other organisms. Fungi can produce fabulous numbers of spores. One large conk of a wood destroyer may produce billions of spores per day and may continue to do so for weeks. Wood exposed under favorable conditions almost always becomes infected.

Climate importantly affects the degree of fungus attack on wood. Long periods of warm, moist weather favor attack. To express such effect, Dt. T. C. Scheffer, at U. S. Forest Products Laboratory, Madison, Wis., devised a "climate index" based on the formula:

$$\text{Climate index} = \sum \frac{(T - 35)\,(d - 3)}{30}$$

where T = means monthly temperature, degrees F.

d = number of days during the month with precipitation amounting to 0.01 inch or more.

$\sum$ signifies summation of values for each month, Jan. through Dec.

Figure 33 shows zones of equivalent climate index within the United States. Areas most favorable to fungus attack have indexes greater than 65; least favorable areas have indexes less than 35. In using this information, one must remember that sharp local differences in elevation can create differences in climate index that do not appear on the map.

The "working" parts of fungi are their microscopic hyphae which secrete enzymes that dissolve wood substances or materials stored in wood. The resulting soluble materials are absorbed as food by the hyphae. The five groups of wood-destroying micro-organisms differ in the parts of the wood dissolved, and their effect on the wood.

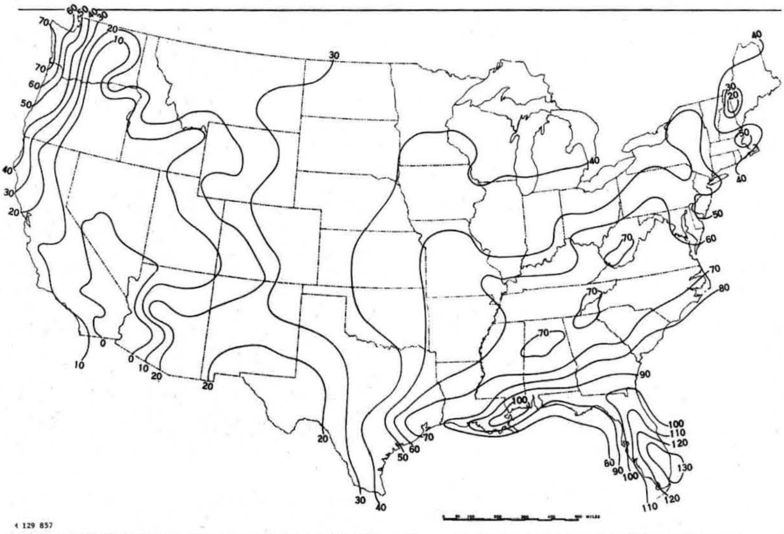

FIGURE 33. *Decay indexes in the United States, based on average monthly temperatures and number of rainy days. High-hazard areas have indexes over 65; low-hazard areas indexes less than 35.* Photo by U. S. Forest Service

## MOLDS

Molds are fungi which live mainly on materials stored in sapwood; heartwood seldom molds appreciably. Hyphae are colorless and, therefore, do not discolor wood deeply, but they do discolor the surface by producing masses of colored spores. The common molds are green, black, or white. An interesting orange mold commonly develops on wood which has been steamed. When green veneer is bulk piled, dense masses of hyphae and spores develop in a few days, almost completely covering a pile. Veneer to be air dried usually is dipped in a fungicide to prevent development of this mold and other fungi.

Except for slight reductions in toughness, molds have little effect on the strength of wood, but they may greatly increase its permeability. This results from destruction of ray cells, from which carbohydrates and other stored materials are extracted (Fig. 34). The greatest effect is in pine; it is less uniform in Douglas-fir and the sapwood of sweetgum. The most severe molding usually occurs before the original seasoning, but rewetted wood also will mold.

The increased permeability of molded wood can facilitate preservative treatment or chemical pulping, but may make it unsuitable for use where subject to wetting. It can, if the wood is fully dried, aid preservative treatment. Very likely the cold-soak treatment of pine fence posts is effective only because during air seasoning, posts almost always develop stain and mold. If seasoned in the open, molded posts, poles, etc., can rewet severely with each rain. Thus, in wet weather molded pieces may contain more moisture than bright material and may require different treating schedules with most treating methods. Infected and uninfected wood in the same charge may account for some of the variability found with pressure treatment. Therefore, to benefit from increased porosity induced by molds, wood should be seasoned under cover.

If used for such purposes as siding, where it is subject to periodic wetting, molded wood can wet more frequently and more severely, resulting in more decay and paint failure than with uninfected wood.

Wood with high permeability pulps more easily than sound wood, but at present, industry does not take advantage of this.

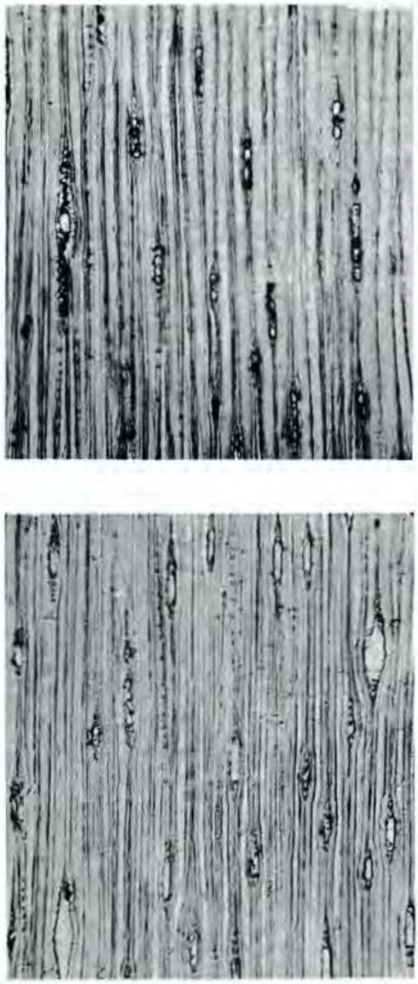

FIGURE 34. *Molds increase wood porosity.* Upper: *Tangential section of normal Douglas-fir wood.* Lower: *Similar section after attack by a mold which has destroyed cells in wood rays, leaving unobstructed channels for passage of liquids into the wood.*

Photo by U. S. Forest Service

## STAIN FUNGI

Stain fungi are similar to molds in their method of action on wood (Fig. 35A). Unlike molds, however, they have dark hyphae which discolor wood deeply so that stain cannot be planed off. Some minor stain is caused by pigments produced by hyphae rather than by colored hyphae directly. Stains may be of almost any color: blue, brown, yellow, red, green, or orange. Blue and brown stains are most common.

Stain develops most rapidly during spring, summer, and fall, but in the South also occurs in the winter. Stain fungi develop most luxuriantly in wood containing its original sap and, therefore, develop mostly in stored logs and in wood products during air seasoning. They will, however, develop somewhat in rewetted wood.

Stains spoil the appearance of wood for uses where natural finishes are desired. They also increase absorbency, but usually less markedly than do molds. Heavily stained wood almost always has incipient decay infections which may not be killed by air seasoning but merely become dormant. They revive if the wood is rewetted. For this reason, only bright kiln-dried lumber should be used for exterior woodwork of buildings.



FIGURE 35. *Fungal hyphae.*

A. *Hyphae of a stain fungus aggregated in a wood ray, where they live on carbohydrates and other materials stored in parenchyma cells.*

B. *Hyphae of a wood-rotting fungus in pine tracheids. They attack cell walls primarily from the lumens.*

C. *Cross section of pine latewood, showing bore holes made by soft-rot fungus hyphae in secondary cell walls.*

D. *In longitudinal section, spiral striations mark paths of soft-rot hyphae following the angle of microfibrils within the cell wall.*

Photos by U. S. Forest Service

## DECAY FUNGI

Decay fungi usually start grwth by utilizing reserve materials stored in wood parenchyma, just as molds and stainers do, but they eventually attack the cell walls and destroy the wood (Fig. 35B). Some decay fungi remove mainly cellulosic materials, causing brown rot; others remove both lignin and cellulose, causing white rot (Fig. 36). Many are intermediate between these two extremes. Significant weakening occurs before decay is obvious.

Incipient decay in lumber can be detected by:

(1) The pick test. An ice pick or knife point is jabbed into the wood and pried down. Sound wood pries out in long splinters; decayed wood, being brash, breaks out in short chips.

(2) Bleaching. This is particularly obvious in stained areas.

(3) Loss of natural sheen on planed surfaces.

(4) Mycelial fans or strands on the surface of boards.

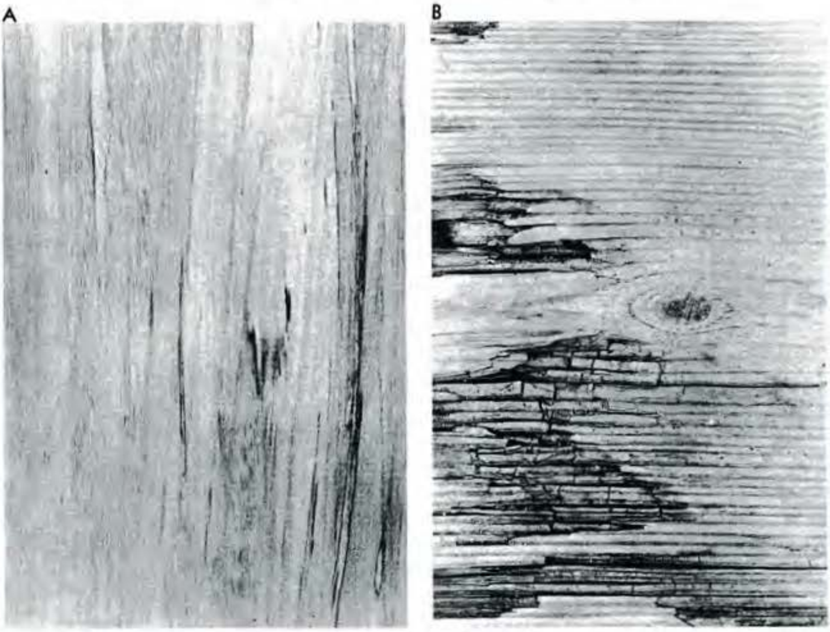


FIGURE 36. *Types of wood rot. A. White rot fungi remove both cellulose and lignin leaving a light-colored mottled decay which does not shrink much on drying. Black zone lines often are present. B. Brown rot fungi remove mainly cellulose, leaving a brown, amorphous rot which shrinks excessively and checks across the grain.* Photos by U. S. Forest Service

Most of the general construction woods are susceptible to decay. The heartwood of a few species, such as redwood, baldcypress and the cedars, contains natural preservatives and is decay resistant. The sapwood of all species will decay. Sapwood, as it comes from the living tree, usually is too wet to decay because it contains too little oxygen; it must dry some to establish a suitable water-oxygen ratio. For most decayers, moisture contents of 40 to 60% of the dry weight of the wood are optimum for growth. Below fiber saturation (about 30% of dry weight) wood is safe from decay because it lacks available water.

In the Gulf States, temperatures are suitable for decay during most of the year. Temperatures reached in standard kiln-drying and pressure-treating schedules sterilize wood. Dip and cold-soak treatments kill only where the preservative reaches the fungus; internal decay is common in dip-treated wood exposed to severe rain seepage.

Decay fungi vary in their resistance to toxicants. At least one species shows an important degree of resistance to each of the common fungicides used on wood. Fortunately, a fungus resistant to one type of toxicant usually is susceptible to other types. Resistances normally do not lead to widespread failure of treated wood, but variations in tolerance of different fungi to different chemicals explains why mixtures of toxicant must be at concentration that will prevent growth of the most resistant fungi.

## SOFT-ROT FUNGI

In recent years we have become aware of a special type of rot caused by fungi related to the molds and stainers rather than by regular decayers. These are soft-rotters, which can tolerate both wetter and dryer conditions than the usual decay fungi. Soft-rot fungi grow within the secondary walls of the wood cells; ordinary decay fungi grow almost exclusively in cell cavities (Fig. 35C). Soft-rot develops rather slowly, first softening the wood surface, and gradually working into the interior. Usually, there is a sharp demarcation between decayed and sound wood and the surface has profuse fine cracking across the grain similar to weather-beaten driftwood.

Soft-rots attack many of the so-called decay resistant woods and have been found in wood treated with creosote, tanalith, pentachlorophenol, ZMA, and other preservatives. Soft-rot is most common in cooling tower slats but also has been found in utility poles, railroad cars, ammunition boxes, and other wood products stored or used under wet conditions. As far as is known, soft-rot is not causing early failure of large numbers of poles or other pressure-treated wood, but it may be more important than has been realized. One might speculate that without soft-rot the normal service life of treated wood exposed under wet conditions might be appreciably greater.

## BACTERIA

Earlier, it was pointed out that bacteria cause wetwood in living trees and that in the case of aspen, wetwood tends to collapse during seasoning. Bacteria also commonly infect logs during storage in ponds or under water sprays. The effect is much like that of molds — the permeability is increased without appreciable loss in strength.

Recent investigations show that some anaerobic bacteria slowly reduce the strength of wood. Pilings removed from bridges or buildings on wet soil, after many years of service, have been greatly weakened. Because no fungi are present, it is logically assumed that the bacteria present have caused the weakening.

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# FUNGUS ATTACK ON UNSEASONED WOOD

While the normal moisture content of sapwood in living trees is too high for the growth of most fungi, cutting the tree starts a drying process which eventually admits enough oxygen into the wood for fungus development. The remaining moisture in the wood then becomes the chief source of the water needed by fungi for continued growth.

Until moisture in the wood dries to a level at which fungi cannot grow, harvested wood is subject to damage by stain, mold, and decay. Since logs and other round wood dry slowly, they are vulnerable over longer periods than such smaller material as standard lumber. Protection of green wood from mold, stain, and decay is a vital step in the manufacture of all wood products.

## DETERIORATION OF ROUND GREEN PRODUCTS

Logs, pulpwood, and other green products are subject to attack by molds, stain, and decay fungi until they are utilized or until they have dried below fiber saturation. There are three basic controls:

(1) Quick utilization, before damage can occur.

(2) Fungicidal treatment to prevent fungus infection.

(3) Special handling methods to maintain moisture contents too high or rapidly reduce it too low for fungus attack.

Since fungus spores are usually abundant in the air, cut surfaces are promptly infected. Fungi also are carried by insects; especially important are bark beetles and wood-borers, which carry fungi beneath the bark. Control of such insects is necessary to effectively prevent fungus attack on unpeeled round green producs.

### Sawlogs

Quick utilization is the most effective means of preventing degrade from stain and decay. Most small mills did this, but the wage and hour law has essentially eliminated the small mill which did not utilize labor efficiently. Large mills must store logs, frequently for several months during the winter, as insurance against shutdowns.

How long logs can be safely dry stored depends on the wood species, season, and geographic area. During the summer in the South, logs stored more than two weeks begin to deteriorate rapidly, mainly by fungi carried by bark-penetrating insects. During the cooler winter months, storage for longer periods frequently is safe. Even though methods have been developed for storing logs with little deterioration, the most successful mills rotate their log supply to minimize storage time.

In the early days almost all logs were pond stored. Currently, logs are mostly second growth with sufficiently high specific gravity that they sink, making recovery from ponds costly. Consequently, by 1935 most mill ponds in the South had been abandoned. Even though ponding kept logs bright, it permitted penetration of bacteria and some moldlike fungi which increased porosity resulting in a deleterious effect on lumber for some uses. Floaters raised another problem because the exposed portions lost enough moisture to be attacked by insects and fungi. Attempts to roll floaters periodically to maintain high moisture contents in all parts of the logs failed, because the soaked wood in the formerly submerged portion was heavier and caused the logs to assume their former position. This can be prevented by nailing planks across the tops of groups of logs after rolling them.

Recently, mills have begun to use continuous water sprays to protect logs by maintaining a moisture content too high for the usual stain and decay to develop. Water sprays, of course, are not new; in 1920 the fire underwriters recommended water sprays in the North as a fire preventive measure. The following year the decay control value of sprays was recognized.

Under a continuous water spray, the bark and ends of logs become slimy with the growth of microorganisms but the interiors remain bright. However, colorless fungi and bacteria do penetrate both pine and hardwood logs. The resulting increased porosity makes lumber cut from sprayed logs unsuited for such uses as exterior woodwork where rain seepage is important. So far, it has not been determined how long a period of water spraying is possible before serious increases in porosity occur.

Residual sprays afford another means of protection. A single spraying of logs with a solution consisting of 2.5% pentachlorophenol plus 0.5% gamma benzene hexachloride in No. 2 fuel oil, will prevent attack by fungi and insects for several months. A water emulsion can be prepared by using sodium pentachlorophenate and an emulsifiable form of BHC. For best results, from May through October, the logs must be thoroughly sprayed (to runoff) on the ends and all sides the day the trees are felled. During other months a day or two delay usually is not serious.

Incipient infections of stain, mold, and decay fungi are now less serious than in the past because most pine lumber is kiln-dried green from the saw. This kills any incipient infections present in the logs. But when lumber cut from logs with incipient infections is air dried, stain, mold, and decay may develop to degrading proportions. Log infections are most important in hardwoods. Hardwood lumber usually is partially air dried before kiln drying. Thus, hardwood lumber cut from infected logs may be seriously stained before it is kiln dried.

**Posts, poles, and piling**

These and other large items to be preservatively treated are peeled before seasoning. If stored long enough to become fully air-dried before treatment, heavy stain frequently develops, and in large items, serious decay also. The pressure-treating industry often avoids this by only partially air seasoning and using treating schedules that complete the drying in the treating cylinder. Or poles are dried in kilns or wind tunnels to avoid air seasoning altogether.

In the South, a fungicidal spray commonly is applied as the poles come through the lathe before air seasoning. Unfortunately, the usual stain-control chemicals afford only surface protection, and do not prevent interior stain and decay. Recently, the Forest Products Laboratory found that southern-pine poles soaked for 15 minutes in 30% ammonium bifluoride remain free of stain and decay for at least a year in air-seasoning yards. At one time a few treating companies gave their green poles a light pressure treatment after steaming or partial seasoning. Then, after complete air seasoning, the regular pressure treatment was applied. This double treatment appreciably increases cost but insures a good final product.

Successful cold-soaking treatment of southern-pine fence posts probably depends on increased permeability resulting from mild fungus infections. When fresh peeled posts are fungicidally treated and rapidly air dried, poor penetration by cold soaking is likely. With usual air seasoning, sufficient mold and stain develops to improve penetrability. But it must be remembered that infected posts can absorb sufficient rain water to interfere with preservative treatment; posts must be dry before being treated by soaking. Therefore, seasoning under cover is safest.

Dipping in low concentrations (5% to 10%) of fluorides to stimulate mold development seems particularly suitable for posts to be cold soaked, because it increases permeability but prevents decay during normal seasoning periods. This will be discussed further under pulpwood protection.

**Pulpwood**

Under usual conditions, the loss in specific gravity of stored rough southern pine bolts averages 3 to 5 percent in two months of summer storage or 5 to 6 months of fall and winter storage. To this loss must be added increased loss as fines in chipping and screening, and, with brown rot, a decreased yield per pound of chips. Stain (Fig. 37) also increases bleaching cost. Thus precautions to limit biological deterioration can yield important economic returns.

Loss from stain and decay can be reduced by the following measures:

**Prompt utilization.** Many mills limit deterioration of pulpwood by processing the bulk of their input directly from the woods, limiting storage to just enough wood for a few days emergency use. If the small amount of stored wood is rotated with a maximum storage of a few weeks, losses from stain and decay will be insignificant. For longer storage periods, special protective measures are needed.

**Continuous water spraying** or storing in ponds. This effectively prevents stain and decay. The bacteria and specialized fungi that attack water-logged bolts merely increase porosity which, instead of being a defect as in lumber, actually reduces cooking time in the pulping process. Some mills have constructed large circular ponds for the storage of pulpwood, but neither ponding nor spraying has been generally adopted.

**Spraying or dipping in 2.5%** pentachlorophenol plus 0.5% gamma BHC. When pulpwood is stored at concentration yards, where it can be handled mechanically, dipping is not prohibitively costly. To be fully effective, treatment must be done shortly after felling. During summer, this is the day of felling, at other seasons a few days delay sometimes is safe. Longer delays permit fungi and beetles to penetrate before treatment.

FIGURE 37. *Stain in a pine log associated with bark beetle attack. Since the stain hyphae aggregate in the ray cells, the stained areas appear pie-shaped in cross-section.*

Photo by U. S. Forest Service

**Spraying with 5% fluoride** (ammonium bifluoride, sodium fluoride, etc.) solution in water. This stimulates development of the mold *Trichoderma,* which inhibits stain and decay. After six months, another decayer, which is not inhibited, becomes prevalent. When treatment must be delayed more than 12 hours, this is the most promising control.

**Regulating type of wood and piling method.** During the first two months of summer and four to five months of fall and winter storage, peeled wood decays more rapidly than rough wood. Peeled wood dries faster to the optimum water-oxygen ratio for decay while rough bolts maintain moisture contents above the optimum for appreciable time. Rough bolts of larger diameter and longer lengths dry to the optimum range for decay slower than small bolts. Thus, if possible, the separation of large sizes for storage would be advantageous. Also, drying is slower in large, tight piles, either jack-straw or ricked with adjacent rows abutting to prevent end drying. The advantage of storing large-sized, rough bolts in large piles applies to the normal storage periods used in the South. Where longer storage periods are used, as in the North, small, peeled bolts, ricked for optimum drying, will result in minimum deterioration.

### Chip Storage

Most southern pulp mills now store chips in compacted piles. In 1968, 20.4% of the total wood supply of southern mills was in the form of chips from sawmills and other wood-using industries. Several factors make chip storage attractive: ease of handling, better wood measurement, and the possibility of chipping at the wood source. Loss in yield and quality of pulp are about the same for chip storage as for round wood storage, but there is a significant reduction in the yield of tall oil. Also there may be more trouble with dirt in chips, particularly if piles are located where they can become contaminated with cinders from a smoke stack.

Stored chips are attacked by the common stain and mold fungi but, unlike roundwood, more of the decay is by soft-rot organisms than by typical decay fungi. Temperatures in chip piles may reach 135°F. Both temperature and moisture content vary with zones within the pile, and zone configurations change with time. Chips dry markedly during the heating period but rewet with rainwater after the pile interior cools.

## DETERIORATION OF AIR-SEASONING LUMBER

Lumber cut from green logs is subject to attack by stain, mold, and decay fungi until its moisture content is below fiber saturation. Molds and stains develop more rapidly than decay and, therefore, account for most of the commercial degrade. Decay fungi do attack, however, even though frequently they are less obvious. Some incipient decay infections are not killed by air seasoning, but remain alive for years in a dormant state to revive should the wood be rewetted. Such incipient decay infections are a common cause of rapid deterioration of siding and other exterior woodwork of buildings not adequately protected against rain seepage.

Species of stain, mold, and decay fungi attacking green lumber during air seasoning vary with wood species, geographic location, and season. Degrade can result from the further development of infections already present in the log, or from spores produced on the ends of infected logs being thrown around mills by machinery, or spores carried by wind or insects to the lumber after it is in the seasoning pile.

Fungus deterioration of air-seasoning lumber is prevented by dipping freshly cut lumber in fungicidal solutions (Figs. 38 & 39). Chlorinated phenols (as sodium pentachlorophenate) and organic mercurials (as ethyl mercuric phosphate) are the bases for most dips.

The species of mold and stain fungi vary in their tolerance to different types of fungicides so that the concentration of a dip must be sufficient to prevent the development of the most resistant species. Also, fungus species are comprised of physiologic races which may vary in tolerance. A resistant species or race can build up in a seasoning yard sufficiently to prevent satisfactory protection by a specific fungicide. Two practices can be used to obviate these difficulties of tolerances:

**Use of mixtures.** Fungi resistant to a mercurial are almost never


FIGURE 38. *Vats for dipping lumber in stain-control solutions.* A. *A small vat depending on gravity for immersion of lumber.* B. *Mechanical vat with chains to move lumber through the vat and wheels to insure immersion.* C. *Vat for hand dipping.* Photos by U. S. Forest Service

FIGURE 39. *Heavy stain developed during the air-seasoning of the three untreated sapgum boards (left) while those dipped in a stain-control fungicide remained bright.*

Photo by U. S. Forest Service

resistant to a chlorinated phenol. Therefore, by using mixtures of these, control can be secured with lower total concentrations.

**Periodic changing of fungicides** when there is evidence of a build-up of a resistant species or strain. To be effective changes must involve widely different chemicals.

The effectiveness of such fungicidal dips is predicated upon the following practices:

**Fresh log supply.** If logs are infected before milling, fungi can continue development during air seasoning despite a chemical dip. During poor drying weather stain may develop to the surface of the lumber. During good weather, chemical dips usually keep the surface bright but interior stain may develop, and this can be exposed by planing.

**Minimum delay** between milling and chemical treatment. A delay of more than 12 hours in summer and 24 hours during other seasons often permits stain to penetrate further than the chemical does. These incipient infections do not color the exterior of the lumber, but interior stain may result.

**Proper solution preparation.** Chemical dips must be of proper concentration and well stirred to insure complete solution. Experience shows that a separate mixing tank is superior to mixing in the dipping vat.

**Good vat design.** The vat must be designed so that the lumber is immersed for several seconds. A good vat has a steep entering side, rollers to hold the lumber under the solution, and a long drain board (Fig. 38).

**Good vat maintenance.** The vat must be drained and cleaned of sawdust every few days. The solution level must be kept high, particularly with mercurials; this influences concentration.

**Protection from rainwetting.** Dipped lumber needs protection from rain wash by having the vat, sorting chain, and buggies covered. This is particularly important the first hour or so after dipping, i.e. before the chemical is adsorbed to the wood.

**Prompt seasoning.** Dipped lumber should be put in regular seasoning piles as soon as possible because bulk piling is conducive to staining.

**Good seasoning-yard practices.** The seasoning yard should be well drained, laid out to promote good air circulation, and free of high weeds. Piles should be on elevated foundations, boards well spaced on clean stickers, and covered with a rain-tight roof. Mechanical handling of lumber has, in general, led to poorer piling practices, but a number of mills have shown that good piling can be done with machines.

**Double strength solutions** for lumber to be bulk piled more than two days and larger sawed timbers which require additional protection.

The surest means of preventing fungus attack on freshly-cut lumber is to kiln dry it promptly. Much southern pine lumber is now kiln-dried from the green state, but most hardwoods are air dried even when they are finally kiln dried. In most sections of the country during the summer, and in the warmer sections throughout the year, rapid air seasoning without a chemical dip cannot be relied on to prevent staining and molding or even decay. In the arid southwest where drying is rapid, some lumber is chemically treated so that it can be close piled to reduce drying rate and thus minimize checking.

Large sawed timbers for use in protected places without preservative treatment usually are marketed without seasoning. If sprayed with a stain-control solution (see section on air-seasoning lumber) and promptly put into use where they can dry rapidly, little deterioration results. However, if drying is restricted by bulk piling before use, or if used under circumstances hindering drying, serious stain and decay can result. Timbers cut from heartwood are less subject to deterioration because they are initially drier and subject to attack by fewer fungi.

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# WOOD DECAY IN BUILDINGS

Wood is an excellent building material — it is readily available in a variety of shapes and sizes, is easily shaped on the job with portable equipment, can be joined together by such simple means as nailing, and repairs and replacements can be made easily. Wood will give longtime service if standard building practices are followed; important amounts of decay occur only if a building is poorly designed or improperly maintained, permitting wetting by rainwater, condensate, tap water, or soil water. Basically, controls consist of keeping wood dry or using naturally decay-resistant or preservatively-treated woods.[6]

Preservatives include creosote and various chemicals dissolved in oil or water. Some leave paintable surfaces after drying; others make wood unpaintable. Some can be leached out by water while some are water insoluble. Some have objectionable odor. The effectiveness of any pre-

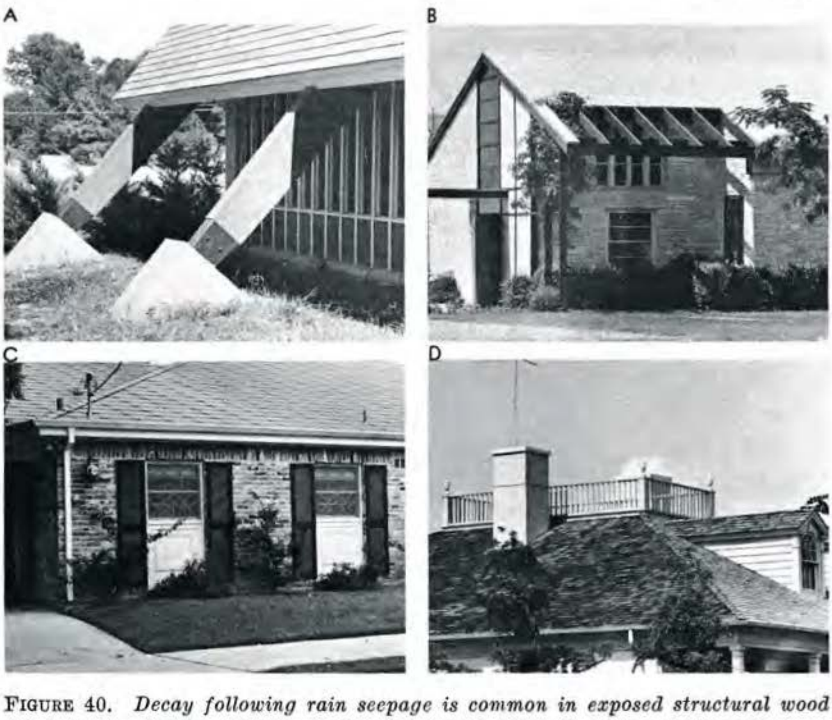


FIGURE 40. *Decay following rain seepage is common in exposed structural wood (A and B), window shutters and wood panels not well protected by roof overhang (C), and exposed decorative structures (D).*

[6]Details on preservatives, methods of application, and suitability for specific uses are included in the references at the end of this chapter. This material is summarized in Appendix I.

servative depends on the amount retained by the wood, its distribution in the wood, and the type and severity of exposure in use.

## DECAY ASSOCIATED WITH RAIN SEEPAGE

Rain seepage accounts for most decay losses in buildings. The most common points of decay are the roof edge, wooden steps and porches, and siding (Fig. 40).

Rain seepage usually can be detected and often stopped before actual decay occurs. The signs indicating seepage are:

Rust stains around nail heads.

Paint peeling and blistering, particularly at joints.

Paint darkening, particularly at joints.

Swelling and buckling of wood.

Backing out of nails.

Fungus fruiting bodies or actual decay.

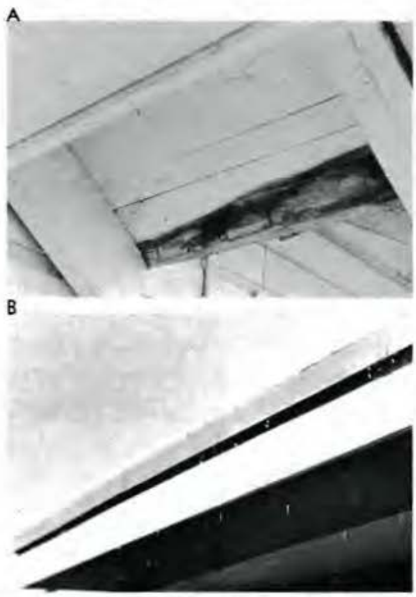


FIGURE 41. *The high decay hazard of the roof edge (A) can be removed by using a metal flashing (B) and treated or naturally decay-resistant wood for facia, rakeboards, and molding.*

**Roof Edge.** Roof runoff commonly wets facia, molding, and rafter ends at the eave and rake edges unless a well-designed drip edge is installed (Fig. 41). In addition, in high rainfall areas, all wood exposed at the roof edge should be naturally decay resistant or treated. Metal drip edges are needed, particularly with asphaltic roofs, because water creeps around the edge of asphalt shingles to wet the roof edge. There should be no exposed nailing of metal edging or roll roofing. In the latter case the edge should be glued down. Horizontal joints in metal gravel stops on flat roofs are difficult to keep water tight. Seals should be reworked at the first sign of leakage.

**Porches and steps.** These have such a high decay hazard that, in high rainfall areas, they should be made of pressure-treated or naturally decay-resistant woods. Design alone has little effect on decay rate.

**Walls.** Deterioration of siding, trim, windows, and other wood in walls can be reduced by:

**A good roof overhang.** A hip roof with 2½- 3-foot overhang will protect the walls of a one story building from serious rain wetting. On higher buildings, overhang does not give complete protection to the lower wall.

**Eave gutters.** These prevent roof runoff from being blown against siding or splashing up onto the lower wall. Splash is particularly severe when a concrete walk or driveway is under the roof edge.

**Proper sheathing paper.** The paper used under wood siding should be of the breathing type, i.e. asphalt-saturated but uncoated papers not heavier than 15 pounds per roll. Wetted siding dries mainly to the inside; vapor-barrier papers prevent prompt drying.

**Water-repellent preservatives.** These greatly reduce the amount of rain seepage (Fig. 42). A three minute dip gives adequate protection, provided all surfaces exposed by cutting after treatment are retreated by dip, brush, or spray. Retreatment can be done after siding or trim is attached. Water repellents are effective only if the major seepage is prevented by good design. Spraying all joints with a water-repellent preservative before repainting often prevents recurrence of minor rain seepage.

**Restrict projections** from the wall. Water tables or rafters, beams, and wooden arches extending beyond the roof edge are subject to excessive seepage. If any of these features are desired for architectural effects, they should be made of pressure-treated or naturally decay-resistant woods.

Use of **standard siding patterns,** such as bevel, 105 drop, or vertical boards and battens. Such novelty patterns as V-joint drop siding should not be used unless well protected by a wide roof overhang.

**A good clearance** between the siding and the ground. A minimum of two feet is best. With slab-on ground buildings, clearance should be at least 12 inches and, in addition, the use of treated siding is desirable, at least for the bottom few courses.

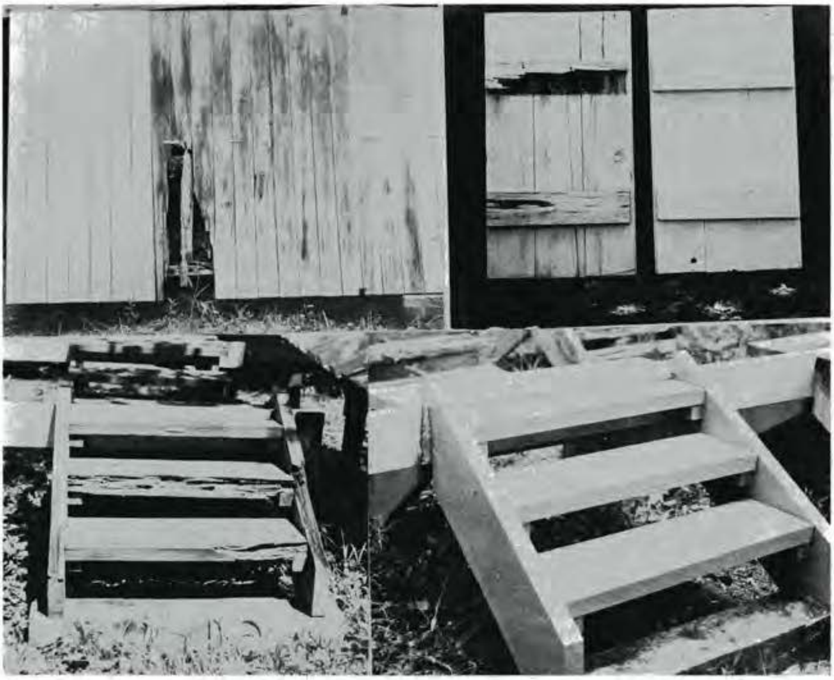

FIGURE 42. *Dipping precut lumber in a water-repellent preservative reduced rain seepage and resulting decay. Dipped and undipped experimental units of porch flooring, window shutters, and steps.* Photo by U. S. Forest Service

## DECAY ASSOCIATED WITH CONDENSATION

Condensation is a common phenomenon—for example, the dew found on automobiles parked outdoors overnight. The amount of water vapor the atmosphere will hold depends on temperature; as the temperature drops, the relative humidity increases until it reaches saturation. Further lowering of the temperature causes the excess water vapor in the air to condense out. The temperature at which this starts is called the dewpoint temperature. Dewpoint temperatures can be created in buildings by heating in cold weather or by air-conditioning by refrigeration in the summer. There are also other special cases.

Most building materials—including plaster, wood, concrete, most kinds of brick, and many building papers—are permeable to water vapor. Under usual building conditions, vapor moves from the warm side of a floor, wall, or ceiling toward the cool side. If sufficient temperature differential exists, the warm vapor will encounter and condense on a surface at the dewpoint temperature somewhere on or within the wall, floor, or ceiling (Fig. 43).

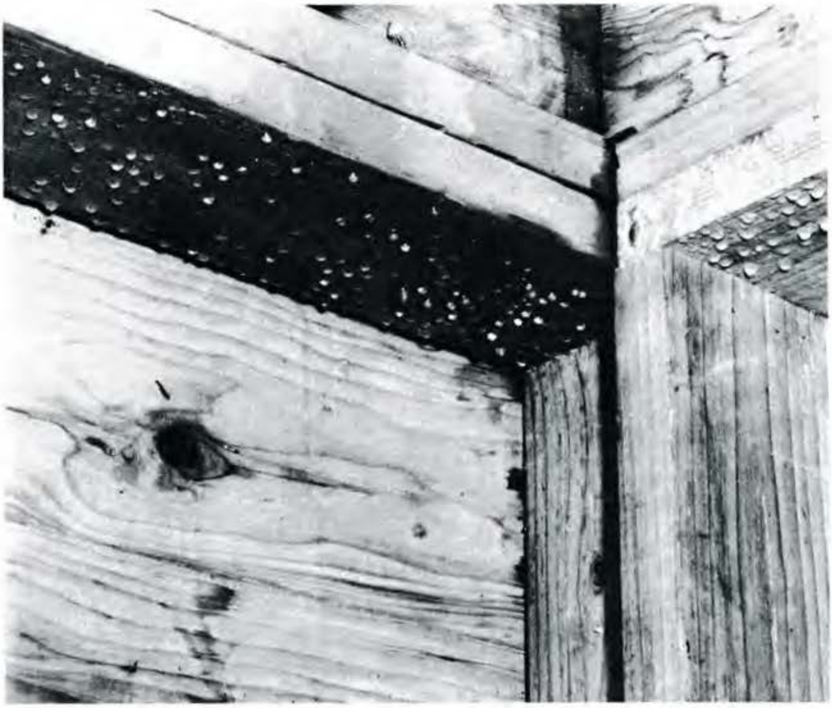

FIGURE 43. *Condensation can cause serious wetting of wood at the periphery of a wet crawl space during winter.* Photo by U. S. Forest Service

Several types of condensation problems exist in buildings, and each requires different control measures.

**Condensation associated with heat radiation**

On clear still nights heat radiates from building surfaces sufficiently to lower the building surface several degrees below the surrounding air, creating a dewpoint temperature. Condensation from this cause commonly occurs on screens, the undersides of thin-roofed car-ports and eaves, or siding. Such condensate seldom leads to decay but is a common cause of paint molding. Often it is so slight that it goes undetected. Painting with an oil paint before the condensate dries is a common cause of severe paint peeling. Emulsion paints are not subject to this type of failure. Heat radiation condensation cannot be prevented, but the use of paints containing a mildewcide will reduce molding.

**Cold-weather condensation in walls**

This is a problem in areas where the average January temperature is 35°F or below (Fig. 44). Warm interior air moves out through walls


FIGURE 44. *Winter condensation hazard is greatest in areas above the line marking an average January temperature of 35°F. Below this line winter condensation is largely limited to wet crawl spaces.*

Photo by U. S. Forest Service

until it hits a cold surface where vapor condenses out. The usual point of condensation is the inner surface of the sheathing. In severe cases, the wall becomes filled with ice. Again, the main danger of winter condensation in walls is paint failure, although some decay may result. Control consists of installing a vapor barrier near the inner surface of the wall and sufficient thermal insulation outside the barrier to insure that the dewpoint temperature remains outside the vapor barrier. Restriction of vapor release inside the house also helps.

**Winter condensation in the crawl space**

This is similar to condensation in walls expect that it is more severe, commonly leads to decay and floor buckling, and occurs as far south as the Gulf Coast. The water condensing in crawl spaces comes mainly from evaporating soil water. This suggests the three methods of control, any one of which is effective.

**Soil drainage.** If the top layer of soil in the crawl space is dusty dry, there is practically no danger of winter condensation, even when foundation vents are closed. Grading to prevent surface water running under houses often is all that is needed to keep the soil dry. Sometimes it is necessary to install general site or neighborhood soil drainage to lower the water table. In this case, other methods of control will be cheaper.

**Ventilation.** Adequate vent area through the foundation will prevent most condensation if the vents are well spaced and not obstructed by vegetation. A vent area equal to 1/150 of the crawl space area is adequate. Ventilation during winter when condensation control is needed, however, has a disadvantage; it may lead to cold floors and frozen water pipes.

**Soil covers:** Covering the crawl--space soil with a 6-mil polyethylene film or smooth-surfaced roll roofing weighing 45 pounds or more will prevent evaporation of soil water and resulting condensation (Fig. 45). Soil covers not only prevent condensation when vents are closed but also aid in reducing mold problems in the living space.

**Condensation associated with air-conditioning by refrigeration**

Here, the principle is the same as with winter condensation, but the vapor pressure gradients are reversed and vapor moves inward from the

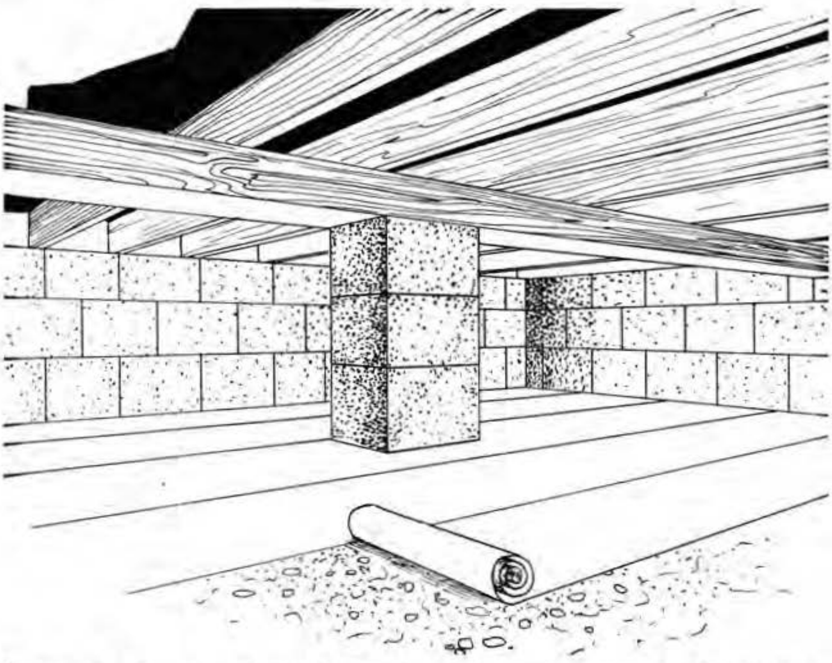

FIGURE 45. *Covering the crawl-space soil with a vapor barrier (roll roofing or polyethylene film) effectively prevents winter condensation.*

Photo by U. S. Forest Service

warmer outdoors. Damage consists of decay in floors, floor buckling, mold on interior walls, and rusting of metal lath.

In the coastal area from Corpus Christi to Key West, the dewpoint temperature under average conditions in June, July, and August varies from 74 to 77°F. Therefore, it is likely that with any refrigeration a dewpoint temperature will exist part of the time; for long periods if indoor temperatures are in the low 70's, and almost continually at temperatures below 70°F.

To control air-conditioning condensation, the crawl space should be kept dry by drainage or a soil cover, but not by ventilation if severe refrigeration is used. Intermittent (day time) cooling, when feasible, will minimize condensation. If cooling is continuous, a minimum temperature above 75°F will prevent most condensation. When lower temperatures are desired, the use of a subfloor vapor barrier should be considered, particularly if the crawl space cannot be kept dry.

Even after condensation is controlled, there may still be some floor buckling. In its upward passage through the floor, air will cool and, thus, its relative humidity will increase. This will result in an increasing equilibrium wood moisture content from the crawl space to the upper floor surface. Some wood swelling problems with moderate air-conditioning can thus be explained without condensation. Flooring usually is dried to 6 to 8% moisture content. Before being laid, such flooring should be opened to the air until its moisture content reaches 11%. When asphalt tile or linoleum is used over a wood subfloor, it restricts drying and increases moisture problems. Under such coverings a plywood subfloor is safer because it is dimensionally more stable.

**Condensation in cold-storage rooms**

The principles here are the same as with regular air-conditioning except the problem is more severe and requires stringent control measures. These include carefully installed heavy-duty vapor barriers and adequate thermal insulation, vestibules or double entrances to minimize inflow of warm air, vapor permeable inner wall finishes, pressure-treatment for all wood used, and adequate termite control.

## DECAY BY WATER-CONDUCTING FUNGI

The water-conducting fungus, *Poria incrassata,* causes the most spectacular decay of buildings in the United States (Fig. 46). Fortunately this fungus is rather rare. Once well established, *P. incrassata* can destroy large areas of flooring and walls in a few years, so that wood may need replacement at 2- to 3-year intervals unless the contributing causes are removed.

FIGURE 46. *The substructure, flooring, and lower walls of this building were removed because of decay by* Poria incrassata. Photo by U. S. Forest Service

Several physiological characteristics of *P. incrassata* have important bearing on control. *P. incrassata* will attack all the common construction woods, including such "decay-resistant" woods as heart baldcypress and redwood. The fungus is extremely sensitive to drying and quickly dies in air-dry wood. It develops large, tough water-conducting strands that can transport water from a constant source to otherwise dry wood at least 20 feet away. Thus any construction permitting contact of untreated wood with the soil, moist concrete, or other constant water supply is subject to attack. Some practices permitting this are wood sills not sealed from dirt fills under concrete porches and steps, wood forms left after pouring concrete, and basements permitting seepage.

Standard building designs, such as those described in the Federal Housing Administration's publication, "Minimum Property Requirements," provide adequate protection against attack.

If attack does occur, the source of water must be located and removed. The decayed wood then will dry out and the fungus will die. Only wood too weak to fulfill its structural function needs replacement. If there is doubt that the water supply has been removed, decayed wood should be replaced with pressure-treated wood. "Decay-resistant" woods must not be used as a substitute for pressure-treated wood.

FIGURE 46. *The substructure, flooring, and lower walls of this building were removed because of decay by* Poria incrassata. Photo by U. S. Forest Service

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# DECAY OF CROSSTIES, POSTS, POLES, PILING, AND MINE TIMBERS

Decay is a common problem with wood products in contact with the soil. Through the years this has led to the use, or attempted use, of non-wood substitutes. For example, in the United States, steel has largely replaced wood for high-tension line towers and, in cities, where wires can be serviced from hydraulic lifts, aluminum poles are becoming common, particularly for high poles. A few utility companies still insist that wood gives them the best service per dollar in high-tension lines.

Except in temporary structures, satisfactory service from wood in contact with the soil requires all heartwood of such naturally decay-resistant species as redwood, western redcedar, baldcypress, white oak, and black locust; or wood adequately treated with a suitable preservative. For general information on preservatives see Appendix I: for details of treatments suited to different exposures, see "Wood Preservation" by Hunt and Garratt. Posts, poles, and timbers preservatively treated to meet Federal and commercial specifications for various uses are generally available at woodtreating plants.

## CROSSTIES

Few woods with natural decay resistance have sufficient density for ties in modern railroads. Most ties are pressure treated with creosote, creosote-coal-tar solutions, or creosote-petroleum mixtures. Treatment increases service life two to four times. Most ties are replaced because of mechanical failure, i.e. rail plates cutting into the wood. Probably fungi, both regular decayers and soft rotters, weaken ties and increase the rate of plate cutting.

## POSTS AND POLES

For long-time service as posts, woods which are not resistant to decay require preservative treatment. Usual recommendations call for 6 to 7 pounds of creosote and oil-borne preservatives per cubic foot, or 0.5 to 1.15 pounds (dry chemical) of water-borne preservatives per cubic foot, depending on the salt used.

As we have already learned, southern pine posts to be treated by cold soaking are benefitted by some mold and stain infection to increase penetrability. Fortunately, this happens without serious accompanying decay during usual seasoning periods prior to treatment. This, of course, does not apply to pressure and hot-and-cold treatments, which easily treat uninfected poles.

Some naturally decay resistant woods are used untreated for posts and poles. Split posts are preferable, to provide a durable heartwood nailing surface.

Most poles of decay resistant species are given a hot-cold butt treatment to prevent saprot. Untreated western redcedar poles may develop shell rot above ground, even with a butt treatment. Such decay may occur under a thin sound shell, making the pole dangerous to climb. At one time some cities required poles to be painted to make them more attractive. This increased the prevalence of shell rot. In general, pressure-treated poles of non-decay resistant species will outlast untreated poles of naturally decay-resistant woods.

No preservative treatment gives a uniform distribution of the preservative; at the center of a pole even if all sapwood, there is invariably less chemical than at the surface. This is particularly true of such woods as Douglas-fir, where the heartwood resists treatment. Therefore, poles should be gained, framed, and bored before treatment; if done after treatment, the prevalence of top rot increases. When light-colored treatments are used, any molding that occurred during seasoning may show through. This has caused some objections where poles are to be used in residential areas.

When poles are cut for stubbing or any other purpose, the cut surface can be given considerable protection with penta grease. This grease, with a high concentration of pentachlorophenol, is spread in a thick layer over the cut surface and covered with a waterproof paper. The penta will penetrate quite deeply. Penta grease also is used as a blanket on poles with incipient surface decay at or just below the ground line.

## MINE TIMBERS

Mine exposure has some unusual features. First, most mines are damp and have a uniform temperature throughout the year, creating near optimum conditions for decay. Some parts of mines are used only temporarily so that untreated shoring timbers can be used. The development of decay mycelium can be fantastic, festooning timbers with great gobs of growth. If used for many months, replacements because of decay are common and frequent. Incidentally, even though many decay fungi occur in mines, a common one is our old friend **Fomes annosus.** In the more permanent shafts, pressure-treated wood is used.

## PILING AND DOCK TIMBERS

Marine borers are a major problem in salt or brackish water. Piling for such exposure is pressure treated to refusal with coal-tar creosote. Even for land and fresh-water use, retentions of 12 to 14 pounds per cubic foot of creosote or oil-borne preservatives are recommended.

The decay problems are above water because the below-water parts remain too wet to decay. Piling has one bothersome problem that poles do not have. They are driven, which may smash the piling top, requiring that the top be sawed off, exposing wood which does not have the best treatment. Also, any framing and drilling usually must be done after driving which again exposes interior wood.

Tops can be protected by a coating of penta grease plus a metal cap. Or, special built-up caps of fabric and coal tar pitch, etc., can be used. The penta grease also can be used after framing.

Another troublesome feature is the splitting of 10 x 10 inch or larger curb timbers where mooring hitches are attached. The rope from a docking ship gives the cleat a terrific twist that most curbs cannot long resist. The resulting splits permit wetting and infection of the less protected centers of the timbers. Then, of course, there is the mechanical damage to fender piling and fenders by ship hulls. Curbs and other above-water timbers of docks usually are pressure-treated with creosote or oil-borne preservatives to insure long-time service.

Related to the above and also to building decay is decay in wooden boats. This need not be discussed here beyond stating that most decay in boats is associated with rain seepage through the deck. Decking and its supports, tops of frames, and frames plus hull planking near the high water line in the bilge are common places for decay. Controls include careful caulking, use of decay-resistant or treated wood, and the use of preservatives in bilge water.

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# CONTROL OF FOREST DISEASES

Intensive direct control of diseases is feasible and generally practiced in nurseries and seed orchards where values per acre are high. In commercial forests, the relatively high cost of direct controls in proportion to the values involved has precluded most direct controls in the past. Conditions are changing and more and more direct controls are becoming feasible in the forest. Foresters should remember, however, that many forest diseases are ecological problems, **i.e.,** the reaction, directly or indirectly, of a tree to its environment. Thus, in many cases, controls must be indirect through regulation of the environment.

Now let's look at the prospects of disease control in the forest—what can be done now and what the future holds. There are five general approaches to disease control.

## EXCLUSION OF FOREIGN PARASITES

Some of our most destructive parasites were introduced on living plant parts: chestnut blight and white pine blister rust on nursery stock and the Dutch elm disease fungus in green logs. Almost invariably, introduced parasites are well established before detection, so they have rarely been eradicated; usually we must learn to live with them. American forest trees have been widely planted abroad, so we know some foreign parasites we must guard against. For example, a destructive Japanese disease is voilet root rot, caused by *Helicobasidium mompa,* which can live as a saprophyte in the soil. Two highly susceptible trees are yellowpoplar and loblolly pine! It would be utter folly to introduce any tree seedlings from Japan and run the risk of getting *H. mompa* into this country.

To reduce the chance of entry of such pathogens, Federal plant quarantines have been imposed. These require: an import permit, certification at the origin of apparent disease-free condition, including inspection during the growing season, and freedom from soil (except from Canada). Importations are restricted to certain ports and are inspected and given fumigation or other treatment if necessary. Some tree genera are prohibited from certain countries or continents. Most genera, including *Acer, Eucalyptus, Fraxinus, Larix, Picea, Pinus, Populus, Quercus,* and *Ulmus,* require post-entry quarantine until freedom from infection is established. This permits destruction under restrictive conditions of any plants found diseased, minimizing the change of escape of a new pathogen.

## GENETIC CONTROL

The development of resistant strains or hybrids will be important in the future. Noteworthy progress has been made in developing southern pines resistant to fusiform rust, little-leaf, and brown spot, white pine resistant to some types of air pollution, and cottonwood resistant to leaf rust. What can be done for a tree disease was vividly shown by mimosa selections that have remained resistant to fusarium wilt for 20 years. One difficulty with pines will be that of multiplying a resistant individual into sufficient numbers to plant much area. Improved methods of grafting resistant material onto common root stock to establish seed orchards will aid multiplication of desirable genetic material of southern pines. With many hardwoods, reproduction by cuttings will ease this problem.

In a certain number of cases we may find that resistant stock becomes susceptible through genetic change or the build-up of particularly virulent strains of some parasites. The tendency toward monoculture in southern forestry can lead to catastrophic losses should a virulent pathogen attack the chosen tree species. Undoubtedly monoculture played a role in raising fusiform rust from a minor problem 40 years ago to one of our major disease problems today. If we carry this a step further by planting a single strain of a single species, we might even compound the problem. This has happened with certain agricultural crops. With some, such as potatoes, an attempt is being made to find and replace in horticultural varieties genes which have been lost and which have a bearing on disease resistance as well as other characteristics. The most promising leads in forest genetics are not those culminating in a pure genetic strain, but those in which a gene for a desirable quality, such as disease resistance, is incorporated in a wide population retaining considerable variability.

## BIOLOGICAL CONTROL

As far as can be seen now, this holds little promise in the forest. Part of the control attained by soil fumigation in nurseries may be due to rapid reinvasion of harmless saprophytes such as *Trichoderma viride*, which hold back pathogens. The English studies on the use of *Peniophora* to inoculate fresh pine stumps and thus, through biological competition, exclude *Fomes annosus* may be developed into practical use. Otherwise, biological controls do not look too promising.

## DIRECT CONTROLS

In the forest proper, these will be most feasible, from an economic point of view, if they need to be applied only once, or very infrequently, during the life of a stand. The most common direct control for plant diseases is a fungicidal spray or dust, which usually must be applied repeatedly during each growing season and hence, is not feasible in the forest. However, some direct controls are feasible now and more will become so very soon:

(1) Fungicidal control of brown spot under some circumstances.

(2) Prescribed burning for brown spot control.

(3) Selective pruning in young plantations after years of heavy infection with fusiform rust.

(4) Stump treatment for annosus root rot control.

(5) Removal of trees with dwarf mistletoe, or other sanitation operations.

In special-use areas, more intensive direct controls are practical. Thus, in picnic and recreational areas, individual trees may be given the same intensive treatment as shade and ornamental trees. This phase is rapidly becoming more important as recreation becomes an integral part of forestry.

## MANAGEMENT MANIPULATIONS

The creation of conditions unfavorable for disease development holds great promise:

(1) Altering cutting plans for stands with wounded trees to take into account the rate of rot development can reduce loss from heart rot. Or, in areas where littleleaf is severe, the use of short pulpwood rotations will avoid severe mortality that occurs with older age classes. Managing pine stands on very poor sites, which induce early heartwood development, for pulpwood, posts, and other small products will reduce loss from redheart.

(2) Spacing or number and frequency of thinnings have an important bearing on disease occurrence by promoting increased tree vigor or early pruning.

(3) Soil water management, through irrigation, drainage, and the manipulation of vegetative cover, will soon become an important forest practice with disease-control implications. Some such moisture regulation is currently practical in bottomland forestry. The research basis for such management in pine stands is well advanced.

acteristics as leaf size and color, rate of growth, and dying. Thus, research must make many contributions before general disease surveys can be made effectively.

Conversely, where importance is obvious, as is true with annosus root rot, surveys are feasible. But they must be made very carefully to gather information not only on occurrence but also on severity of attack as correlated with soil type, previous land use, season of cutting, and any other environmental factor or practice which might influence the disease. Thus, survey and research are difficult to separate — in fact, they complement each other. Both are essential to the development of a sound forest disease control program.

## SERVICES TO LANDOWNERS

In addition to surveys, there must be public agencies to which forest owners can turn for identification of disease material and for advice on the need for and the methods of control. States with well-developed forest services, particularly those with pest-control sections, usually have the best knowledge of local pest problems. Also, keeping them informed of disease conditions helps them to accumulate the state-wide information needed to best advise land owners. Other local sources of information are State Agricultural Experiment Stations at Land Grant Universities and forestry schools. Another excellent source is the U. S. Forest Service. It maintains Forest Insect and Disease Control Offices in the Division of State and Private Forestry in each forest region and disease research units at each of its Forest Experiment Stations. Addresses can be secured from any U. S. Forest Service office. Failure to take advantage of these sources of information can lead to costly errors. Securing correct diagnosis and applying sound control measures before disease losses become serious is good forest management.

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**More leachable types**

To be used where wood will not be in contact with wet ground or otherwise subjected to much wetting:

Chromated zinc chloride

Copperized chromated zinc chloride

Fluor-chrome-arsenate-phenol (Osmosalts, Tanalith)

Acid copper chromate (Celcure)

**Less leachable types**

Suitable for use in wet situations:

Ammoniacal copper arsenite (Chemonite)

Chromated zinc arsenate (Boliden Salt)

Chromated copper arsenate (Erdalith)

## PRESERVATIVES AND RETENTIONS COMMONLY RECOMMENDED FOR GENERAL USES.[1]

| *Preservatives* | *Lumber, Plywood, and Timber for use* | | *Piles* | | *Poles* | *Posts* |
|---|---|---|---|---|---|---|
| | *Not in contact with ground or water* | *In contact with ground or in fresh water* | *Foundation* | *Marine* | | |
| *Oils* | | | *Pounds per cu. ft.*[2] | | | |
| Coal-tar creosote | 6 | 10 | 12 | 17 | 8-10 | 6 |
| Creosote-petroleum solution (50-50) | 7 | 12 | 14 | —— | —— | 7 |
| Pentachlorophenol, 5% in petroleum oil | 6 | 10 | 12 | —— | 8-10 | 6 |
| *Waterborne* | | | | | | |
| Acid copper chromate (Celcure) | 0.50 | 1.00 | —— | —— | —— | 1.00 |
| Ammoniacal copper arsenite (Cheminite) | .30 | .50 | —— | —— | —— | .50 |
| Chromated copper arsenate (Erdalith) | .35 | .75 | —— | —— | —— | .75 |
| Chromated zinc arsenate (Boliden Salts) | .50 | 1.00 | —— | —— | —— | 1.00 |
| Chromated zinc chloride | .75 | 1.00 | —— | —— | —— | 1.00 |
| Copperized chromated zinc chloride | .75 | 1.00 | —— | —— | —— | 1.00 |
| Fluor-chrome-arsenate-phenol (Tanalith, Osmosalts) | .35 | .50 | —— | —— | —— | .50 |

[1]Most of the retentions specified can be obtained only by pressure treatment, or hot-and-cold bath. However, very porous wood, such as moldy southern yellow pine sapwood, can be soaked to attain these retentions. Other applications are intended only for short-time durability or for uses under low to moderate hazards.

[2]Total solution, except for waterborne chemicals, where quantity refers to dry chemical retained.

## METHODS OF APPLYING WOOD PRESERVATIVES

The durability of treated wood depends not only on the type of preservative used and the exposure conditions, but also on the amount in the wood and the depth and distribution within the wood.

### Pressure treatments

The preservative is applied under pressure in special treating cylinders.

**Full cell.** This system leaves maximum amounts of solution in the wood, so that the cell cavities are essentially filled. It is used mainly to treat marine piling with creosote or for treating with waterborne preservatives.

**Empty cell.** The wood is given a full-cell treatment and then 20 to 60% of the preservative is removed by applying a final vacuum. Most wood on the general market pressure-treated with creosote, creosote-petroleum mixtures, and pentachlorophenol, in heavy oils, is empty-cell treated.

A variation of this, the liquified-gas process, is used mainly with pentachlorophenol. The preservative is dissolved in a liquified volatile gas, which quickly evaporates from the treated wood when the pressure in the treating cylinder is released. The treated wood has a clean, paintable surface, and is free of any carrier oil.

### Non-pressure processes

**Cold soaking.** By long-time soaking (days) a preservative will deeply penetrate wood. Soaking is most effective on easily penetrated woods, such as southern pine sapwood. If the porosity of the wood has been increased by mold or bacterial attack, excessive amounts of preservative may be absorbed.

**Hot-and-cold bath.** The wood is soaked in a hot solution and then immersed in a cold solution of the same preservative. Contraction of the air in the wood draws the preservative into the wood. It may be followed by a second hot bath, to remove excess preservative. This is an excellent home treatment for fence posts.

**Diffusion.** Unseasoned wood is put into a water solution of a preservative. The chemical diffuses into the sap in the wood. Sometimes wood so treated is placed in a solution of a second chemical which diffuses into the previously treated wood, and reacts with the first chemical to leave an insoluable chemical in the wood. This is called double diffusion.

**Dipping (soaking for less than 15 minutes).** This gives only a surface treatment resulting in short-time protection except under relatively low hazard. A 3-minute dip in a water-repellent preservative is a standard treatment for window sash and other exterior wood-work of buildings.

**Vacuum treatment.** This is used mainly with clean, paintable, water-repellent preservatives. The wood is subjected to a vacuum to remove the air from the wood cells before the treating solution is introduced. When the vacuum is released, atmospheric pressure forces the preservative into the wood.

**Brush or spray treatment.** These are the least effective of the treatments, but can be used to advantage to re-treat cuts made into wood treated by other methods, or to apply a water-repellent preservative to joints in siding or other wood subject to minor rain seepage.

**Wicking.** This can be used to treat the bases of porch columns resting on a concrete slab. With a little ingenuity, the method can be used to treat other wood showing signs of rain seepage. A piece of strong cord is tied snugly around the base of the column and in contact with the concrete. About 8 ounces of a water-repellent preservative in a bottle is inverted in a shallow dish, similar to the common chick watering device. The free end of the cord is placed in the preservative in the shallow dish. The oil, by capillarity, moves along the cord and into the wood. If applied when the wood is dry, worthwhile protection will result.

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U. S. Forest Service. 1955. *Wood Handbook,* U. S. Dept. Agr. Handbook No. 72.

## Appendix II

# LIST OF TREES MENTIONED IN THIS TEXT

| | |
|---|---|
| Ash | *Fraxinus* sp. |
| Ash, green | *Fraxinus pennsylvanica* Marsh. |
| Aspen, quaking | *Populus tremuloides* Michx. |
| Baldcypress | *Taxodium distichum* (L.) Rich. |
| Boxelder | *Acer negundo* L. |
| Catalpa | *Catalpa* sp. |
| Chestnut, American | *Castanea dentata* (Marsh.) Borkh. |
| , Asiatic | *Castanea crenata* Sieb. & Zucc. and *Castanea mollissima* Blume |
| , European | *Castanea sativa* Mill. |
| Chinquapin, Allegheny | *Castanea pumila* Mill. |
| , Asiatic | *Castanopsis diversifolia* (Kurz) King. |
| Cottonwood | *Populus deltoides* Bartr. |
| Cottonwood, swamp | *Populus heterophylla* L. |
| Cypress | *Cupressus* sp. |
| Dogwood | *Cornus florida* L. |
| Douglas-fir | *Pseudotsuga menziesii* (Mirb.) Franco |
| Elm | *Ulmus* sp. |
| Elm, American | *Ulmus americana* L. |
| , European | *Ulmus carpinifolia* Gleditsch |
| , Siberian | *Ulmus pumila* L. |
| , slippery | *Ulmus rubra* Muhl. |
| , winged | *Ulmus alata* Michx. |
| Fir | *Abies* sp. |
| Hemlock, eastern | *Tsuga canadensis* (L.) Carr. |
| , western | *Tsuga heterophylla* (Raf.) Sarg. |
| Hickory | *Carya* sp. |
| Honeylocust | *Gleditsia triacanthos* L. |
| Juniper | *Juniperus* sp. |
| Larch, European | *Larix decidua* Mill. |
| , western | *Larix occidentalis* Nutt. |
| Locust, black | *Robinia pseudoacacia* L. |
| Maple | *Acer* sp. |
| Mimosa | *Albizia julibrissin* Durazz. |
| Mulberry | *Morus rubra* L. |
| Oak | *Quercus* sp. |
| Oak, live | *Quercus virginiana* Mill. |
| , Nuttall | *Quercus nuttallii* Palmer |
| , overcup | *Quercus lyrata* Walt. |
| , runner | *Quercus pumila* Walt. |
| , scarlet | *Quercus coccinea* Muenchh. |
| , shingle | *Quercus imbricaria* Michx. |
| , southern red | *Quercus falcata* Michx. |

| | |
|---|---|
| Oak, water | *Quercus nigra* L. |
| , white | *Quercus alba* L. |
| , willow | *Quercus phellos* L. |
| Peach | *Prunus persica* Batsch. |
| Persimmon | *Diospyros virginiana* L. |
| Pine, Australian | *Casuarina* sp. |
| , Austrian | *Pinus nigra* Arn. |
| , Caribbean | *Pinus caribaea* Morelet |
| , Cooper | *Pinus cooperi* Blanco |
| , Coutler | *Pinus coulteri* D. Don |
| , eastern white | *Pinus strobus* L. |
| , Italian stone | *Pinus pinea* L. |
| , Jeffrey | *Pinus jeffreyi* Grev. & Balf. |
| , Jelecote | *Pinus patula* Schl. & Cham. |
| , loblolly | *Pinus taeda* L. |
| , lodgepole | *Pinus contorta* Dougl. |
| , longleaf | *Pinus palustris* Mill. |
| , Monterey | *Pinus radiata* D. Don |
| , Nicaraguan | *Pinus pseudostrobus* Lindl. |
| , pitch | *Pinus rigida* Mill. |
| , ponderosa | *Pinus ponderosa* Laws. |
| , red | *Pinus resinosa* Ait. |
| , Scotch | *Pinus sylvestris* L. |
| , shortleaf | *Pinus echinata* Mill. |
| , slash | *Pinus elliotii* Engelm. |
| , South Florida slash | *Pinus elliotii* Engelm. var. *densa* Little & Dor. |
| , sugar | *Pinus lambertiana* Dougl. |
| , Swiss stone | *Pinus cembra* L. |
| , Torrey | *Pinus torreyana* Parry |
| , Virginia | *Pinus virginiana* Mill. |
| , western white | *Pinus monticola* Dougl. |
| , West Indian | *Pinus occidentalis* Sw. |
| Poplar, Lombardy | *Populus nigra* (L.) var. *italica* Muenchh |
| Redbud | *Cercis canadensis* L. |
| Redcedar, eastern and southern | *Juniperus* sp. |
| , western | *Thuja plicata* Donn |
| Redwood | *Sequoia sempervirens* (D. Don) Endl. |
| Spruce | *Picea* sp. |
| Sugarberry | *Celtis laevigata* Willd. |
| Sumac | *Rhus* sp. |
| Sweetgum | *Liquidambar styraciflua* L. |
| Tamarack | *Larix laricina* (DuRoi) K. Koch |
| Tanoak | *Lithocarpus densiflorus* (Hook. & Arn.) Rehd. |
| Tupelo | *Nyssa* sp. |
| Walnut, black | *Juglans nigra* L. |
| Willow | *Salix* sp. |
| Yellow-poplar | *Liriodendron tulipifera* L. |

## Appendix III

# LIST OF DISEASES AND THEIR PATHOGENS

| | |
|---|---|
| American mistletoe | *Phoradendron* sp. |
| Annosus root and butt rot | *Fomes annosus* (Fr.) Karst. |
| Birch dieback | Cause unknown |
| Black root rot | *Fusarium* sp., *Sclerotium bataticola* Taub. and other fungi |
| Brown spot | *Scirrhia acicola* (Dearn.) Siggers |
| Canker rots | *Irpex mollis* Berk. & Curt.<br>*Polyporus hispidus* Bull. ex Fr.<br>*Poria spiculosa* Campbell & Davidson |
| Chestnut blight | *Endothia parasitica* (Murr.) P. J. & H. W. Anderson |
| Clitocybe root rot | *Clitocybe tabescens* (Scop. ex Fr.) Bres. |
| Damping-off | *Fusarium, Rhizoctonia, Pythium*, etc. |
| Dothiorella wilt of elm | *Dothiorella ulmi* Verrall & May |
| Dothiostroma needle blight | *Dothiostroma pini* Hulbary |
| Dry face | *Diplodia pinea* (Desm.) Kickx. and *Ceratocystis ips* Rumbold and other fungi associated with dry weather. |
| Dutch elm disease | *Ceratocystis ulmi* (Buism.) C. Moreau |
| Dwarf mistletoe | *Arceuthobium* sp. |
| Eastern mistletoe | *Phoradendron flavescens* (Pursh.) Nutt. |
| Elm mosaic | Virus |
| Elm phloem necrosis | Virus: *Morsus ulmi* Holmes |
| Elytroderma needle blight | *Elytroderma deformans* (Weir) Darker |
| Fusiform rust | *Cronartium fusiforme* Hedgc. & Hunt |
| Heartrot | Varius species of *Poria, Polyporus, Fomes, Hydnum*, etc. |
| Hypoderma needle blight | *Hypoderma lethale* Dearn. |
| Laminated root rot | *Poria weirii* Murr. |
| Larch canker | *Dasyscypha willkommii* (Hartig) Rehm. |
| Leaf blister of oak | *Taphrina caerulescens* (Mont. & Desm.) Tul. |
| Littleleaf | *Phytophthora cinnamomi* Rands. In New Zealand also *P. cactorum* (Leb. & Cohn) Schroet. |
| Loblolly pine die-out | Cause unknown |
| Mimosa wilt | *Fusarium oxysporium* f. *perniciosum* (Hepting) Toole |
| Non-girdling cankers | Various species of *Nectria, Strumella, Cytospora, Botryodiplodia*, etc. |
| Oak wilt | *Ceratocystis fagacearum* (Bretz) Hunt |
| Persimmon wilt | *Cephalosporium diospyri* Crandall |
| Pitch canker | *Fusarium lateritium* Nees f. *pini* Hepting |
| Pole blight | Cause unknown |
| Poplar leaf rust | *Melampsora* sp. |

| | |
|---|---|
| Powdery mildew | *Uncinula* sp., *Microsphaera* sp., and others |
| Rhabdocline needle cast | *Rhabdocline pseudotsugae* Syd. |
| Red-brown butt rot | *Polyporus schweinitzii* Fr. |
| Red heart | *Fomes pini* (Brot. ex Fr.) Karst. |
| Slime flux | Bacteria |
| Southern cone rust | *Cronartium strobilinum* Hedgc. & Hahn |
| Sweetgum blight | No specific organism: root rot under adverse soil conditions. |
| Sweetgum lesion | *Botryosphaeria ribis* (Fr.) Gross. & Dug. |
| Systemic brooming of black locust | Virus: *Chlorogenus robiniae* Holmes<br>*Polycladus robiniae* McK. |
| Violet root rot | *Helicobasidium mompa* Tanaka |
| Water-conducting decay fungi | *Poria incrassata* (Berk. & Curt.) Burt<br>*Merulius lacrymans* Fr. |
| Wetwood | Bacteria |
| White pine blister rust | *Cronartium ribicola* A. Fisch. |
| Zonate canker of elm | Virus |

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