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Diseases of Forest Trees and Forest Products

A. F. Verrall
Stephen F. Austin State University

Corrected

SCHOOL OF FORESTRY
STEPHEN F. AUSTIN STATE UNIVERSITY
NACOGDOCHES, TEXAS 75961

DISEASES OF FOREST TREES

AND FOREST PRODUCTS

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A TEXT FOR GENERAL FORESTRY STUDENTS

PRICE: $1.25

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INTRODUCTION

This text is primarily for foresters, not pathologists, and 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 the important southern diseases representing 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. However, to understand diseases, the forester must learn the essentials about fungi, bacteria, viruses, 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.

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:

(1) Mortality, i.e. trees are killed.

(2) Reduction in growth rate. The infected tree survives but decreased height or diameter growth reduces volume increment.

(3) Delayed regeneration. Diseases which kill seedlings may delay regeneration for important periods of time.

(4) Deficiency in 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.

(5) Mortality among preferred species may permit inferior or weed species to take over a site. Chestnut blight essentially eliminated one of our most valued timber trees.

(6) Destruction of merchantable wood. Heartrots usually do not kill but decay the merchantable part of the stem.

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

(8) Deterioration of the site through soil erosion or the buildup of soil-borne pathogens.

(9) Enforced species substitution. A disease may become sufficiently severe to require the favoring of another tree species. For example, in parts of East Africa the fast-growing *Pinus radiata* was abandoned as a plantation species because of *Dothistroma pini*. The slower-growing but resistant *P. patula* was substituted.

The last 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
Diseases	1.2
Insects	1.2
Fire	0.3
Weather and Other	1.8
Unknown	1.1

(Timber Trends in the United States. U. S. Forest Service Forest Resource Report No. 17 Feb. 1965)

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

	BILLIONS OF CUBIC FEET	
CAUSE	Growth Loss	Mortality
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

(Timber Resources for America's Future. U. S. Forest Service. Resource Report No. 14. Jan. 1958)

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. Or trees weakened by a disease or fire may be attacked by bark beetles.

Some important losses were not considered in the above estimates:

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

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

(3) When uncontrolled, black root rot becomes a limiting factor in most southern pine Nurseries.

(4) Damping-off and heat injury occasionally seriously reduce nursery stands.

(5) Fungus attack on wood products in storage and use were not considered:

(a) In a single 3-to-4 month rotation of stored pulpwood, loss from decay at a medium-sized mill can amount to 2000 cords.

(b) Country wide, rot of wood in buildings amount to 10 billion board feet annually. In the south, where conditions are favorable for rapid decay, annual losses are particularly high, despite a heavy bill for control by the use of wood preservatives.

Thus losses due to diseases are an important factor in increasing the cost of raising timber and in shortening the service life of wood products. Also, contrary to general belief, diseases can be controlled and controls are practical and economical.

Types of Diseases

What is a disease? A 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.

Diseases are of two general types:

(a) 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.

(b) 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 part or all of its food therefrom. All parasites are not pathogenic. In pathology we are concerned mainly with harmful parasites (i.e. pathogens) although we will look at such beneficial parasites or symbionts as mycorrhizal fungi and root nodule bacteria.

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

(1) Native pathogens. These usually remain in an endemic state, i.e. they are present but not causing appreciable damage. The reason for this is that under natural forest conditions, the higher plants and animals, the insects, and microorganisms live in a harmonious but dynamic balance. When some disturbing factor occurs a native pathogen may increase in numbers and strength sufficiently to cause an epidemic. Some common distrubing factors are drouth, fire, and logging.

Modern 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 causes very little damage until slash and loblolly pines were extensively planted on longleaf pine sites. Slash and loblolly are susceptible; longleaf is resistant. Perhaps the most basic control for forest diseases will be the planting of the right tree on each site. Remember that pathology is strongly ecological, i.e. the mutual reaction of pathogen and host to a particular set of environmental conditions. Native pathogens play the major role in forest pathology.

or may find new hosts without natural resistance.

(2) Introduced pathogens. When a fungus or other pathogen is brought from one continent to another or even from one region to another in a single continent, it frequently arrives without its natural enemies. Devastating epidemics may result. This happened when the chestnut blight fungus came to the United States on nursery stock from Asia. 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 four groups:

(1) Obligate saprophytes or those capable of living only on dead material. For example, most fungi causing wood decay in buildings cannot attack living trees.

(2) Facultative saprophytes or parasites which also can exist on dead material. Most Pathogens fall in thjs class.

(3) Obligate parasites or those which can live only on live tissue. The rusts are all in this class.

(4) Facultative parasites which normally live as saprophytes but under unusual conditions become parasitic. Many forest pathogens attack trees only when drouths or other unfavorable conditions weakens the tree; at other times they live on dead branches, leaf litter, etc.

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Chapter 1

NON-PARASITIC DISEASES

Periodically non-parasitic, or non-infective, diseases cause important damage, 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 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--drought, soil compaction, etc.

Non-infectious diseases may be due to any of several causes:

Adverse Weather

Man has never experienced a period of normal climate when there is fairly uniform weather over the entire Earth, between winter and summer, or between day and night; when the Earth's surface is more level; and when there are no violent storms. What we know and must contend with is the tail end of the last glacial period. Rather than the "normal" uniformity we have dry and wet areas, polar ice caps lowering temperatures many degrees near the poles, and hot equatorial regions. Interactions of air masses from these extremes result in violent storms, and periods with marked variations of temperature and rainfall which can have important effects on vegetation. These climatic periods 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 l0th and llth were again warm and dry -- so much so that the polar ice caps may have disappeared completely. 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^{o}F and winter temperatures 2 to 4^{o}F which is equivalent to about 100 miles of latitude.

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. Some important direct effects are:

(a) High temperatures. The most common damage due to high temperature is the heat canker that kills very young pine seedlings. This will be discussed under nursery diseases. Sun scald also may cause cankers on the boles of larger trees. However, this is not a very important trouble.

(b) Low temperatures. Low temperatures can result in frost killing or frost cracks in boles of trees. Frost killing is most prevelent by early frost before trees have hardened for the winter or by late frosts after spring growth has started. A few years ago, thousands of exotic trees were frost killed in New Orleans. Native trees, better adapted to the climate, were unharmed. Many of our most serious non-infectious diseases have occurred with trees planted out of their natural range.

Frost cracks (i.e. radial splits in trunks) can occur in either hardwoods or conifers when sudden drops in temperature occur. Presumably, the inner wood remains warmer so that with rapid cooling, the outer layers shrink and split. Sudden warming can lead to a reverse effect

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and periferal shakes. Splits and shakes are particularly common in some northern hardwoods and cause considerable degrade in lumber.

(c) Water deficiency. Drouth or excessive soil drainage can deprive roots of sufficient water for normal development, leading to top dieback and mortality. This is a common trouble in East Texas which is a transition zone between forest and prairie. Greatest damage, however, occurs during drouths in areas normally with high rainfall. During the prolonged drouth of the early 1950's, drouth-caused dieback and mortality was widespread in southeastern United States, particularly with sweetgum and other hardwoods. 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 noticably less affected.

(d) 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.

Loss of growth and mortality due to adverse weather are 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 sylvicultural systems to relieve 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 over abundance 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 so that too much soil water will not be drained off in dry years.

Air Pollution

Industrial plants, household furnaces, and automobiles account for most air pollution. Long-burning city dumps, trash burners, and bog fires are other sources. A number of chemicals have been recognized as pollutants affecting trees and other vegetation. Oxides of sulfur and fluorines are the oldest known air pollutants.

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; Spokana, Washington; and the "copper basin" in Tennessee.

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

More recently we are recognizing new sources of pollutants that are affecting tree growth:

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

(2) The volume of urban photochemical smog is ever increasing. In cities 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 highly deleterious oxidizing substances, including ozone and peroxyacetyl nitrate.

(3) Undoubtedly new types of gases are being released in connection with many new industrial processes.

Plants are damaged by gases absorbed mainly through their leaves. During the growing season, the incidence of temperature inversions that accentuate polution damage usually is less than at other seasons. Because of this, damage to deciduous trees generally is less because they are without leaves during the worst pollution periods. Pines and other conifers that retain their leaves more than one year, are exposed to damage during the fall and winter periods of maximum incidence of inversions. Both here and in Europe, the serious forest air pollution problem is mostly with conifers.

Now, lets look at specific instances of damage:

(1) Ponderosa pine is showing oxidant damage from Los Angeles smog.

(2) Italians report severe damage to *Pinus pinea* around Rome due to pollutants from automobiles.

(3) The British National Pinetrum was moved from Kew, near London, to Kent to avoid the London air pollution problem.

(4) German foresters are changing their views on species composition in some areas to avoid spruce and firs which are most susceptible to SO_2 and fluoride injury.

(5) The landscape within a half mile of the Geige plant in south Alabama is being denuded. This company, in making DDT, uses chlorine extracted from salt pumped from a dome under the forest. The injury may be due to HCL.

(6) Pines started dying up to a half mile from a cresoting plant in south Louisiana. The damage is in line with the cylinder doors and undoubtedly is due to creosote fumes emitted when the doors are open. This is one of the many cases of forest damage we are noticing around industrial plants located in rural areas. The general trend is for industry to move from crowded urban to rural areas. Thus more and more industry is nearer to our forests.

(7) White pine is very sensative to air pollutants. Over much of its range chlorosis, tipburn, and even mortality are frequently encountered. Decline has been most severe in eastern Tennessee where TVA has enormous coal-burning power plants. An individual plant burns thousands of tons of coal a day. These are modern plants which remove most SO_2 and other common toxicants, but in the tall chimneys stack gases are generated after the cleaning process. These unidentified gases lead to what is known as post emergence chronic tipburn (PECT). This first shows up during the winter. The damaged needles

vary from normal color at the base to brown tips with no sharp demarcations. This type of damage has appeared not only around the Kingston TVA plant but also around a ferro-alloy plant, a pulp mill, an iron smelter, and some lesser industries.

A second white pine trouble, emergence tipburn (ET), is more widespread, particularly further north in the white pine range. ET is characterized by a sharp demarcation between brown tips and the green bases. ET first appears in the summer. It is caused by ozone and it doesn't take much to damage white pine, 7 pphm is more than enough. 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. In 1954, the U. S. had no power plant with a boiler capacity of 2 million pounds of steam per hour, but by 1962 over 60% of our power was generated by such plants. This is largely due to new metals that will withstand high pressures. Auto exhaust pollution will have to be prevented by better muffler systems. We will have to find ways to dispose of trash that lessens the current smoke problems of city dumps and trash burners. Perhaps one of the biggest tasks will be the improvement of home heating plants since so many small units are involved.

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. Individual strains resistant to air pollutant damage have been noted with respect to:

Fluoride and ponderosa pine
Ozone and ponderosa pine
Ozone and white pine
PECT and white pine

Perhaps we will never get the general public steamed up about pollutant damage to forest trees but the same pollutants and associated materials are having a grave effect on humans and are even causing alarming degredation of buildings. The last is causing considerable concern with historic buildings in Rome. Thus, even though the general public isn't concerned about forest trees, the forester will indirectly get their support.

Herbicides

Large amounts of 2,4,5-T, 2,4-D, and other plant killing or defoliating chemicals are used annually. Much of this is legitimate to kill weeds and unwanted trees and shrubs, to defoliate crops 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.

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

(b) A serious decline of boxelder shelterbelts in the Dakotas was shown to result from continued exposure to small amounts of a week killer used on adjacent agricultural fields.

(c) The live oaks along the highways in the sugarcane and rice area of Louisiana are gradually being killed. There is little doubt that this is due to drift of herbicides applied to adjacent fields by airplanes.

(d) Pines commonly die or are seriously damaged around electric transmission substations. A soil sterilant, used to prevent plant growth in the substation, gets into the soil water and is absorbed by tree roots. Effects have been noted 50 yards from substations.

(e) In Texas and Oklahoma several million acres a year are sprayed with herbicides to kill brush and unwanted trees on ranges. These chemicals are applied by air. Even with reasonable care, drift to nearby valuable trees occurs occasionally.

Mechanical Injury

Damage by snow, ice, hail, and lightning can be important. Periodically, ice has seriously damaged pine in the south, particularly slash pine. Even when stems are not broken off they can be bent over and never recover. Lightning causes small but continuous mortality in southern pine. A lightning-struck pine almost invariably dies; hardwoods may live but usually have strips of dead bark through which decay fungi may enter. Frequently the struck trees are the tallest ones containing the most wood. One Alabama company maintains a mobile crew to salvage lightning-struck trees before they deteriorate from stain and mold following beetle attack.

Soil Compaction

Soil compaction often adversely affects root development. Poor growth, top dieback, or even total mortality may result. Perhaps the most important effect is increased susceptibility to canker and other fungi. Soil compaction will be an important factor in maintaining recreation areas.

Salt Spray

During storms, 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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Chapter 2

VIRUSES, BACTERIA, AND FUNGI

Viruses and bacteria play only a minor role in forest tree diseases--fungi 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 be of major importance.

Viruses

Viruses are submicroscopic infective principles that can pass through the finest filters that 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. They contain only protein and nucleic acid. The composition of the nucleic acid and the amino acids of the protein vary with different viruses. These components of viruses are the same as those produced in normal plants. It is thought that the virus within the living plant cell causes the plant to form new virus particles rather than normal plant constituents. This would explain why viruses multiply only in living cells.

Viruses cause such important human diseases as small pox, measles, mumps, scarlet fever, and rabies. Also there are a number of destructive plant diseases of virus origin. Heavy economic losses occur with sugar beets, sugarcane, tomato, and tobacco. On the positive side, research indicates that a virus can be used to control the gypsy moth.

The most common symptoms of virus diseases appear in leaves. These include chlorotic spots, mottling, curling, and striping; these may be associated with small-sized leaves and proliferation of branches or brooming. Not all virus infections are descructive. Some varieties of tulips with variegated flowers or shrubs and other ornimentals with whitish or yellowish variegations in leaves, frequently are merely common varieties infected with a virus.

The most common means of transmission of viruses is by sucking insects. In many cases a virus can be transmitted no other way.

There are only a few virus diseases of forest trees and only one of these is of much importance.

(1) 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 elm is susceptible. No control is known.

(2) 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.

(3) 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 mainly unicellular but sometimes 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 must worked out.

Bacteria are extremely important to man. They cause such important diseases as tuberculosis, typhoid fever, and diphtheria; and anthrax and brucellosis of 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 ethyl alcohol, and the control of gypsy moth. Bacteria also cause nodules on the roots of clover, locust, and other leguminous plants. These nodules 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 of main importance in truck and farm crops. Perhaps the most important tree disease incited by a bacterium is fire blight 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.

(1) Wetwood. When using an increment borer on hardwoods, water sometimes flows out of the hole. This indicates a bacterial infection, mainly in the heartwood. The heartwood 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 are suspected of contributing to decline and death.

(2) Water-stored logs. Logs stored in ponds or under water sprays frequently become polluted with bacteria. Although no appreciable lose in strength occurs during normal storage periods, the bacteria do disintegrate ray cells and thus greatly increase the porocity of lumber cut from infected logs. Such porous wood is unsuited for such uses as siding because it is subject to increased danger of rain seepage. Also, if given a dip treatment in a water-repellent preservative, the porous wood absorbs excessive amounts which increases the cost of treatment and interfers with subsequent painting.

(3) Slime in pulp mills. Bacteria, along with fungi, form slime in the closed water systems in pulp mills. Water is used over and over resulting in sufficient nutrients being dissolved from the pulp to support dense populations of microorganisms. Slime coats rollers and paper surfaces and may become so thick that hunks 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, resistant strains of organisms may develop. The development of resistant strains of bacteria, and also fungi, is common. Resistance may develop in one of several ways:

(a) Educatibility. A microorganism constantly exposed to non-lethal amounts of a toxicant becomes educated to tolerate it. For example, one manufacturer of organic mercurials uses a species of *Penicillium* to test the toxicity of their fungicide. Each batch is tested by mixing a series of concentrations in nutrient agars and inoculating with the mold. The batch is accepted if a given concentration inhibits growth. At one time the mold began growing on very high concentrations of ethyl mercuric phosphate. The batches were not inferior but the mold had developed a high tolerance. A new lab assistant was using the mold from plates containing low concentrations of mercury from the previous test. When the mold was regrown on agar without mercury, the resistance was lost. Thus, this type of resistance is not genetically controlled. The actual mechanism involved is not known but it is suspected of being related to changes in the organism's enzyme system.

(b) 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 severly by 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 or 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 make up.

(c) Mutation or hybridization may result in the formation of a new strain. It is not known how important this is in increasing resistance to toxicants, but both processes commonly occur in microorganisms and must be taken into account in breeding plants for disease resistance. This phase will be amplified later, in relation to certain fungus diseases.

Fungi

Fungi are chlorophylless plants whose vegetative structure consists of microscopic filaments. They reproduce by means of spores. Being without chlorophyll, 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.

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

(1) Temperature: Mostly between 15 and 35° C
Most optima between 20 and 30° C
Most maxima between 30 and 35° C

Most fungi will survive severe cold, down to -195° C but temperatures over 50-60° C usually kill in a few hours.

(2) Oxygen: Required but usually only in small amounts.

(3) 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 apparently can stand a higher water-to-oxygen ratio.

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

(5) Light: Fungi will grow in the dark but some require light to sporulate.

These requirements form the basis for much fungus control. For example, by keeping wood air-dry there is no free water and, therefore, it won't decay. 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.

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, primative peoples use fungi as narcotics. Certain poisonous mushrooms are the most common fungi 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) 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, as ringworm and lung infections.

The mycelium (plural, mycelia) or the vegetative structure of fungi may be visible to the naked eye--at least when grown in culture. The mycelium is composed of microscopic threads called hyphae (singular, hypha). Reproduction is 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.

Classification is based on hyphal and fruiting characteristics. We will study only the barest outline of fungus classification because we are more interested in the diseased tree than the fungus causing the disease.

There are four main classes of fungi:

(1) Phycomycetes

The hyphae of these are coenocytic and contain many nuclei, i.e. there are no cross walls except at fruiting structures.

Asexual spores are of three types:

(1) Swarm spores borne in sporangia, which look like bulbous swellings on hyphae. Swarm spores have celia and thus, being motile, are most common in aquotic fungi.

(2) Nonmotile spores borne in sporangia.

(3) Sporangia which germinate without forming spores, i.e. they form a germ tube directly.

Sexual spores are formed after the fusion of male and female elements. 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. Plus and minus sexual elements may be similar or differenciated into distinct male and female structures. A mycelium may be hermaphroditic, i.e. have both + and - elements; or mycelia 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.

(2) Ascomycetes

The hyphae of Ascomycetes are septate and usually have one nucleus per cell. The sexual spores are ascospores borne in asci or sacs. The formation of ascospores involves nuclear fusion and reduction division, which usually results in 8 ascospores in each ascus. Ascospores may be 1-celled or 2 or more celled and germinate by producing a germ tube. In most cases asci are aggregated in special fruiting structures. Most ascocarps are bulbous and sunken in bark or leaf tissue.

Asexual spores are conidia which vary enormously in shape amoung different species. Conidia are borne singly, in chains, or in heads; they are free on hyphae or in special structures resembling ascocarps.

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

(3) Basidiomycetes

The hyphae of Basidiomycetes are septate and, in many cases, binucleate. Sexual spores, i.e. basidiospores, are borne on basidia which are club-shaped modified hyphae. 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 puff balls.

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.

(4) Fungi Imperfecti

These are fungi known to reproduce only asexually. Many undoubtedly have sexual stages which have not yet been found; some many 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 their Fungi Imperfecti name. The members of the Fungi Imperfecti cause the same types of diseases as do the Ascomycetes.

In the above classes there are at least 133 families in 52 orders. 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 actual 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.

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Chapter 3

NURSERY DISEASES

In recent years artificial regeneration has assumed a major role in forestry, both in the United States and in most foreign countries where forests are managed. In the seedling stage, trees are more susceptible to disease. Fortunately, in nurseries values per acre are high and, as a result, intensive controls are feasible.

More recently, the tendency in artificial regeneration is toward direct seeding rather than the planting of nursery-grown seedling. Direct seeding, of course, transfers the seedling disease problem to the forest where it is seldom feasible to practice intensive controls. The few that are economical will be discussed later. In most direct seeding operations it is necessary to use sufficient seed per acre so that surviving seedlings will produce a fully stocked stand. This is natures method of regeneration.

For the time being we will discuss only seedling diseases in nurseries, stressing southern diseases. The same types of diseases occur in other regions but causal organisms and control details may be different.

Damping-off

Damping-off is a general term for the rotting of very young seedlings. To some degree it probably occurs in all nurseries--both coniferous and hardwood. When severe it can wipe out entire beds. There are three types of damping-off:

(1) 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, diognosis is difficult.

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

(3) Top damping-off. This usually occurs with older seedlings during periods of high humidity. The tops are killed.

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

Damping-off is caused by a number of fungi including *Fusarium*, *Rhizoctonia*, and *Pythium*. Many damping-off fungi are common soil fungi which are able to survive in the soil without the host plant, and seldom cause appreciable damage to seedlings. Because of this, damping-off usually can be kept at a low level by manipulating the environment in which the seedlings are growing:

(1) Choose a well-drained site for a nursery.

(2) Delay seeding until the soil temperature is about 60° F at a depth of 6 inches.

(3) Keep the soil pH at 6 or below. Most nursery soils in the South have a pH of 5.5 or lower, which explains why damping-off is rarely serious in southern nurseries.

(4) Avoid dense stands.

(5) Maintain a low level of nitrogen until seedlings are at least 6 weeks old, i.e. are past the damping-off stage. Sawdust as a soil amendment helps regulate the availability of nitrogen. Nitrogen fertilizers are usually applied before cover crops are planted, i.e. a year before pine seedlings are planted. However, they may also be applied as a side dressing after seedlings are a month old.

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

(7) Use only enough mulch to conserve moisture.

Usually, damping-off appears and runs its course in a very short time, and, therefore, it is doubtful that chemical controls applied after the disease appears are worthwhile. None-the-less, Thiram, Captan, and PCNB sometimes are used as soil drenches on pine.

When damping-off consistantly causes losses in pine nurseries over a period of years, treating the seed with Thiram or Captan (l pound per 100 pounds of seed) will pay. The seed treatment may reduce germination by 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 where moisture stress is marked.

The most serious root rot in southern pine nurseries is black root rot. The early stages are like any other root rot, i.e. small roots are decayed. Later, characteristic reddish-black swellings develop on the taproot and large laterals. The seedlings are then chlorotic and stunted. The disease is most severe during late summer when temperatures are high. New lateral roots may appear just below the groundline in early fall but still survival on outplanting is often poor.

Black root rot is caused by a *Fusarium* and *Sclerotium bataticola*. The former causes most of the rot of the laterals; the latter the swellings of the larger roots. Nematodes also frequently are present but many of them are thought to be scavangers.

Preplant fumigation with a complete soil fumigant is the best control. Methyl bromide (at the rate of 1 pound per 150 square feet of bed) is best, and if properly applied the nuresery will be free of serious root rot for 3 to 5 years. Seedlings from fumigated beds are larger and survive better when outplanted than those from unfumigated beds. If the seedlings tend to be too large, withholding water and reducing fertilization will make them smaller.

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

Nematodes

Nematodes are microscopic eel-shaped animals which, in nurseries, feed on roots. Parasitic nematodes may build up gradually over a period of time until severe damage occurs. Because

the symptoms are similar to root rot, i.e. death of fine roots, chlorosis, and stunting, oftentimes it is difficult to determine whether nematodes or root rot 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 lump root rot and nematodes into one complex.

Nematodes are controlled by preplant fumigation. 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 DNCP as a drench after planting.

Fusiform Rust

Fusiform rust, caused by *Cronartium fusiforme*, probably is the most serious disease of loblolly and slash pine seedlings. Shortleaf and longlead pines are resistant. Later fusiform rust will be discussed in detail. For the present, all we need to know is that it spreads from oak to pine during March through June. Most infection occurs in April and early May. The first symptoms are tiny purple spots on needles or stems of small seedlings. The typical spindle-shaped galls on stems are not evident until late summer, and 10 to 20% of the infections may be latent and not evident at lifting time. Infected seedlings, even with latent infections, almost invariably die within three years. Therefore, all infected seedlings should be culled out during grading at lifting time.

Without control losses from fusiform rust commonly are 10 to 20 per cent and, when weather is favorable for infection, may be up to 90 per cent. Losses are most severe in the southern halves of the Gulf States.

Fusiform rust is controlled by spraying nursery beds with ferbam at the rate of 2 pounds per 75 gallons of water per acre. One or two sprays a week are needed through 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 temperatures between 60 and 80°F. Sprays must be on before rainy weather sets in; it will be too late to spray after a 24-hour rainy spell.

Brown Spot

Brown spot, caused by *Scirrhia acicola*, is a serious disease of longlead pine. Later it will be discussed in detail. The fungus attacks the needles which die back from the tips. If uncontrolled, seedlings are defoliated, and so weakened that mortality on outplanting is high. Even when not killed, brown-spotted seedlings may remain in the grass stage for years. Brown spot usually appears about June but is most severe in late summer and fall.

Brown spot is controlled by spraying with 4-4-50 bordeaux mixture. 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, it is a good practice to apply a final spray just before lifting to allow an extra period of protection after outplanting. Once a seedling is established and in vigorous height growth it is resistant.

Non-parasitic Troubles

(1) 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 beds loosely mulched with pine straw.

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

(2) Sand splash. Rain or irregation 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 ¼-inch or more thick. This reduces photosynthesis and lowers growth rate, and favors fungus attack which may kill the seedlings.

To prevent sand splash use adequate mulch. A soft rake or flap can be pulled over beds to dislodge soil from seedlings.

(3) Chlorosis. is a general term for yellowing of foliage. Much chlorosis is due to iron deficiency. With this type the new needles are creamy-yellow while older needles may be normal color. In severe cases, however, the older needles also become chlorotic.

There may be sufficient iron in the soil but unavailable to the seedlings because soil pH (above 7) will bind Fe. 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 use of an iron chelate is the quickest way to correct chlorosis. An application of 3 pounds of actual Fe per acre usually is sufficient.

If the needles of the 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.

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

Control Technics

(1) Fungicides. When a fungicidal spray is used, it is essential that the correct fungicide is correctly mixed and applied in the correct amount at the correct time. Here I want to discuss proper methods of application after you have determined what fungicide is needed to protect against a specific disease.

The plants must be uniformly covered by the use of very small droplets. This requires nozzle orifices not larger than 1/32 inch and pressure of at least 300 pounds per square inch. The other alternative is to apply the fungicide with a mist blower. Large volumes applied as large drops due to insufficient pressure or large orifices will not give good protection.

Nozzles must be of sufficient number and properly spaced and at the proper height above seedlings so that the cones of spray overlap slightly above the seedlings. The amount of spray applied depends on orifice size, pressure, and speed of the tractor. A rig must be calibrated and the tractor speed adjusted to deliver the proper amount of fungicide per acre.

A spreader and sticker usually must be added to a fungicide so that the spray droplets spread over the waxy leaf surfaces and stick to them.

(2) Soil fumigation. To fumigate, a volitile chemical is introduced into the soil which releases toxic vapors. They are used against weeds, nematodes, and fungi. Some are specific for one; some are effective against all three. Success depends on:

(a) Soil temperatures of 50-80^{o} F are best. Usually the lower the temperature, the longer it takes to fumigate.

(b) Soil moisture near field capacity is best. High moisture contents result in poor soil penetration and slow escape.

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

(d) Most recommendations are based on a light-textured soil with little organic material. On heavy soils or those with high organic content, increase the rate of application by 25 to 50%. Also wait longer between fumigation and planting. Turn under cover crops at least two months before fumigating.

(e) Covering beds with a polyethylene film increases effectiveness in most cases.

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CHEMICALS USED FOR CONTROL OF NURSERY DISEASES

Fungicidal Sprays	Manufacturer	Used Against
1. Bordeaux Mixture	(Home made)	Brown spot
2. Ferbam		Rusts
Fermate	Du Pont	
Ferrodow	Dow	
Nu Leaf	California Spray	
Karbam Black	Sherwin-Williams	
Fungicidal Soil Drenches		
1. Thiram		Damping-off
Arasan 75	Du Pont	
Tersan 75	Du Pont	
Thiram 75W	U. S. Rubber	
2, Captan		Damping-off
Captan 50 - W	Stauffer	
Orthocide 50	California Spray	
Fungicidal Seed Treatment		
1. Thiram (see above)		
Preplant Fumigants		
1. Methyl bromide		Fungi, Nematodes
MC-2	Dow	Weeds
Bedfume	Niagara	
Pestmaster	Michigan	
Methyl bromide	Kolker	
Brozone	Dow	
2. Ethylene dibromide (EDB)		Nematodes
Dowfume	Dow	
Soilfume	Niagara	
3. Dichloropropane-dichloropropene		Nematodes
DD	Shell	
Post-plant Fumigant (drench)		
1. DBCP		Nematodes
Fumizone	Dow	
Nemagon	Shell	
Other Chemicals		
1. Iron chelate		Iron chlorosis
Sequestrene	Giegy	
Versonol	Dow	
2. Spreaders and stickers		(with fungicidal sprays)
DuPont spreader-sticker	Du Pont	
Ortho Spray sticker	California Spray	
Santomerse S	Monsanto	
Triton B 1956	Rohm & Haas	

Chapter 4

ROOT DISEASES

We have already mentioned some root rot problems in nurseries. Now we will discuss root rots in the forest.

The forest soil is very complex biologically, and contains multitudes of bacteria, nematodes, fungi, insects, and small animal forms such as earthworms. To these are added the roots of plants, including the trees we are primarily interested in. Under normal conditions, all these organisms are in natural balance; a dynamic balance which changes with season and gradually over a period of years with the ecological succession. Trouble starts when some change in the environment permits a pathogen to gain the upper hand. Flooding, drowth, and fire can radically change an environment. Forest management and harvesting operations also result in important soil changes, but perhaps the most drastic changes come with agriculture. Cultivation results in changes which persist for years after reversion to a forest. Mismanagement in either forestry or agriculture which permits erosion, compaction, etc. is particularly destructive. Under the best forest conditions, probably every tree has some minor root rot because fungi capable of attacking roots are usually present; the main problem is to determine under what conditions root rots become destructive.

Sweetgum Blight

In the 1950's a serious decline of sweetgum appeared from Texas to Delaware. At first a few small twigs die but later larger branches die until the tree is stagheaded or dead.

In 1298 plots in 1954, 67% had dieback. In the 9 states surveyed, 3 to 40% of the sweetgum were affected and 6% of all trees had over 50% of their tops dead. These top symptoms are an expression of root damage. Diseased trees have a greatly reduced number of fine feeder roots. Dead roots contain many common soil fungi and no single species predominates.

On better sites where sweetgum is more vigorous, drowth effects are noticably less. On poor sites with heavy soils, particularly where high contents of sodium and potassium decreases available water, more roots die. The disease was most damaging during the prolonged drowth of the 1950's.

Sweetgum blight is typical of many hardwood diebacks. It is immaterial whether facultative parasĭtesplay a major or minor role in the death of roots. The important point is that most tree species are better adapted to particular sites where they can better withstand occassional adverse weather.

Littleleaf

Littleleaf, like sweetgum blight, is a general decline resulting from a reduction of the feeder root system. It is primarily a disease of shortleaf pine, although other southern pines may be affected to a lesser extent. Trees under 20 years old are seldom attacked.

Symptoms include sparce crowns of short, chlorotic needles; abrupt reduction in diameter growth; dead branches, and large crops of undersized cones. Death follows 1 to 12 years after symptoms first appear.

About 35% of the commercial area of shortleaf east of the Mississippi river is affected. In 1950, 13% of all shortleaf pines over 6" DHB in 18 S.C. Piedmont counties were diseased. Thus littleleaf is one of the most serious diseases of Southern pines.

Littleleaf is primarily a disease of the Piedmont. There 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 removed much of the top soil. Now little remains in most of the Piedmont, and in many places the poor clay subsoils are visible. When the agricultural land was abandoned 50 to 100 years ago, much of it was invaded by shortleaf pine.

The etiology of littleleaf is complex. The trees are weakened by unfavorable soil conditions such as low fertility, poor aeration, and periodic moisture stress. Root tips are killed by the common soil fungus *Phytophthora cinnamomi* and, as a result, the tree is starved, particularly for nitrogen, and littleleaf results.

There are 2 longtime approaches to reducing 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 red cedar, soils eventually could be improved to a point where littleleaf would be unimportant.

In the mean time two practices are available to reduce losses:

(1) In stands with few diseased trees, make light cuts at 10-year intervals. Where 10 to 25% of the trees are affected, cut at 6-year intervals and remove all trees showing littleleaf. If over 25% of the trees are affected, cut all shortleaf as soon as it is merchantable. Short pulpwood rotations are safest on high-hazard sites. These recommendations are based on evidence of how long it takes stands with different degrees of infection to degenerate.

(2) Favor loblolly and other pines relatively resistant to littleleaf and encourage 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 *Pinus radiata* 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 causes a root and butt rot of conifers in many temperate parts of the world. Damage is increasing in the southern states, especially in planted stands following thinning. Losses have been heavy in some plantations and, with large acreages of plantations reaching the thinning age, there is increasing concern among foresters.

Distribution

F. annosus is prevalent throughout the North Temperate Zone and is also found in some tropical and subtropical areas. The fungus is native to the United States and can be found wherever

conifers are grown. 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 incidence is in the coastal states from Virginia to Texas. Although damage has been high in some individual plantings, general losses have not occurred over wide areas.

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

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

Another survey of slash and loblolly pines in the southeast showed that incidence was higher in thinned stands and that damage was greatest in planted stands. Probably most of the planted stands were on old fields.

TYPE OF STAND	Stands with F. annosus	STANDS IN WHICH MORTALITY WAS lacking	occassional	general
Planted, thinned	82%	27%	47%	26%
Planted, unthinned	9%	91%	9%	0%
Natural, thinned	70%	43%	52%	5%
Natural, unthinned	13%	87%	13%	0%

Damage has been greater along the eastern seaboard than from Alabama to Texas.

Hosts

Most conifers probably are susceptible to annosus root rot and it has been reported on 20 species of hardwoods in Europe. Although found fruiting on hardwoods in the United States, none is known to have been killed by it. In the Placerville genetics arboretum in California, the fungus has killed 24 species of pine. The Danes report that 26 species of conifers are susceptible. All the southern pines are attacked and, contrary to general belief, loblolly pine is just as susceptible as slash. The disease is particularly sever on eastern red cedar; root rot is the major cause of mortality in this species.

Signs and Symptoms

Frequently infected southern pines die before there are clear above-ground symptoms, but usually a slight thinning of the crown is evident.

The main signs and symptoms are at the ground level or below:

(1) Fruiting bodies formed at the base of trees or stumps. These may be small buttons or well developed conks several inches across. Frequently, conks are formed below the litter some distance from the trunk but these probably are attached to roots. They are irregularly shaped with a

light-gray to brown upper surface and a creamy white under surface. The undersurface darkens with age. Conks can live for several years. Fruiting bodies may be abundant to scarce or absent. They are most prevalent in cooler weather. Also they can be easily overlooked unless duff is scraped from the bases of trees or stumps.

(2) Light yellowish stringy rot. Initial stages may be irregular pinkish to dull violet stain of the sapwood. Later, whitish pockets of rot develop, sometimes with black spots or flecks in them. These pockets finally merge producing the typical yellowish stringy rot.

(3) Resin infiltrated roots. Resin may ooze out to form incrustations of resin and soil on the root surface.

(4) As the root dies mycelial mats 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 very much like that caused by bark beetles and careful examination is necessary to distinguish the two. Trees weakened by *F. annosus* are attractive to bark beetles and there is little doubt that much annosus root rot mortality is diagnosed as beetle attack.

There is considerable evidence that *F. annosus* will not grow in the soil and can survive in the soil only within roots and butts of trees. Stands apparently become infected mainly by wind-borne spores and because annosus root rot is essentially a disease of thinned stands, it is assumed that most infection occurs through fresh stumps. Other wounds probably account for the small amount of infection in unthinned stands. From the fresh stump the mycelium spreads out through roots into the roots of adjacent rasidual trees. When it reaches the bases of these trees it girdles them. The process is repeated, resulting in an ever increasing number of residuals dying until large openings result.

More stumps become infected than those that lead to infection of residual trees. Some 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. Anyway, conks are found on stumps in healthy stands.

Several site and stand factors apparently influence the severity of *F. annosus* root rot:

(1) Severe mortality is essentially limited to thinned stands, presumably because infection usually occurs through fresh stump tops.

(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.

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

(4) Damage has been greater on old agricultural sites. Such sites probably have 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 create new infections.

The English have found that mortality occurs mainly in young stands and that with age, is greatly reduced; and that later damage is mainly butt rot instead of root rot. There is till no evidence that this will apply to southern pines but in certain west coast species, *F. annosus* is a common butt- and heart 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 permit early infection by *Peniophora gigantea*. 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 here, was creosote but this is no longer recommended. A more effective treatment is technical grade borax dusted onto the tops of stumps with a perforated can. Application must be made at the time the tree is felled.

Recently, Rishbeth in England has found that dried cultures of *P. gigantea* can be used to inoculate fresh stumps so as to get 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. With later thinnings, infection rose sharply.

The summer months are likely to be drier and hotter, which would interfere with spore production and spore germination and infection, should spores land on stumps. *F. annosus* is a relatively low 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 agricultural sites were thinned in the summer, infection might be low even without stump treatment. This certainly should be further investigated.

Other Root Rots

Several fungi cause important root rots of forest trees in other sections of the country, such as *Poria weirii* and *Armillaria mellea*. In the south the agaric *Clitocybe tabescens* has caused considerable damage to introduced tree species in Florida; native trees seem to be resistant. Also black root rot, the destructive nursery disease, damaged considerable acreage of slash pine plantations (2-7 years old) in the sand hills of western Florida. This sandy area was originally covered with the deep-rooted longleaf pine but after these were cut scrub oaks took over. These two cases, *Clitocybe* and *Armillaria*, again illustrate the need for care in planting species out of their natural range or on off sites.

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Chapter 6

LEAF DISEASES

Hardwoods

Hardwoods commonly are attacked by a variety of leaf-spotting fungi. Most are of little or no economic importance in the forest but their disfigurement of shade and ornimental trees is an important factor. As foresters, you frequently will be asked about non-forest trees; and one of the morecommon questions will deal with leaf diseases. Furthermore, a few leaf diseases can become damaging to forest trees when epidemics last more than a year, particularly when defoliation occurs early in the season. Late defoliation seldom affects growth. Also hardwoods have good recuperative power, so a single complete defoliation usually will not kill.

Some hardwoods, as sweetgum, commonly are heavily leaf spotted late in the summer and it believed that this causes premature leaf shedding perhaps a month ahead of normal leaf fall almost every year. There is no noticable effect on growth. In contrast, a heavy infection of leaf blister, which attacks as the leaves unfold in the spring, may seriously reduce growth that year.

There are three common leaf diseases of southern hardwoods:

Leaf Blister of Oaks

This disease, caused by *Taphrina coerulescens,* is widespread and is most common in the southern states during spring and early summer. It is not a major forest tree disease but occasionally causes 50 to 85% defoliation by midsummer which undoubtedly weakens oaks 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. With heavy infection, affected leaves fall prematurely so that the foliage is sparce in late summer.

Direct control measures are not recommended for forest trees. However, fungicidal sprays afford effective control and are feasible on shade, ornimental, and nursery trees. 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. Applications of sprays after buds have burst and leaves have emerged are not effective.

Powdery Mildew

These are common on elms, oaks, and many other hardwoods and crop plants. There are six genera of powdery mildew fungi but the most common in Texas are: *Uncinula* on elm and *Microsphaera* on oak.

The powdery mildew fungi are obligate parasites, i.e. they live only on live tissue. The fungus overwinters on fallen leaves and in the spring the ascospores are wind disseminated and inoculate young leaves. In contrast to most fungi, little moisture is needed for spore germination, which

probably explains the common occurance of powdery mildew during the relatively dry springs and summers in Texas.

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. The mycelium 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 different genera are distinguished by the number of asci per perithecium and the nature of appendages on the perithecia.

Because the fungus overwinters on fallen leaves, the collection and burning of leaves in the fall is an effective control. 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 apt to be moist, or lime-sulfur spray are effective. Control in the forest is not feasible.

Poplar Leaf Rust

Poplar leaf rust is caused by several species of *Melampsora*.

Susceptible young trees can be severely damaged by rust but in general most damage is disfigurement of ornamentals. However, with extensive areas in the South being planted with cottonwood for pulpwood, 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 are at first orange but become brown or even black. These crusty areas contain the teliospores which overwinter on fallen leaves. In the spring, the teliospores germinate to form sporidia which are wind disseminated to inoculate the alternate host. One species infects hemlock; another larch. Aeciospores produced on the coniferous hosts reinfect the poplars. Since neither alternate host occurs in the south, it is assumed that our poplars are infected by uredospores from northern poplars. The evidence for this is further strengthened by the later appearance of rust on poplar in the South than in the North.

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 rapidly multiply resistant stock for nursery use, and to plant only rust resistant cottonwoods in the pulpwood program. This, however, is not being done at present.

Conifers

Conifers, like hardwoods, are attacked by a number of leaf fungi. One of these, brown spot, needs detailed attention; another, leaf rust, will be mentioned in the chapter on rusts.

Brown Spot

Brown spot, caused by *Scirrhia acicola*, is one of the four most important diseases of southern pines. Brown spot occurs in the coastal and gulf states from North Carolina to Texas, and in

Arkansas, Tennessee, 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 *Pinus ponderosa, P. strobus,* and *P. taeda.* 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 not until fire control became a regular practice that brown spot built up to economic proportions. Now it is a limiting factor in longleaf pine management. A 10% destruction of seedling foliage may reduce 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 mesoplyll cells but does not kill the vascular system, explaining why green tissue persists so long between spots. Eventually, however, spots coalesce and the needles die back from the tips. In late winter and early spring the fungus rapidly extends to the needle base without forming spots. Repeated defoliations result in strongly tapered stems of trees in early height growth.

Conidia are produced all year in black fruiting bodies on spots. The sexual spores (ascospores) are produced on dead needles and are most prevelent in early spring. The ascospores are wind borne and are spread 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.

Control

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. With average foliage infections of 35% or more on December 1, burn the following January or February. Infection percentages of 12 to 20 % of dead leaf area indicate burning probably will be necessary in a years time. This advance warning permits preparation (fire breaks, funding, etc.). If there is serious infection during the second year, burning should not be delayed until the third year when burning ordinarily is first needed. Earlier burning sometimes is desirable if the planting stock was not given a final bordeaux spray at lifting time, or if direct seeding is used on areas with a few infected natural seedlings.

Burning should be thorough enough to reach practically all infected seedlings and hot enough to brown all needles as high up as infection occurs. Actual consumption of needles on plants is not desirable, because this means there is enough heat to damage buds and stems. If the needle is killed, the fungus in it also is killed. Longleaf 6 inches to 4, 5, 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 2 to 5 years.

Burning may have an adverse genetic effect. If seedlings have a genetic factor for early height growth or brown-spot resistance they 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 only occassionally used in plantations. In some low flat areas, longleaf is direct seeded on plowed ridges to avoid excessive water damage to newly germinated seed. Brown spot not only develops more rapidly on such exposed seedlings, but there may be insufficient grass to support a sterilizing burn when needed. With this type of seeding, one company in Louisiana applies a bordeaux spray in May of the second year, with a spray rig mounted on a jeep. This has given fairly 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, as slash or loblolly pine on longleaf sites will reduce the brown spot problem because these species are seldom seriously brown spotted. The use of slash and loblolly pines for this reason has been extensive but has created another disease problem, i.e. fusiform rust.

Eventually, the use of longleaf pine individuals genetically resistant to brown spot may be an important means of control. Individual longleafs have been found which have a genetic factor for brown-spot resistance, carried in both the male and female genes. Since longleaf is reproduced only by seed, the multiplication of individuals into extensive seed or planting stock will require many years.

Other Leaf Diseases of Conifers

Several additional leaf diseases occur on conifers, particularly in other sections of the country. In the South, most of these are usually inocuous but periodically flare up; some are important from an ornamental point of view even though they have little effect on growth. One of the latter in the South is hypoderma needle blight of pines caused by *Hypoderma lethale*. Some or all the needles on a branch die back and damage usually is more prevelent 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, such as the scenic Natchez Trace Parkway in Mississippi.

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Chapter 6

CANKERS

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

Some parasitic cankers are annual, i.e. the causal organism operates only during one season after which it dies and the wound calluses over, provided it is not too large. Very likely most annual cankers are caused by very weak parasites attacking trees under moisture stress. Other annual cankers are caused by non-parasitic agents, as frost and heat.

The important cankers are perennial cankers caused by fungi, although bacteria cause 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 repell attack and the rate of canker spread increases. Many canker fungi are most active during the semidorment season. During the active growing season of the tree, the advance of the fungus is stopped and the canker begins to callus over. There are, of course, exceptions to this rule and then girdling and death may follow in short order.

Cankers on Conifers

Larch Canker

This disease, caused by *Dasyscypha willkommii*, 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 near by. All infected trees were destroyed but the fungus was again found in the same localities in 1935 and 1952. Our eastern larch is susceptible and there is no assurance that we can eradicate the fungus in the United States, again illustrating the foolishness of importing planting stock from abroad. How much better it would be to import surface-sterilized seed.

Pitch Canker

Pitch canker, caused by *Fusarium lateritium* f. *lini*, 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 *Pinus occidentalis*. The causal *Fusarium* can attack any of the southern pines. It is the most damaging disease of *P. elliottii* var. *densa* and is one of the few fungi that can readily kill Virginia pine regardless of size. Pitch canker could become a major disease.

The main symptom is a copious flow of pitch. The cankers retain the bark and are usually sunken and the wood beneath cankers in 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 commonly 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, pitch canker often is the main factor in guiding thinning operations.

Dry Face

Another canker-like disease of southern pine is dry face of naval-stores pines. Dry face is characterized by a permanent cessation of gum flow from a portion or all of a turpentine face. It may occur as early as the third year of work on a front face, but is more common on back faces. Dry faces are more subject to attack 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.

Drought 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 technics can aggravate drought effects. Such technics include: (1) making faces greater than one third of the tree circumference, (2) working 2 or more faces simultaneously, (3) chipping deeply into the wood, and (4) using broadaxe incisions for inserting gutters. Controlling crown length by proper thinning helps because trees with crowns less than one third the height are more prone to dry face. Thinning stands well ahead of turpentining helps develop long crowns. In older stands having short crowns, cupping should be avoided. Bark chipping with acid treatment instead of wood chipping, and the use of nailed instead of inserted gutters in recent years has reduced the incidence of dry face by 50%. Many operators limit naval stores work to 3 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.

Several fungi, including the common stainers *Diplodia pinea* and *Ceratocystis ips*, are associated with dry face. These fungi probably accelerate and aggravate the rate of dry face extension and are not the primary cause.

On Hardwoods

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 phloem, but the important ones also kill the cambium. As in the case of conifer cankers, many are of minor importance and are believed to be caused by facultative parasites able to attack only trees weakened by moisture stress or other unfavorable site factor.

Four cankers, or groups of similar cankers, are of economic importance in the South.

Typical Hardwood Cankers

Cankers caused by various species of *Nectria*, *Strumella*, *Cytospora*, and *Botryodiplodia* on all the commercial southern hardwoods. 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 we went through the most serious drought known in the South; we have had more severe individual drought years but because of the number of years involved the over all effect was more pronounced. In the Mississippi River bottomlands, water tables fell as much as 9 feet. The weakening effect of this caused a plethora of hardwood cankers all over the South. Many of the cankers described in the 1950's have essentially disappeared now that more normal rainfalls have returned. (3) Planting large acreages of such species as cottonwood without paying sufficient

attention to site requirements. On the heavier clay soils cottonwood, and some other hardwoods, grow with low vigor and thus are susceptable to cankering.

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

Sweetgum Lesion

Sweetgum lesion, caused by *Botrysphaeria ribis*, occurs in the southern 100 miles of the sweetgum range. It does not kill but seriously degrades lumber and veneer cut from them.

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. Lesions later heal over forming a ridge or hump. Many infections occur year after year until the lower bole becomes knarled and deformed. Lesions occur mainly on the lower 8 feet of the trunk but have been found at a height of 28 feet. As many as 28 healed cankers have been found in a single cross section.

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

Canker Rots

A few of the heartrot fungi that attack southern hardwoods, work out through the bark and cause cankers:

Polyporus hispidus, mostly on willow and water oaks.
Poria spiculosa, on willow and water oaks and honeylocust.
Irpex mollis, on red oaks.

Other species, of course, are also attacked. In one study in the Piedmont spiculosa cankers were found on 8.1% of hickories and 7.7% of red oaks. In a 2000 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 heartrot caused.

No practical controls are known. Because of rapid heartrot 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*, was first found in the United States in 1904 and undoubtedly was introduced from Asia on nursery stock. By 1913, it was apparent that American chestnut was doomed as a commercial timber tree. Chestnut was one of our most beautiful timber trees: had high quality wood, grew rapidly, and was easily managed silviculturally. This is another example of the foolishness of introducing foreign tree species in the seedling stage.

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

Spores of the pathogen can be carried long distances by birds, wind, or the transportation of infected material such as logs. Blight was an unusually fast spreading disease. The area of 80 percent 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 timber. No hybrid suitable for timber production has been developed. Some recent research is directed toward creating resistant mutants

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Chapter 7

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, by direct action, it causes wilting or (2) the toxin stimulates the production of tyloses or gums which occlude the vessels so that the sap flow is cut off and wilting results. Many wilts also cause discolorations in the xylem or cambial region of stems and branches. Some of these are sufficiently characteristic to be of diognostic value but in many cases it is necessary to isolate and identify the pathogen for positive identification.

At present, tree wilts are of most concern to arboriculturists. The Dutch elm disease and phloem necrosis (see Viruses) have essentially eliminated the beautiful American elm from many cities in the Northeast and mimosa wilt raised havoc with mimosa in the Southeast. However, two important forest trees, i.e. the oaks and elms, have serious wilt diseases that could importantly affect the hardwood forests. The more common wilts are:

Persimmon Wilt

Persimmon wilt, caused by *Cephalosporium diospyri*, occurs from North Carolina to Florida westward to Texas and Oklahoma. It is fast acting and lethal; death usually occurs within two years. It has not been found in the bottomlands where persimmon reaches commercial timber size. In the 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*, may have been introduced from Haiti. It was first found in the United States in 1930 in North Carolina and has gradually spread westward to the Louisiana border. Once the disease appears in an area, the common mimosa (*Albizzia julibrissin*) is eliminated. The fungus spread 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*, occurs through the range of *Ulmus americana*. It is common on American elm and occasionally attacks slippery and Siberian elms. It usually takes several years to kill.

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

Dutch Elm Disease

The causal fungus, *Ceratocystis ulmi*, probably originated in Asia, because Asian elms are resistant, and entered Europe during World War I. It first appeared in the United States in 1930 in Cleveland and Cincinnati and now occurs throughout northeastern United States and southeastern Canada and as far west as Colorado.

All American and European elms are susceptible. Trees of all ages are attacked and seldom does an infected tree survive. The fungus entered the United States on elm burl logs from Europe. It is spread mainly by *Scolytus multistriatus*, a small bark bettle introduced from Europe many years ago on green elm used in crates for English china. This beetle and a similar American beetle, breed in wilted trees, become contaminated with spores, and inoculate healthy elms by feeding in twig crotches.

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 or (2) by spraying live trees with DDT to prevent beetle feeding. These controls are effective only with a concerted effort by an entire community.

A resistant selection of *Ulmus carpinifolia* has been found but it does not have the desirable form of the American elm. Search is continuing for a resistant strain of American elm and for hybrids of this and the resistant Asian elms. Neither search has been successful so far.

Oak Wilt

Oak wilt, caused by *Ceratocystis fagacearum*, is a puzzling disease. It is a very rapid and sure killer that would devastate our oak forests if the fungus ever had an effecient means of infecting oaks. Personally, I believe the fungus is native everywhere it has been found from Texas, Tennessee, and North Carolina northward. In a few areas it has caused extensive mortality but most places it leads only to occassional mortality. 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 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 in 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; this is what one would expect with a native pathogen.

One disturbing factor is that many foreign countries will not accept oak lumber from any state known to have oak wilt. Thus many oak producing states are excluded from the foreign market. This quarantine seems silly to me. 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.

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PLANT RUSTS

Economically, the rusts are one of the most important groups of the Basidiomycetes--in fact of all fungi. Two well known rusts are black stem-rust of wheat and white pine blister rust, which cause enormous damage and emphasize the economic importance of this group. Other rusts seriously attack coffee, asparagus, beans, juniper, snapdragon, carnation, and many other crops. Cereal rusts were recognized by the ancient Romans who believed that two gods were responsible for them. Rust epidemics have caused serious food shortages and famines over the ages.

In recent years some pathologists claim to have grown rusts in artificial culture, but most still consider them to be obligate parasites that 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 protoplast.

The typical rust has a complex life cycle composed of 5 stages:

STATE		SPORE	NUCLEAR CONDITION	PRODUCED ON HOST	SPORE FUNCTION
0	Pycnial	Pycnospore	Haploid	1	Sexual reproduction only
I	Aecial	Aeciospore	Dicaryotic	1	Infects host 2
II	Uredinial	Uredospore	Dicaryotic	2	Infects host 2
III	Telial	Teliospore	Dicaryotic - Diploid	2	Germinates to produce IV
IV	Sporidial	Sporidium	Haploid	2	Infects host 1

Certain rusts apparently have lost some stages. One tree rust, *Peridermium harknessii*, undoubtedly is a *Cronartium* that now regularly produces 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 in the East on Scotch pine. Another western rust, *Cronartium coleosporioides*, produces all 5 stages and has an alternate host (paintbrush) but the aeciospores can reinfect pine. Therefore, it can exist as stage I only.

Each section of the Northern Hemisphere has at least one important forest tree rust.

White Pine Blister Rust *(Cronartium ribicola)*

This rust attacks most of the five-needle pines and has been particularly destructive on eastern white and sugar pines. It must be considered in the management of these species.

Blister rust originally was a relatively inocuous Asian rust on Swiss stone pine. When our eastern white pine was introduced and extensively planted in Europe during the 1700 and 1800's, the rust gradually spread over most of Europe and became a pest on *P. strobus*. When we started serious forest management in the early 1900's, we had no experience in nursery management. Consequently, we imported 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 spread to the western white pine forests.

The alternate hosts, i.e. the gooseberries and currents of the genus *Ribes*, occur wild almost everywhere white pines are native.

The primary control of blister rust is eradication of the alternate host. The sporidia are very delicate and quickly lose viability so that the effective distance of sporidial dissemination from native *Ribes* usually is less than 900 feet. Spread from the European black current, which is extensively planted in this country, can be as much as a mile. Normally, removal of *Rives* within 900 feet of white pine stands gives adequate protection, provided no European black currents 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. They are applied in oil mainly to the bases of stems, or in water to the foliage where *Ribes* is abundant.

In the West, antibiotics (Actidione and Phytoactin) are being used to treat infected pines. At first, basal sprays in oil were used but more recently application has been by aerial foliar sprays. There is considerable controversy on the effectiveness of the antibiotics for blister rust control. There is good evidence that they are ineffective on eastern white pine for blister rust control or on southern pines for fusiform rust control. The antibiotics applied directly to cankers or galls certainly can inhibit sporulation for some time but it has not been proven that the fungus is killed.

Fusiform Rust *(Cronartium fusiforme)*

In 1930, fusiform rust 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 the common occurrance of the alternate host (oaks) are coextensive with the natural range of longleaf pine which is fairly resistant to this rust. Susceptibility to brown spot and delay in initial height growth militate against longleaf in the managed forest and, therefore, slash and loblolly pines have been encouraged on longleaf sites so that now very little acreage of longleaf remains. Slash and loblolly are highly susceptible to fusiform rust. So by encouraging a change in pine species, we merely exchanged one problem for another.

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 stopped at the Mississippi River, but now it extends into the eastern tier of counties of Texas. So far, however, fusiform rust is not severe in most of the Texas pine area.

Natural infections have been found on 12 pines: *Pinus elliottii* (typical and var. *densa)*, *P. palustris*, *P. taeda*, *P. echinata*, *P. rigida*, *P. serotina*, *P. caribaea*, *P. cooperi* var. *orneiasi*, *P. nigra*, *P. pseudostrobus*, and *P. torreyana*. Inoculations have shown 13 other pines are susceptible. These include *P. ponderosa*, *P. radiata*, *P. contorta*, *P. coulteri*, and *P. jeffreyi*.

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 found on shortleaf pine actually were not on natural hybrids of shortleaf and loblolly pines.

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 *Castanopsis diversifolia*, *Lithocarpus densiflora*, and 4 species of *Castanea*.

Cronartium fusiforme is a heteroecious, long cycle rust, i.e. it requires 2 hosts and produces all 5 stages:

Pycnia 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.
Telia 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 occassionally heavy infection leads to defoliation. The uredia appear as bright orange pustules and the telia as brownish hairs on the undersides of leaves or occassionally on succulent stem tissue.

Pine infections occur through stomata on new needles or succulent stem tissue, resulting in purplish spots. Six to 12 months later, a spindle-shaped gall develops on the stem or branch adjacent to the infected needle. 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 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. Stem infections on old trees lead to weak, distorted boles that are easily windbroken.

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 frequently are envolved largely with removal of badly rusted trees.

Seedlings infected in the nursery seldom survive outplanting. Seedlings from 4 nurseries planted in south Mississippi showed the following survivals:

IN NURSERY	SURVIVAL ON OUTPLANTING	
	10 MO.	19 MO.
Non infected	78%	76% (8% latent infection)
Infected	29%	16%

Conditions Necessary for Infection

All spore forms will germinate at temperatures between 15 and 28^{o} C, with an optimum around 21-22^{o} C. Because spring temperatures usually range from 15 to 25^{o} C, temperature seldom is a limiting factor for rust infection of either pine or oak.

Adequate moisture is the critical factor determining the amount of infection with 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 spordidia germinate in an additional 6 hours. Thus for heavy infection of pine, a saturated atmosphere for at least 18 hours is needed.

Only new succulent pine tissue is subject to infection. Frequently, rust spores start to be produced before pine buds open and, therefore, any factor which hastens opening of pine buds will increase the danger of rust infection. Pine stands burned over during the winter or those cultivated or fertilized start growth earlier and are more subject to infection.

As many as 6 to 8 years may pass without serious infection in any 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

(1) Fungicidal sprays (Ferbam) are used in nurseries and young seed orchards. The same schedules are used for both (See nursery diseases).

In Georgia, it has been found possible to limit spraying to preceed periods when 18 hours of wet weather are predicted. In Louisiana and Mississippi, there are more foggy nights and even though fogs seldom last for the 18 hours needed for maximum infection, they commonly persist for 8 to 12 hours which permits limited infection. Because the number of these limited infection periods is high over the entire infection period, the total amount of infection may be high. Therefore, spraying at 3-day intervals is safer.

(2) On high-hazard sites, longleaf and shortleaf pines should be encouraged. 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.

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

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

(5) 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 already with stem infections except where the stem infection is on the terminal where it 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 will prevent stem infections even when the branch gall is quite close to the stem.

(6) Someday genetic resistance will play a role in rust control. Some individual slash pines show some resistance but the more promising strains are hybrids of shortleaf with slash or loblolly. With cereals new rust-resistant plants must be constantly developed because the cereal rusts are comprised of physiologic forms and eventually some form capable of attacking a resistant cereal builds up. So far there is no evidence that this will happen with fusiform rust.

(7) 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 the west is less rust susceptible than that from east of the planting site.

Southern Cone Rust (*Cronartium strobilinum*)

Twenty years ago, cone rust was only an oddity of which few foresters had ever heard. Today it is an important disease in the Southeast. This change resulted from the locating of several expensive seed orchards 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 South Atlantic and Gulf Coasts and across south Georgia and north Florida. In Texas the live oak belt widens but the pine hosts are not common.

Among the pines, only longleaf and slash pines are susceptible. The main alternate hosts are the live oaks (*Quercus virginiana, Q. pumila,* and *Q. nigra* 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 overwinters on living oak leaves.

On oak, the symptoms and signs are the same as those of fusiform rust except for time of sporulation and inconspicuous color differences. On pine, infected first-year conlets increase rapidly and by late spring are as large as normal second-year cones. 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

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

(2) 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.

(3) 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 5 to 6 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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Chapter 9

HEART ROTS

Considering all factors (including 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 5500 million board feet and, in addition, reduce the quality of an additional volume. Therefore, it is essential that foresters are 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*; but 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 or microscopic hyphae within the bole which secrete enzymes that dissolve the wood constituents. Each tree species, even those with so-called decay resistant heartwood, is attacked by at least one species of heart-rotting fungus.

Most decay in living trees is heart rot because sapwood usually has too high a moisture content for decay fungi to develop. Of course, at wounds or dead parts the sapwood dries sufficiently to decay. Not all decayers are harmful; those which decay down and dead timber and logging slash are highly important in that they reduce fire hazard and break down the complex lignins and celluloses of wood and return them to the soil as simpler compounds reusable by higher plants.

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 cellulose and lignin materials 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 other characteristic of the decayed wood (as pocket, stringy, mottled, and cubical rots).

Annosus Butt Rot

In Europe, *Fomes annosus* is less likely to cause mortality after stands reach about 20 years of age on acid soils and 35 years on alkaline soils, after which it causes butt rot. In the West, *F. annosus* causes the most important heart rot of over mature hemlock, usually of the butt log but has been found as high as 40 feet. We are hoping that mortality in southern pine will cease with age, but so far there is no indication of this in stands up to 30 years of age on root-rot susceptible sites (see chapter on root rots).

Red - brown Butt Rot of Southern Pines

Polyporus schweinitzii causes red-brown butt rot in southern pines and other conifers elsewhere. Occassionally this velvet-top fungus attacks and kills small trees by rotting their roots, but it is most important as a butt rotter. 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 such basal wounds as fire scars. When found on unwounded trees, it is assumed they entered through a root.

Red Heart

Red heart or red ring rot, caused by *Fomes pini*, like other heart rots, now is of minor importance in southern pine because of the small amount of heartwood in second-growth pine. However, dead branch stubs do become infected, so that any factor which increases the amount of heartwood 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 pocked 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. The tops are rough, zonate, and nearly black; the under pore surface and recent marginal growth is light to dark brown. Any fruiting bodies at branch stubs in southern pine usually are *F. pini*.

Rots of Hardwoods

Heart rot is extremely important in southern 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 wild fires in the past created many wounds through which fungi could enter.

There are three general types of heart rot in hardwood stands. (1) Butt rot mainly associated with fire wounds is a common source of cull. 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. (2) Top rots enter through dead branch stubs or stag-headed tops such as those due to dieback during droughts. Top rot is assuming more importance with the current tendency to salvage topwood for pulpwood and other uses. (3) 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. The important canker rots are caused by *Polyporus hispidus*, *Poria spiculosa*, and *Irpex mollis*. Canker rots are among the fastest acting rots and, therefore, infected trees should be salvaged as soon as feasible after finding; 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 be 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 of rot to be expected behind recent fire wounds the following can be used:

A. 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.

B. Rate per decade after first 10 years

Overcup oak and sugarberry:	2.0 ft.
Red oaks and green ash:	1.3 ft
Water hickory:	1.6 ft.
Sweetgum and elm:	0.9 ft.

This data can be used in routine timber marking as a guide in deciding what trees to leave. But it should be remembered that the most valuable part of the tree will rot, breakage may destroy the entire tree, and stain and insect degrade often associated with wounds, can increase the amount of degrade. In heavily fire-wounded stands, consideration should be given to complete harvesting before decay becomes serious and to make room for a new stand.

The amount of rot behind old fire scars will depend on tree species, the decay fungus causing the rot, and the age and size of the scar. The amount 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 DBH reduced 1 inch for every 6 feet of rot. Also DBH 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 chapter. Cull trees should be felled or deadened to make room for replacement trees.

Lessening decay in sprout stands. Information on decay in hardwood sprout stands is based mainly on studies of oak stands in the Appalachian and Allegheny Regions and in Illinois and Missouri and in sweetgum stands in Mississippi.

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

With older stands (over 20 years or so) 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 some evidence that one member of fused sprouts of sweetgum of commercial size can be harvested without serious decay development in the remaining sprout for 10 years. However, decay is present and will develop rapidly thereafter.

What to do about rot entering through branch stubs. General rules have been devised for making deductions in top logs with rot (see references). The average length of the rot column in southern bottomland hardwoods is as follows:

SPECIES AND SCAR AGE	LENGTH OF ROT COLUMN IN FEET Branches 1-3"	Branches 4-6"	Branches 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 6 inches in diameter.

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

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

Deterioration of Logging Slash

This is important because it affects fire hazard and salvage possibilities. Usually, fire hazard is the most important consideration. In the South, slash decays more rapidly than in most other parts of the country and consequently, special handling methods are seldom employed and slash is left as it falls. In general, rate of deterioration appears to be about the same for 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 2 years and a low hazard in 3 years. Other species reach a medium hazard in 4 years and a low hazard in 6 years.

Salvage value as pulpwood and dimension bolts is reduced rapidly with age. Usually fall cut sapwood is usable up to 6 months while spring cut is cull after 2 months. Heartwood is usable for about 2 months longer than sapwood. Even for the lowest quality products, topwood is essentially valueless after one year.

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 wood. If the borings are at breast height, these discolorations are well up in the butt log and average 3 to 13 inches in length in two years. Some of this discoloration undoubtedly is physiological in origin, but stain and decay fungi have been isolated from an appeciable proportion of borings sampled. Even without decay, the stain associated with borings is a defect in factory or veneer logs. Therefore, the number of borings should be kept at a minimum, particularly in valuable hardwood stands.

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FUNGI ATTACKING WOOD DURING SEASONING AND USE

By far the most important deteriorating agents 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 preservation techniques and the use of wood.

To understand fungi, remember they are plants and to grow they require water, air, food, and suitable temperature. Because fungi do not have chlorophyll to combine minerals, air, and water into complex organic substances, they live on foods already elabortated 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 continue to do so for weeks explaining why wood exposed under favorable conditions almost always becomes infected.

The working parts of fungi are their microscopic hyphae which secrete enzymes that dissolve wood substances or carbohydrates stored in wood. The resulting soluble materials are absorbed as food by the hyphae.

Depending on the part of the wood dissolved and the effect on the wood, wood-inhabiting fungi can be divided into four groups:

(1) Molds live mainly on materials stored in sapwood; heartwood seldom molds appreciably. Mold hyphae are colorless and, therefore, do not cause deep coloration of wood; but they do discolor the surface by producing masses of colored spores. The common molds are green, black, or white.

Molds have no practical effect on the strength fo wood, except for the most exacting uses. Only a slight reduction in toughness occurs. But molds do have a profound effect on wood. To secure the starches and sugars stored in ray cells they dissolve the ends of the ray cells, which greatly increases the permeability of the wood. The greatest effect is in pine; it is less uniform in Douglas-fir and gum. The most severe molding usually occurs before the original seasoning but rewetted wood also will mold. The increased permeability of molded wood can affect its usefulness in several ways:

(a) 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 under some weather conditions, molded and bright pieces have different moisture contents and require different treating schedules regardless of the treating method used. Infected and uninfected wood in the same charge may be responsible for some of the variability found with pressure treatment.

(b) If used for such uses 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.

(c) Wood with high permeability is favored by the pulp industry because it is penetrated more easily by digesting chemicals.

An interesting orange mold commonly develops luxuriantly on wood which has been steamed. When a veneer mill is shut down over the weekend, buggies of wet veneer may become completely encased in mold by Monday morning. Veneer to be air dried usually is dipped in a fungicide to prevent development of this mold and other fungi.

(2) Staining fungi are similar to molds in method of action on wood but unlike molds, have dark hyphae which discolor wood deeply so that stain cannot be planed off. Stains spoil the appearance fo wood for uses where natural finishes are desired.

Stains increase absorbency of wood, but usually less markedly than do molds. Also heavily stained wood almost always has incipient decay infections which are not killed by air seasoning but merely become dormant. They revive when the wood is rewetted. It is mainly for this reason that bright kiln-dried lumber should be used for all exterior woodwork of buildings.

Stains may be almost any color: blue, brown, yellow, red, green, or orange. Blue and brown stains are most common.

Most molds and stains develop rapidly during spring, summer, and fall weather. They use mainly the original sap in wood for moisture and, therefore, develop mostly in stored logs, and in wood products during air seasoning. Decay fungi start growth at the same time but since they develop more slowly, they frequently are not obvious during the seasoning period.

(3) Decay fungi usually start growth by utilizing stored carbohydrates, just as molds and stainers do, but they eventually also attack the cell walls and destroy the wood. Some decay fungi, i.e. the brown rotters, remove mainly cellulosic materials. Others remove both lignin and cellulose and cause white rot. Many are between these two extremes. Significant weakening occurs before decay is obvious.

In the Gulf States, temperatures are suitable for decay during much of the year.

Most of the general construction woods are susceptible to decay. The sapwood of all species will decay. The heartwood of a few species, such as redwood, cypress, and cedars, contains natural preservatives and is decay resistant.

Sapwood, as it comes from the living tree usually is too wet to decay because it contains too little air. 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% water) wood is safe from decay because it lacks available water.

Incipient decay in air-seasoned lumber can be detected by:

(a) The pick test. An ice pick or knife point is jabbed into the wood and pried down. Sound wood will pry out in long splinters; decayed wood is brash and breaks out in short hunks.

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

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

Decay fungi vary in their resistance to toxicants. There is at least one species that shows an important degree of resistance to each of the common fungicides used on wood. Fortunately, a fungus resistant to one toxicant usually is susceptible to others. Also resistances normally do not lead to widespread treatment failure but variation in tolerances of different fungi to different chemicals explains why mixtures of toxicants may have some advantage over single toxicants. When used alone toxicants must be at concentrations that will prevent growth of the more resistant fungi.

Temperatures reached in standard kiln-drying and pressure-treating schedules sterilize wood. Dip and cold-soak treatments kill only where the preservative reaches the fungi and, as a result, internal decay is common in dip-treated wood exposed to severe rain seepage.

(4) Soft-rotters. In recent years we have become aware of a special type of rot caused not by regular decayers but by fungi related to the molds and stainers. These are soft-rotters which can tolerate both wetter and drier conditions than the usual decay fungi. Soft-rot fungi grow within wood cell walls proper; ordinary decay fungi grow almost exclusively in cell cavities. Soft-rot develops rather slowly, first softening the surface, and gradually working into the interior. Usually there is a sharp demarcation between decayed and sound wood and the surface has profuse cracking across the grain similar to weatherbeaten driftwood. Many of the so-called decay resistant woods are attached and soft-rot has 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 is realized. One might speculate that without soft-rot the normal service life of treated wood exposed under wet conditions might be appreciably greater.

Earlier it was pointed out that bacteria cause wetwood in living trees and that in the case of aspen, wetwood tends to collapse during kiln drying. 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.

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FUNGUS ATTACK ON UNSEASONED WOOD

The sap in a living tree serves as a source of water for wood-inhabiting fungi in logs and other round green products and also in unseasoned products cut from them. Usually the moisture content of sapwood in a living tree is so high that many fungi cannot develop in it until seasoning starts and thus, sufficient oxygen is available within the wood. Sometime between the felling of a tree and complete seasoning, the water-oxygen ratio will be suitable for the attack of any of the wood-deteriorating organisms. Therefore, the protection of green wood products is a vital step in the manufacture of 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 dry below fiber saturation. There are three basic controls:

(1) Quick utilization.

(2) Fungicidal treatment.

(3) Special handling methods to promote rapid drying or, conversely, to maintain high moisture contents.

Fungi are carried by insects as well as by the wind. This means that it is also necessary to control bark beetles and wood-boring insects to effectively protect from fungus attack round green products with the bark attached.

Sawlogs

Quick utilization is the most effective means of preventing degrade from stain and decay in logs. Most small mills did this but the wage and hour law has essentially eliminated the small mill. Large mills store logs, frequently for several months during the winter, as insurance against shutdowns.

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 did permit penetration of bacteria and some mold-like fungi which increased porocity that has a deleterious effect on lumber for some uses. Also, floaters raised a problem in ponding because the submerged portion develops a higher specific gravity than the exposed portion. Eventually, the exposed parts are attacked by insects and fungi. Attempts to roll floaters periodically to maintain high moisture contents in all parts of the logs failed because the higher specific gravity of the formerly submerged portion 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.

Spraying logs with a solution consisting of 2.5% pentachlorophenol plus 0.5% gamma benzene hexachloride in No. 2 fuel oil, will keep fungi and insects out of logs for several months. A water emulsion can be prepared by using sodium pentachlorophenate and an emulsifiable form of BHC. For best results, the logs must be thoroughly sprayed on the ends and sides the day the trees are felled during May through October. A day or two delay during other months usually is not serious.

Recently, mills are beginning to use a continuous water spray 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 but the interiors remain bright. However, several colorless fungi and bacteria do penetrate both pine and hardwood logs under sprays. The resulting increased porocity 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 porocity occur.

Incipient log infections of stain, mold, and decay fungi are less serious in pine than in the past. Now most pine lumber is kiln dried, which kills all incipient infections. But when lumber cut from logs with incipient infections is air dried, stain, mold, and decay may develop to degrading proportions during seasoning. Also, air drying does not kill incipient decay infections so that, even if serious development does not occur during seasoning, the infections merely become dormant and can revive if the wood is rewetted in storage or use.

Log infections now are of most importance in hardwoods. Most hardwood lumber is partially air dried before kiln drying. Thus lumber cut from infected logs may be seriously stained before it is kiln dired. In contrast, pine lumber is kiln dried green from the saw.

<u>Posts, poles, and piling</u>

These products are peeled before seasoning. If stored long enough to become fully air-dried before being preservatively treated, it is extremely likely that heavy stain will develop, and in large items, serious decay may develop. The pressure treating industry sometimes avoids this by only partially air seasoning and by using treating schedules that complete the drying in the treating cylinder.

A common practice in the South is to apply a fungicidal spray as the poles come through the lathe before going into the drying yard. In combination, these two methods (fungicidal spray and partial seasoning) give satisfactory control of stain and decay.

Currently there is a tendency for buyers of southern poles to specify kiln drying. After kilning, poles are often stored for short periods in the open. Kiln-dried poles mold rapidly and heavily — more so than non-kiln-dried ones. This mold discoloration is not hidden by light pentachlorophenol solutions and buyers may reject molded poles. A fungicidal treatment after kilning may be necessary.

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 costs but insures a good final product.

It is probable that successful cold-soaking treatment of southern pine fence posts 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. Kiln-dried posts have been particularly difficult to treat except by pressure methods. In kiln drying not only are fungus infections prevented, but there is a tendency for resins to accumulate near the surface to further reduce the normal low lateral penetrability. With normal air seasoning, sufficient mold and stain development occurs to improve penetrability. But it must be remembered that infected posts absorb sufficient rain water to interfere with preservative treatment; posts must be dry before being treated by soaking. The treatment of heavily and lightly molded pieces in the same charge, either soak or pressure treatment, may result in variable retentions of preservative.

A fluoride treatment 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

In the South, stored pulpwood deteriorates rapidly unless special precautions are taken. In general, peeled bolts stain more rapidly than rough bolts and decay more during the first two months of summer and 4 to 5 months of fall and winter storage. For longer storage peeling helps. Large bolts decay slower than small ones and longer lengths decay more slowly. Large piles are safer than small piles. All this is related to drying rate.

Under usual conditions the loss in specific gravity of stored rough southern pine bolts will average 3 to 5% in 2 months of summer storage and 5 to 6 months of fall and winter storage. To these losses must be added increased loss as fines in chipping and screaning and, with brown rots, a decrease yield per pound of chips. Also, stain increases the cost of bleaching.

Real savings by decay and stain prevention can be secured only by prompt utilization or by the following special preventive measures:

(1) Spray with or dip in 2½% pentachlorophenol plus 0.5% gamma benzene hexachloride. Now that considerable pulpwood is storedat concentration yards in steel-strapped bundles, dipping is not prohibitively costly. To be fully effective treatment must be done shortly after felling, i.e. before fungi and insects have penetrated the bolts.

(2) Spray with a 5% fluoride (ammonium bifluoride, sodium fluoride, etc.) solution in water. This stimulates mold development which in turn inhibits early decay. After 6 months another decayer, which is not inhibited, becomes prevelent. The fluoride spray has most promise when treatment must be delayed.

(3) Continuous water spray or pond storage will effectively prevent stain and decay. The bacteria and specialized fungi that attack water-logged bolts merely increase porocity which, instead of being a defect as in lumber, actually reduces the cooking time in the pulping process. Some mills have constructed large circular ponds for the storage of pulpwood but neither pond storage nor water sprays have been generally adopted.

Chip Storage

Most southern pulp mills now store chips in compacted piles. In 1963, 16% 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. With chip storage loss in yield and quality of pulp are about the same as with 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 cantaminated with cinders from smoke stacks.

Stored chips are attacked by the common stain and mold fungi but, unlike roundwood, decay is more by soft-rot organisms than typical decay fungi. Temperatures in chip piles may reach 135^{o} 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.

Some mills are paying a premium price for chips from sawmills which spray their logs with water. The greater permeability of such chips reduces cooking time.

Fungus 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. However, decay fungi do attack even though frequently they are less obvious. Most 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.

Many species of stain, mold, and decay fungi attack green lumber during air seasoning. The species of fungi vary with wood species, geographic location, and season. Degrade can result from the further development of infections already present in the log; by spores produced on the ends of infected logs being thrown around mills by machinery, or by wind or insects carrying spores 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. Chlorinated phenols (as sodium pentachlorophenate) and organic mercurials (as ethyl mercuric phosphate) are the bases for most dips. The effectiveness of such dips is predicated upon the following practices:

(1) Fresh log supply. If logs are infected before milling, these 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.

(2) 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.

(3) Chemical dips must be mixed in proper proportions and well stirred to insure complete solution. Experience shows that a separate mixing tank is superior to mixing in the dipping vat.

(4) The dipping 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 surface, and a long drain board.

(5) Every few days the vat must be drained and cleaned of sawdust. The solution level must be kept high in the vat, particularly with mercurial solutions.

(6) Dipped lumber should be put in regular seasoning piles as soon as possible because bulk piling is condusive to staining.

(7) Protect dipped lumber 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.

(8) The seasoning yard should be well drained, layed out to promote good air circulation, and weeds kept down. 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 mechanical handling does not preclude good piling practices.

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:

(1) Use of mixtures. Fungi resistant to a mercurial are almost never resistant to a chlorinated phenol. Therefore, by using mixtures of these, control can be secured with lower total concentrations.

(2) Periodic changing of fungicides when there is evidence of a buildup of a resistant species or strain. To be effective changes must involve widely different chemicals.

The surest means of preventing fungus attack on freshly-cut lumber is to kiln dry it promptly. Most southern pine lumber is now kiln-dired from the green state but most hardwoods are air dried even when they are finally 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.

Lumber to be bulk piled more than 2 days and larger sawed timbers require additional protection and, therefore, usually are treated with double strength solutions.

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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. Also 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.

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.

Rain seepage usually can be detected and often stopped before actual decay occurs. The signs indicating that seepage is occurring 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 fruit bodies or actual decay.

Roof Edge. Roof run off commonly wets facia, molding, and rafter ends at the eave and rake edges unless a well-designed drip edge is installed. In addition, in high rainfall areas it is best to use decay resistant wood or treated wood for all wood exposed at the roof edge. Metal drip edges are particularly needed 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 The 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 have such a high decay hazard in high rainfall areas that 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:

(1) A good roof overhang. A hipped roof with 2½-to 3-foot overhang will protect the walls of a 1-story building from serious rain wetting. With higher buildings, overhang does not give complete protection to the lower wall.

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

(3) Sheathing 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 will prevent this.

(4) Water-repellent preservatives greatly reduce the amount of rain seepage. A 3-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 recurrance of minor rain seepage.

(5) Projections from the wall, such as 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.

(6) It is safer to use only the standard siding patterns 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.

(7) A good clearance between the siding and the ground is needed— a minimum of 2 feet is best. With slab-on-ground buildings a minimum clearance of 12 inches is best and, in addition, the use of treated siding is desirable, at least for the bottom few courses.

Decay Associated With Condensation

Condensation is a common phenomenon — for example, the dew found on automobiles parked outdoors over night. 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 will cause the excess water vapor in the air to condense out. The temperature at which this starts is called the dewpoint temperature. Temperature differentials and dewpoints can be set up 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 permeably 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 come in contact with a surface at the dewpoint temperature and condensation will result someplace on or within the wall, floor, or ceiling.

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 which contain a mildewcide will prevent molding.

Cold-weather condensation in walls is a problem in areas where the average January temperature is 35° or below. Warm interior air moves out through walls 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. 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. Also restriction of vapor release inside the house helps.

Again, the main danger of winter condensation in walls is paint failure although some decay may result.

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

(1) Soil drainage. If the upper few inches of soil in the crawl space are 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.

(2) 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 has a disadvantage — it may lead to cold floors and frozen water pipes.

(3) Soil covers. Covering the crawl-space soil with 6-mil polyethylene films or roll roofing weighing 45 pounds or more, will prevent evaporation of soil water and resulting condensation. 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 condensationbut the vapor pressure gradients are reversed, i.e. vapor moves inwards from the 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 continuously with temperatures less than 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. Intermittant (day time) cooling, when feasible will minimize condensation. If continuous cooling is used, 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 equalibrium wood moisture content from 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. Such flooring should be opened to the air until it's moisture content reaches 11% before being laid. When asphalt tile or linolium is used over a wood subfloor it restricts drying and increases moisture problems. Under such coverings a plywood subfloor is safer because it is dimentionally 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; the use of vapor permeable inner wall finishes; the use of pressure-treatment for all wood used; and adequate termite control.

Decay by Water-conductors

The water-conducting fungus, *Poria incrassata*, causes the most spectacular decay of buildings in the United States. It produces large, tough water-conducting strands which, when rooted at a constant and abundant supply of water, can wet wood many feet away. Thus wood normally too dry to support decay can be destroyed. Fortunately this fungus is rather rare.

Once well established, *P. uncrassata* 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.

Poria is primarily an inhabitant of southern United States but occassionally occurs as far north as Canada. It's counterpart in Europe and, to a lesser extent northern United States, is *Merulius lacrymans.*

Up to 1913, *P. uncrassata* was known only from 3 collections in the woods but since then hundreds of cases have been found in buildings and only a few more collections in the woods and such outdoor structures as bridges. Thus it is primarily a building fungus.

Physiology, *P. incrassata* will attack all the common construction woods, including such "decay-resistant" woods as cypress, redwood, and cedar.

P. incrassata is more sensative to high temperatures than most decay fungi. In moist wood it is killed at temperatures considerably below commercial kiln-drying temperatures: in 2½ hours at 40^{o} C and in 30 minutes at 50^{o} C. The common fungi decaying exterior woodwork will grow at 45^{o} C.

P. incrassata is extremely sensative to drying. In tests it survived only 1 day at 30% RH, 5 days at 65% RH, and 10 days at 90% RH. In contrast, *Lenzites saepiaria,* the common decayer of exterior woodwork. has survived for 9 years in wood at 11% moisture content.

The literature mentions that with *P. incrassata* metabolic water is very important so that to control decay by this fungus, all infected wood must be removed. This is not true, because *P. incrassata* is no different than any other decayer in the amount of metabolic water produced. Only under unusual conditions, i.e. in moist wood in a continuously saturated atmosphere, can the fungus perpetuate itself on metabolic water alone. Under most building conditions, it can survive only with a constant outside source of water.

The fungus produces vigorous water-conducting strands up to 2 inches in diameter. These can transport water from the soil or other constant source up as high as the second story of a building even though most decay occurs in the lower parts of buildings.

The water conductor is resistant to copper fungicides but is easily controlled by other fungicides such as creosote and penthachlorophenol, i.e. the most commonly used wood preservatives.

Rot in buildings. The fungus mainly attacks houses only a few years old or with recent structural changes, suggesting that, in most cases, it enters in infected lumber. Further evidence of this is the higher frequency of *Poria* in lumber storage sheds than in other types of buildings.

The main points where the fungus gets established in buildings are:

(1) Unprotected sills adjacent to dirt-filled porches. Standard practice requires that dirt fills be separated from the wood sill by solid concrete or a metal flashing.

(2) Forms used for concrete steps, slabs, or foundations which are not removed after the concrete sets.

(3) Wood on damp groundline concrete slabs or basement floors.

(4) Siding, sheathing, sills, or other wood parts in contact with the soil.

The constant sources of water in well-recorded cases are: soil 78%, rain seepage 16%, moist concrete 12%, leaky plumbing 9%. Two or more sources were frequently involved.

Prevention merely consists of following standard building practices:

(1) The use of uninfected lumber.

(2) Control of soil moisture by:

  (a) Grading the building site so that surface water drains away from the building.

  (b) Using eave gutters and down spouts so that roof runoff does not wet the building. These must be kept water tight.

  (c) Allowing no surface water, condensate from air-conditioners, etc. to run into the crawl space or against walls.

  (d) Maintaining a dusty dry crawl space by drainage.

  (e) If the crawl space is not dusty dry, having vent openings totaling at least 1/150 of the crawl-space area or by using a soil cover.

(3) Removing all concrete forms and grading stakes.

(4) Removing wood debris and stumps under or near the building.

(5) Avoiding dirt-filled porches and terraces. Self-supporting slabs are practical and safer.

(6) Elevating and water proofing slab-on-ground construction.

(7) Seeing that basements have waterproof walls and floors to prevent ground water seepage.

(8) Using treated wood for plates on concrete ground-line slabs, framing and sheathing in walls and floors of shower stalls, and wood below the first floor joists in damp basements.

Buildings meeting FHA minimum property requirements are relatively safe unless the occupants nullify the design by:

(1) Building up flower beds so that the soil touches some wood.

(2) Wetting walls frequently with sprinklers.

(3) Not repairing plumbing leaks.

(4) Allowing down spouts or gutters to become clogged or rusted so that walls are wetted.

(5) Piling wood in the crawl space or against the house.

Control once attack occurs:

In the past control methods called for the removal of all decayed wood and all sound wood within 2 to 3 feet of any fungus growth. This, of course, was very costly. Now we know that, by cutting off the source of water, decayed wood dries out and *P. incrassata* dies because only under unusual conditions will metabolic water maintain growth. Consequently, the control now recommended consists of removing the source of water and replacing only wood too weak to support it's load. If the source of water is in doubt, all infected wood should be removed and replaced with pressure-treated wood. The usual control steps are:

(1) Locate and remove the source of water. Invariably this is where decay occurs and usually where it is most severe:

(a) Dirt fills: Open the foundation, excavate the soil from the sill, paint the exposed concrete and wood with a preservative, and ventilate the opening. If the sill is replaced use pressure-treated wood.

(b) Remove any forms left under concrete steps, porches, or on the foundation. Scrape water-conducting strands and mycelium from the concrete and paint the exposed concrete with a preservative.

(c) Remove any stumps, debris, etc. that make bridges from the soil to the house or act as an infection center from which water-conducting strands extend to the building. Break all such wood-soil contacts and also remove any asphalt papers making such bridges.

(d) See that surface water drains away from foundations. Unless the crawl space is dusty dry, provide drainage, ventilation, or a soil cover as previously described. When correcting an attack, a polyethylene film is a better soil cover than roll roofing because the latter is attacked by *P. incrassata.*

(e) Look for and repair any plumbing leaks. In a shower stall, a completely new water tight lining may be necessary. Any framing and sheathing exposed during repairs is best replaced with pressure-treated wood. The most dangerous leaks are fine ones that often are difficult to detect.

(f) Make a special search for water-conducting strands on foundations. Scrape off any found and treat the foundation with a preservative. If bricks are loose, replace a few layers using a cement morter because the fungus can penetrate soft morter joints.

(2) When an attack occurs in a slab-on-ground house which does not meet waterproofing and ground-clearance standards (12" in the South and 8" elsewhere), replace all

basal plates with treated wood and use non-wood floors. Provide as much outside clearance as possible and treat the slab edge and adjacent soil with 5% pentachlorophenol even though this may kill some shrubs.

(3) If attack occurs in a basement, replace all wood in contact with the walls and floor with pressure-treated wood. Do not permit enclosed stairs, partitions finished on both sides, cupboards, or wood paneling on exterior walls in moist basements.

(4) Where preservatively-treated wood is needed use creosote, pentachlorophenol, or non-copper inorganic salts applied under pressure. For nailing strips, subflooring, studs, or other members to which finish items are nailed, use a clean paintable treatment. Oils may creep out along nails and discolor the finish items.

Do not use the so-called decay-resistant woods in repairing a *Poria* attack because this fungus will decay them. Preservatively treated wood is safer.

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Chapter 13

DECAY OF TIES, 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 they get best service per dollar from wood in high-tension lines.

Ties. Decay of ties in service does occur but most ties are replaced because of mechanical failure, i.e., rail plates cutting into the wood. There is a good chance, but not yet substantiated, that fungi, both regular decayers and soft rotters, weaken ties and increase the rate of plate cutting. Few woods with natural decay resistance have sufficient density for ties in modern railroads. Pressure-treated wood is standard for ties.

Posts and Poles. Some naturally decay resistant woods are used untreated for posts and poles. Split posts are preferable so that a durable heartwood nailing surface is provided. Most poles of decay resistant species are given a hot-cold butt treatment to prevent saprot. In general, pressure-treated poles of non-decay resistant species will outlast untreated poles of naturally decay-resistant woods. Untreated western red cedar 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.

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.

An interesting problem has developed in the South during the past 15 years — the pileated woodpecker. At one time this bird was considered almost extinct. It is again common. The pileated woodpecker can quickly ruin a treated pole by drilling into it. To protect poles many have been wrapped in heavy hardware cloth; light cloth may be torn off. Effective repellent chemicals now are available and are replacing the use of hardware cloth.

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 water-proof 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.

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, with the usual stain and mold development during seasoning prior to treatment. This, of course, does not apply to pressure and hot-and-cold treatments, which easily treat uninfected poles.

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 much untreated timber is used. The development of decay mycelium can be fantastic, festooning timbers with great gobs of growth. Replacements because of decay are common and frequent. In the more permanent shafts, treated wood is used. Incidentally, even though many decay fungi occur in mines, a common one is our old friend *Fomes annosus.*

Piling and dock timbers. Here the decay problems are above water because the below-water parts remain too wet to decay. Below water, marine borers are a major problem in salt or brackish water. Piling has one bothersome problem that poles do not have. They are driven, which usually smashes the piling top requiring sawing the top off and thus 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 pitches, 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.

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.

Chapter 14

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. The relatively high cost of direct controls in proportion to the value of forests have precluded most direct controls in the past. Conditions are changing and more and more direct controls are becoming feasible in the forest. However, foresters should remember that many forest diseases are ecological problems, i.e. the reaction, directly or indirectly, of a tree to its environment and that in many cases, controls must be indirect through regulation of the environment.

Now lets look at the prospects of disease control in the forest – what can be done now and what the future holds. Controls can be divided into 5 general groups.

Excusion 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 that eradication will be the exception; 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 violet root rot caused by *Helicobasidium mompa* which can live as a saprophyte in the soil. Two highly susceptible trees are yellow poplar 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. It is much safer to introduce surface sterilized seeds. If seedlings must be introduced, they should first be grown in the Plant Introduction Garden in Maryland where they can be closely watched and, if necessary, destroyed. Bulbs, grapes, and similar products are imported under strict controls and inspections.

Genetic control, i.e. the development of resistant strains or hybrids, will be very important in the future. Noteworthy progress has been made in developing southern pines resistant to fusiform rust, little-leaf, and brown spot; of 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 immune to fusarium wilt for 15 years. The benefits of tree breeding should be obvious within a few years. One difficulty with pines will be that of multiplying a resistant individual into sufficient numbers to plant much area. 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 parasite. 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 single strains 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 sufficiently wide population to retain considerable variability.

Biological control, as far as can be seen now, 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 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 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. This is not feasible in the forest. However, some direct controls are now feasible 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 ornimental trees. This phase is rapidly becoming more important as recreation becomes an integral part of forestry.

Management manipulations, i.e. the creation of conditions unfavorable for disease development, hold great promise:

(1) Altering cutting plans to take into account rate of rot development in stands with wounded trees 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 by promoting 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.

(4) Soil improvement through the encouragement of soil-building plants may be necessary on some sites. In the worst littleleaf areas it may be desirable to encourage the hardwood componant to create a soil flora and moisture regime unfavorable for the littleleaf fungus and favorable for pines.

(5) Assessing the disease hazard of sites so that non-susceptible species can be favored. Examples include littleleaf, annosus root rot, fusiform rust, and cone rust. Getting the right tree on each site, where it will grow vigorously, probably will do more than any other single factor to reduce losses from hardwood diseases caused by facultative parasites.

Disease Surveys

Effective control of a forest disease frequently requires accurate information on its distribution, i.e. a product of disease surveys. Regular surveys are still a thing of the future. For a number of years, detailed surveys were made annually by some states and the federal government to establish

the range and intensity of oak wilt. Similar surveys included at one time or another: white pine blister rust, chestnut blight, littleleaf, and cone rust; and less extensively fusiform rust and annosus root rot.

Once a pathogen is well established and its range determined, continuing detailed surveys are difficult to justify unless there is an active control program. General surveys coupled with control programs certainly are justified in case of introduced pathogens. This is the only way to determine their potentiality under new conditions and determine if eradication or control is feasible. Surveys to keep detailed track of all native pathogens important to forestry would be prohibitively costly. Instead, each forest owner should keep track of his own holdings and determine when control measures are needed. In addition there must be public agencies to which the forest owner can turn for identification of new diseases and for advice on the need for and the method of control.

To properly service forester's needs, each state forest service should have a section on forest pests. The Texas Forest Service has developed such a section. The insect portion has been active for several years; the disease part became active with the appearance of important amounts of annosus root rot. The section acts not only as a source of information but gradually is building up a fair picture of the state wide forest disease picture. The section can be reached as follows:

Forest Pest Control Section
Texas Forest Service
P. O. Box 310
Lufkin, Texas 75901

Telephone Area Code 713 — 632-3319

The Texas Forest Pest Control Section works closely with the U. S. Forest Service which has a well organized group for Forest Insect and Disease Control in the Division of State and Private Forestry. They will identify disease and insect samples, consult with land owners, and recommend control measures. In the South, Region 8 has 3 pest control offices:

U. S. Forest Service
Forest Insect and Disease Control

Zone 1	P. O. Box 1211, Asheville, N. C. 28802
Zone 2	P.O. Box 1077, Macon, Ga. 31202
Zone 3	P.O. Box 471, Alexandria, La. 71302

Similar offices are maintained in each of the other regions. Addresses can be secured through any U. S. Forest Service office.

Sample identificatons and advice also can be secured from state agricultural experiment stations and forestry schools.

In general it is best, when you have a pest problem, to first consult the State Forest Service Pest Control Section. They have the best over-all knowledge of local pest problems. Where there is doubt they will contact the federal pest-control zone office, state experiment station, or forestry school. By keeping the Texas Forest Service in touch with your problems you help them build up the state-wide information they need to best advise land owners.

Surveys also are closely connected with disease research. We lack sufficient data on distribution and damage to intelligently assign research priorities to many of our forest tree diseases. Fusiform rust, annosus root rot, heart rot, and a few other diseases are obviously of sufficient

importance to require control and, consequently, most current research is on these diseases. Many diseases are of unassessed importance. This is particularly true of those diseases which cause growth loss rather than mortality.

For the major tree species, we need to study and catalog symptom development induced by physiological and other non-pathogenic causes. If we had more complete data on the effects of different nutrient levels, different degrees of water deficiency, temperature abnormalities, soil factors, etc. on such characteristics as leaf size and color, rate of growth, and dying, field diognosis would be more accurate. Thus research must make many contributions before general disease surveys can be made intelligently.

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 occurrance 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 compliment each other. Both are essential to the development of a sound forest disease control program.

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