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R_x for *Abies:* Silvicultural Options for Diseased Firs in Oregon and Washington

Gregory M. Filip and Craig L. Schmitt

Authors

GREGORY M. FILIP is an associate professor of forest science, Department of Forest Science, Oregon State University, Corvallis, Oregon 97331; and CRAIG L. SCHMITT is a zone pathologist, Wallowa-Whitman, Umatilla, and Malheur National Forests, 1401 Gekeler Lane, La Grande, Oregon 97850. At the time the research was done, Filip was a research plant pathologist, Pacific Northwest Research Station, 1401 Gekeler Lane, La Grande, Oregon 97850.

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The true firs are important species in Oregon and Washington forests, but root diseases, stem decays, and dwarf mistletoes cause more mortality, growth loss, and cull in these species than in any other. This paper consolidates research, observations, and management techniques for diseases of true firs, especially the effects of silvicultural activities on root diseases, stem decays, and dwarf mistletoes.

Keywords: Root disease, dwarf mistletoe, stem decay, thinning.

Introduction

The true firs *(Abies* spp.) attain their greatest economic and ecological importance in Western North America. Timber volumes in Oregon and Washington are about 17.1 billion cubic feet (0.5 billion m^3) and are distributed among several species: noble fir *(Abies procera* Rehd.), Pacific silver fir *(A. amabilis* Dougl. ex Forbes), subalpine fir *(A. lasiocarpa* (Hook.) Nutt.), California red fir *(A. magnifica* A. Murr.), white fir *(A. concolor* (Gord. & Glend.) Lindl. ex Hildebr.), and grand fir *(A. grandis* (Dougl. ex D. Don) Lindl.) (Oliver and Kenady 1981). Some of these species readily hybridize: grand fir × white fir and noble fir × California red fir. The true firs are important not only as a timber resource but also as vegetative cover protecting watershed and mountain snowpacks, as hiding cover and thermal protection for wildlife, as aesthetic components of recreational landscapes, and for specialty products such as Christmas trees and greenery. Some of the silvical characteristics of the true firs in Oregon and Washington are summerized in the following tablulation:[1]

Characteristics	Unit of measure	Grand fir	White fir	Subalpine fir	Pacific silver fir	California red fir	Noble fir
Elevation	Feet	600-6000	3000-8000	2000-8000	100-6500	4500- 7000	3000-5500
range	Meters	180-1830	900-2400	600-2400	30-1980	1350-2100	900-1650
Precipitation,	Inches	20-1 00	20- 75	40-1 00	65-130	30- 75	70-1 00
range	Centimeters	50-255	50-1 90	100-255	165-335	75-190	180-255
Shade tolerance		High	Medium	High	Highest	Medium	Low
Frost tolerance		Medium	Medium	High	Medium	High	High
Drought tolerance		Medium	Medium	Medium	Low	Low	Low
Number of forest cover types where found		15	9	8	13	7	6

All true fir resource values are affected by diseases, but the greatest economic impact is in timber production. Root diseases, stem decays, and to a lesser extent, dwarf mistletoes cause tree mortality, growth loss, and cull that impact commercial timber production. This report has been prepared for foresters and others concerned with managing true firs, primarily for timber, in Oregon and Washington. Our objectives for writing this report- were to summarize the biology, recognition, and management of major diseases of true fir and to offer a range of silvicultural management strategies to reduce disease-caused losses in true fir stands. Our intent was to summarize, not to present all that is currently known about true fir disease management: the reader is referred to other sources that treat this subject more thoroughly (Filip and others 1983, Hadfield and others 1986, Scharpf 1964). The information presented in this report was compiled from several sources and represents many years of research and observations by forest pathologists in the Pacific Northwest. Some of the information is new, and research and evaluations are continuing to fill information gaps.

[1]Sources: Fowells 1965, Oliver and Kenady 1981.

Root Diseases

Root diseases are associated with at least 10 percent of the annual conifer mortality in the Western United States (Smith 1984). Losses of true fir are probably much greater because *Abies* spp. are more susceptible to root diseases than are most other conifers. In Oregon and Washington, average annual mortality of white fir and grand fir caused by root diseases has been estimated at 6.5 million cubic feet (183,200 m^3) (Filip and Goheen 1984). This represents an annual loss of 0.1 percent of the total white and grand fir volume, or 6 percent of the annual growth of these species. Other true fir species are less affected, but damage caused by root diseases is increasing as true fir management intensifies.

Three principal root diseases damage true firs: laminated root rot caused by *Phellinus weirii* (Murr.) Gilbertson; Armillaria root disease caused by *Armillaria ostoyae* (Romagn.) Herink *(=A. obscura* (Schaeff.: Secr.) *=A. mellea* sensu lato); and annosus root disease caused by *Heterobasidion annosum* (Fr.) Brat. *(=Fomes annosus* (Fr.) Cke.). White fir and grand fir are highly susceptible (readily infected and killed) to all three species of root pathogens. Pacific silver fir is highly susceptible to *H. annosum.* Noble fir, California red fir, and subalpine fir are moderately susceptible (often infected but only occasionally killed) to all three species of root pathogens. Pacific silver fir is moderately susceptible to *P. weirii* and A. *ostoyae* (Hadfield and others 1986).

Recognition

Crown symptoms of trees affected by root disease include retarded leader growth, sparse and chlorotic foliage, and distress cone crops (Hadfield and others 1986). Windthrown, living or dead trees with decayed roots and ectotrophic (root surface) mycelium commonly are associated with laminated root rot and annosus root disease. Quite frequently, bark beetles are associated with root-diseased trees (fig. 1). The beetles include the fir engraver *(Scolytus ventralis* LeConte) on all true firs (Lane and Goheen 1979), the silver fir beetle *(Pseudohylesinus sericeus* Mannerheim) and the fir root bark beetle *(P. granulatus* LeConte) on Pacific silver fir, the noble fir beetle *(P. nobilis* Swaine) on noble fir, and the western balsam bark beetle *(Dryocoetes confusus* Swaine) on subalpine fir.

Laminated root rot can be distinguished from other root diseases by the presence of rusty-red to brown fungal hairs called "setal hyphae" and laminated decay with pits on both sides of the separated wood sheets (fig. 2). Armillaria root disease is distinguished by abundant resin flow at the tree base, mycelial fans under the root and root-collar bark (fig. 3), rhizomorphs under the bark and on root surfaces, fleshy yellow mushrooms produced in autumn at the tree base, and a yellow, stringy decay with black zone lines. Annosus root disease has either laminated decay with pits on one side only or a white, stringy decay with large black specks. Often, small leathery conks with white to creamy-yellow pore layers are produced in the hollows of old stumps infected by *H. annosum* (fig. 4). Small conks resembling buff-colored pustules may be found on the surface of infected roots. Positive identification of *H. annosum* can be made by incubating infected wood samples in damp paper at room temperature for 10 to 14 days and under x 30 magnification, examining for characteristic conidiophores of *Spiniger meineckellus* (Olson) Stalpers *(=Oedocephalum lineatum* Bakshi), the imperfect stage of the fungus. This same technique can be used for *Phellinus weirii* which produces setal hyphae on infected wood during incubation.

Figure 1—Galleries of the fir engraver beetle often occur on root-diseased true firs; grand fir is shown.

Figure 2—Infection by *Pellinus weirii* causes wood to laminate at the annual rings; grand fir is shown.

Figure 3—Mycelial fans of *Armillaria ostoyae* under the bark of killed trees are diagnostic; infected grand fir is shown.

Figure 4—Conks of *Heterobasidion annosum* often form in the hollows of old, infected stumps; white fir is shown.

Figure 5—Large infected residual stumps serve as inoculum sources for infection of surrounding trees, as in this fir infected by *Phellinus weirii* in northwestern Washington.

Biology

Phellinus weirii and A. *ostoyae* rarely spread by spores; instead, nearly all movement within stands is by underground growth of mycelia across root contacts or grafts (Morrison 1981, Wallis and Reynolds 1965). *Armillaria ostoyae* also spreads by rhizomorphs that can grow several feet through the soil. *Heterobasidion annosum* spreads by subterranean growth of mycelia along roots and by windblown spores from conks. *Heterobasidion annosum* spores adhering to freshly exposed stump surfaces or fresh wounds germinate to produce mycelia that can invade and colonize wood. Subsequent spread occurs by mycelia growing through the roots.

All three species of root pathogens can survive up to 35 years in large stumps and roots before being replaced by other fungi and microorganisms. Duration of fungus survival may depend on tree size and species. Fungal pathogenicity (ability to infect) and host susceptibility may be related to habitat type and site disturbance as has been observed for *Armillaria* spp. in northeastern Oregon and eastern Washington (McDonald and others 1987).

Large stumps infected before tree harvesting serve as inoculum sources for infection of surrounding trees (fig. 5). Large stumps and roots have more inoculum potential (energy available for infection of a host) than small stumps because the large stumps provide more food for the fungi, particularly A. *ostoyae*. Harvesting of infected but living trees thus greatly favors armillaria root disease in-later stands that develop on the site. With annosus root disease, harvesting creates large stumps that are potential infection courts for windblown spores. Small stumps, created by precommercial thinning, may become colonized by root pathogens, but fungus survival time is short and threat of spread is minimal.

Root pathogens decay roots of highly susceptible true fir species and either cause them to be windthrown or to die standing because water and nutrient uptake have been disrupted. Saplings and small poles usually die standing, but larger trees are more prone to windthrow. Infected trees may experience growth reduction for several years before dying. As mentioned above, root pathogens often predispose infected trees to bark beetle attack, and reduced tree vigor often predisposes trees to root pathogens. Tree mortality caused by A. *ostoyae* often increases 1 or 2 years after severe droughts or defoliation by insects (fig. 6).

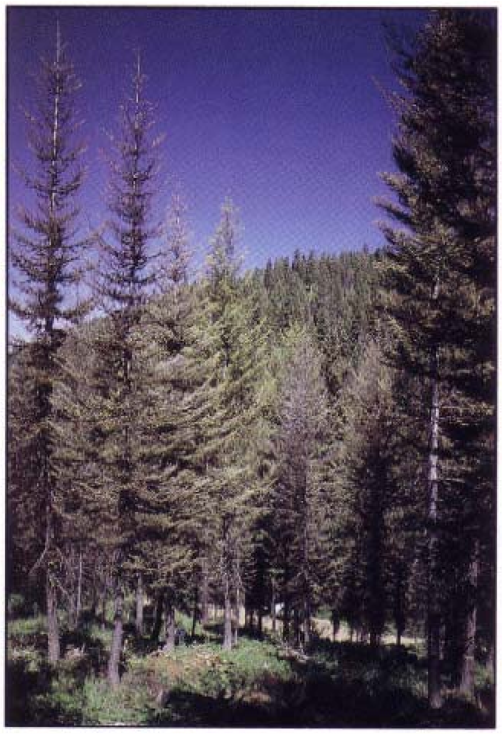

Figure 6—True fir stands defoliated by western spruce budworm may be predisposed to infection by *Armillaria* spp. as in this stand of grand fir in northeastern Oregon.

Disease centers caused by root pathogens form when adjacent trees are progressively infected and killed over many years (fig. 7). Expansion rates average about 1 or 2 feet per year for all three root pathogens. Disease centers often contain large infected stumps, the original source of infection, and living and dead trees in several stages of decline and deterioration (fig. 8). Fortunately, some disease centers eventually become inactive and damage subsides. Crown symptoms and root collar symptoms are displayed on only about half of the infected trees within disease centers (Filip 1986). Lack of crown symptoms and other aboveground indicators makes determination of infection in the remaining trees virtually undetectable.

Besides causing tree mortality, root pathogens can cause butt rot and growth reduction. Trees not killed directly by root pathogens may form a compartmentalized root and butt rot (fig. 9). This occurs when root pathogens kill root bark and the dead bark is walled off. To survive, root pathogens must infect when host defense systems are low and spread as far as possible before host defense mechanisms intensify. Both the tree and the pathogen are able to wall off each other. These mechanisms allow the tree to survive while the fungus colonizes woody tissue (Shigo and Tippett 1981).

Figure 7—Root disease centers form when adjacent trees are progressively infected and killed over many yeas; a white fir stand in southern Oregon is shown.

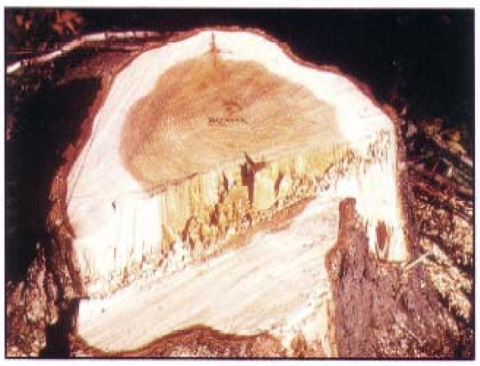

Figure 9—Trees not killed directly by root pathogens may form a compartmentalized root and butt rot, as in this grand fir.

Figure 8—Root disease centers often contain trees in several stages of deterioration; a white fir stand in southern Oregon is shown.

Management

Preferred management strategies are those minimizing the potential for root pathogens to become established or intensify. Root pathogens are present, however, in most conifer types and can be damaging particularly where numerous large stumps have been created. Root pathogens are extremely difficult to eradicate from a site once they become established, but the damage that they cause can be minimized. This can be accomplished by increasing host vigor, favoring disease-tolerant conifer species, or reducing inoculum.

Sawtimber size stands—Root disease control is best achieved when stands are to be regenerated. In harvest units that are mostly infected or that contain numerous scattered disease centers (fig. 10), it is usually advisable to treat the entire unit homogeneously. Where it is advantageous to treat infected and uninfected areas differently, infected areas that include disease centers and a 50-foot (15-m) wide buffer should be identified by a systematic survey of the stand. This can be done in a properly designed, systematic stand exam. Trees immediately surrounding infected areas should be marked low on the root collars so that markings will be visible after logging and slash burning. All hosts should be cut within infected areas and either the stumps excavated or the area replanted with tree species tolerant of root disease.

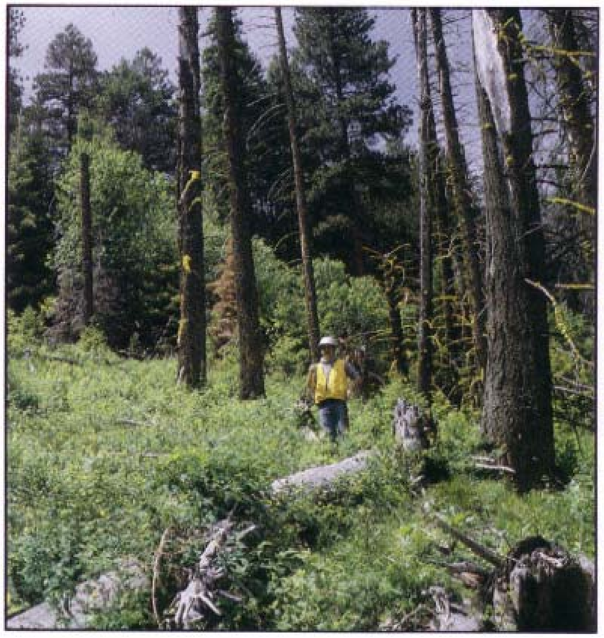

Figure 10—True fir stands that are mostly infected should be treated as an entire unit. A grand fir stand in northeastern Oregon that is infected by *Armillaria ostoyae* is shown.

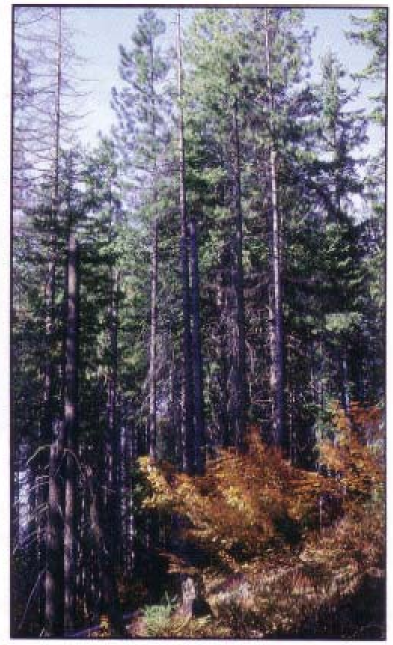

Figure 11—Mixed-conifer stands containing *Phellinus-infected* grand fir should be converted to native disease-tolerant species such as pine and larch. The stand shown is in central Washington.

If root diseases are particularly damaging, stumps can be excavated where terrain, soil type, and economics permit (Roth and others 1977, Thies 1984). Uprooted stumps need not be burned or otherwise disposed of to destroy fungal inoculum because air drying of stumps will kill root pathogens. Also, small, infected root material that remains buried will decay rapidly and probably be of little consequence in future stands. Stump fumigation may be an effective alternative to stump excavation where terrain and soil type are not conducive to excavation; however, stump fumigation has been done only in research trials, and its success in eradicating the pathogen from a site needs to be demonstrated. Newly created but nonstained (uninfected) stumps greater than 18 inches (45 cm) in diameter should be treated with borax to prevent spore infection by *H. annosum,* if true fir is to be managed (Smith 1970).

Root disease-tolerant tree species that can be planted into *P. weirii-infested* sites (fig. 11) include western hemlock *(Tsuga heterophylla* (Raf.) Sarg.), western redcedar *(Thuja plicata* Donn ex D. Donn), incense-cedar *(Libocedrus decurrens* Torr.), western white pine *(Pinus rnonticola* Dougl. ex D. Don), lodgepole pine *(P. contorta* Dougl. ex Loud.), ponderosa pine *(P. ponderosa* Dougl. ex Laws.), sugar pine *(P. lambertiana* Dougl.), western larch *(Larix occidentalis* Nutt.), and any hardwood. One or more site-adapted, less susceptible species should be used to regenerate the site.

Figure *12—Armillaria-infected* stands of subalpine fir are best treated by increasing host vigor through thinning. The stand is in northeastern Oregon.

Figure 13—Sapling-size stands should be treated after surveying for location, extent, and type of root disease. This red fir stand infected by *Armillaria* spp. is in southern Oregon.

Armillaria-affected stands of Pacific silver fir, red fir, noble fir, or subalpine fir are best treated by increasing host vigor (thinning, fertilizing) rather than by manipulating species because these species are not severely affected unless stressed (fig. 12). White fir and grand fir stands with armillaria root disease should be converted to. almost any other tree species; larch and incense-cedar are the most resistant.

Pacific silver fir, noble fir, red fir, or subalpine fir stands with annosus root disease generally need not be converted to more disease-tolerant species because in most cases, damage is related to tree age and severity of wounding (see "Stem Decays," below). Instead, stands should be managed on short rotations of 40 to 120 years and wounding should be minimized by reducing or eliminating intermediate entries. The same is suggested for annosus-affected stands of grand fir and white fir. Where tree mortality is prevalent in infected areas, annosus-tolerant species such as white pine, sugar pine, or incense-cedar should be favored. Although moderately susceptible to *H. annosum,* ponderosa and lodgepole pine also can be planted in infected areas, because the strain of *H. annosum* affecting white fir does not affect the pines.

Sapling slze-stands-Sapling-size stands should be treated after they have been surveyed for location, extent, and type of root disease (fig. 13). True firs with symptoms of laminated root rot and neighboring nonsymptomatic trees whose roots could provide a disease pathway to healthy susceptible trees should be removed. Other tree species, except Douglas-fir and mountain hemlock *(Tsuga mertensiana* (Bong.) Carr.), next to affected trees could be retained. In most sapling stands, the nonsymptomatic pathway trees-trees adjacent to visibly infected trees-will be within a zone extending two normal tree spacings beyond symptomatic trees. If removal of all symptomatic and nonsymptomatic pathway trees creates a stand with unacceptable stocking, consideration should be given to interplanting with less susceptible species, destroying the stand immediately and reforesting the site with less susceptible tree species, or removing residual infected stumps (see above).

If stands are affected by armillaria or annosus root disease, normal timber stand-improvement activities should be performed, because tree vigor improvement should reduce mortality caused by A. *ostoyae* and *H. annosum.* Infected stands with moderate to heavy stocking should be thinned lightly to leave a slight overstocking in anticipation of some mortality. In mixed-conifer stands, disease-tolerant species should be favored. Freshly cut stumps in sapling stands need not be treated with borax, because they are too small to be effective inoculum sources.

Pole-size stands-Pole-size stands with numerous, widely distributed laminated root rot centers (20 percent or more of the area visibly affected) should not be commercially thinned unless frequent subsequent entries can be made to salvage wind-thrown trees. In stands without numerous, widely distributed disease centers, infected trees and true firs within 50 feet (15 m) of infected trees should be harvested during thinning entries.

In pole-size stands affected by armillaria or annosus root disease, healthy parts of the stand should be thinned as usual, but identify and thin the diseased areas as follows: True fir crop trees should be at least 25 feet (7.5 m) from dead trees. If within infected areas not enough crop trees meet the above criteria for a fully stocked stand, consider patch cutting these areas and planting a disease-tolerant species, especially if merchantable trees can be harvested. Care should be taken to minimize tree wounding during thinning. Wounded trees should be removed because decay will be more severe in them than in uninjured trees. Salvage logging should be minimized in armillaria- or annosus-affected stands because frequent entries accelerate damage and increase inoculum. Stumps of pole-size true firs need not be treated with borax to prevent infection by *H. annosum,* because they seldom become effective innoculum sources.

New technology is being developed that may help identify and track root disease centers through time. Geographic Information System (GIS) technology will supplement and eventually replace field marking of root disease centers. Models also have been developed to account for damage caused by root diseases and applications of various silvicultural options (Stage and others 1990).

Stem Decays

Annual losses caused by stem decays in true fir species are estimated at 380 million board feet in Oregon and Washington (Childs and Shea 1967). Losses due to stem decays in mature or overmature white fir and grand fir stands often are very severe. The Indian paint fungus *(Echinodontium tinctorium* (Ell. & Ev.) causes nearly 80 percent of the decay in old-growth grand fir stands in the Blue Mountains of eastern Oregon and Washington (Aho 1977). A similar incidence of decay caused by *E. tinclatium* occurs in old-growth white fir in southern Oregon (Aho and Roth 1978, Aho and Simonski 1975). Other common stem decay fungi in white fir and grand fir include *Phellinus pini* (Thore ex Fr.) A. Ames var. *cancriformans* M.J. Larsen, F.F. Lombard, & P.E. Aho; *Pholiota limonella* (Pk.) Sacc.; *Hericium abietis* (Weir ex Hubert) K. Harrison; and *H. annosum* (Aho 1977, Aho and others 1987, Larsen and others 1979).

Figure 14—The Indian paint fungus probably causes most of the stem decay in noble, silver, red, and subalpine fir. Shown is Pacific silver fir in northwestern Washington that has been decayed by *Echinodontium tinctorium.*

As mentioned above, *Heterobasidion annosum* can cause stem decay as well as root disease. In a survey of advance white and grand fir regeneration in eastern Oregon and Washington, over 20 percent of the decay was caused by *H. annosum,* another 20 percent by *E. tinctorium,* and the remainder by other fungi including *P. limonella, Stereum sanguinolentum* (Alb. et Schw. ex Fr.) Pouz., and *Hericium abietis* (Aho and others 1987).

Stem decay in noble fir, Pacific silver fir, California red fir, and subalpine fir generally is less serious than that in white fir and grand fir; consequently, few reports of damage exist for noble, silver, red, and subalpine fir in Oregon and Washington. *Echinodontium tinctorium* probably causes most of the decay in mature and overmature stands of these species (fig. 14). Other fungi causing decay in old-growth Pacific silver fir and subalpine fir include *Fomitopsis pinicola* (Swartz ex Fr.) Karst, *Perenniporia subacida* (Pk.) Donk, *Stereum abietinum* Pers., S. *sanguinolentum, Phellinus pini, Hericium abietis,* and *Heterobasidion annosum* (Bier and others 1948, Buckland and others 1949, Filip and others 1984, Foster and others 1958). Decay fungi found most commonly in advance Pacific silver fir and subalpine fir regeneration include S. *sanguinolentum* and *E. tinctorium* (Herring and Etheridge 1976, Smith and Craig 1970). Fungi most commonly associated with decay in young-growth California red fir include *Pholiota limonella, H. annosum,* and *E. tinctorium* (Aho and others 1983). Noble fir is probably the most decay-resistant species of true fir, but occasionally *E. tinctorium* causes significant losses in mature timber. Other decay fungi reported in old-growth noble fir include *Phellinus pini, Oxyporus nobilissimus* W. B. Cooke, *F. pinicola,* and *P. robustus* (Karst.) Bourd. and Galz. (Hepting 1971). Incidence of stem-decay fungi in advance noble fir regeneration has not been reported.

Recognition

Mature and overmature trees affected by stem-decay fungi quite frequently show evidence of internal decay either within old, large wounds (fig. 15) or by the presence of conks (sporophores). Conks of some decay fungi *(E. tinctorium, P. pini, F. pinicola, H. annosum, Perenniporia subacida)* are perennial and, when present, are reliable indicators of the presence of advanced decay. The latter three species are rarely seen on live true firs.

Conks of *E. tinctorium* are large and woody with a black, cracked upper surface; a gray, toothed lower surface (spore bearing); and a brick red interior (fig. 16). Advanced decay is yellow to reddish-yellow and fibrous or stringy. Conks of *Phellinus pini* var. *cancriformans* are brownish gray and appear in clusters of several small, bracketlike conks in sunken areas on trunks of affected trees. Advanced decay is a flecked, white pocket rot. Conks of *F. pinicola* are hard, woody, and shelf-to-hoof shaped (fig. 17). The upper surface is smooth and gray to black with a wide red margin (red belt conk). The undersurface is white to yellowish. Advanced decay is brown and cubical.

Conks of *H. annosum* are perennial but are not always apparent. When present, they are often below the duff layer or, more typically, within hollows created by the fungus. Conks are bracket-shaped and leathery (see fig. 4). Upper surfaces are brown to tan and undersurfaces are white. Advanced decay is either laminated or white and stringy with black flecks (see "Root Diseases").

Conks of *Perenniporia subacida,* which can also cause a root disease, are white to cream colored and are found on the underside of root crotches or fallen trees.

Figure 15—Mature or overmature trees affected by decay fungi frequently show evidence of internal decay within old wounds. Shown is grand fir infected by *Armillaria* sp. and the velvet-top fungus, *Phaeolus schweinitzii,* which is an uncommon pathogen of true firs.

Figure 16—Conks of the Indian paint fungus are large and woody with a black, cracked upper surface; a gray, toothed lower surface; and a brick red interior.

Figure 17—Conks of *Fomitopsis pinicola* are hard and woody with a wide red margin; hence the common name, red-belt conk.

Sporophores of other decay fungi are annual, and therefore decay is often present without an external indicator. Sporophores of *Hericium abietis* are often large, corral-like, and white to buff colored. They form in autumn. Advanced decay appears as long spindle-shaped pockets in the wood. *Pholiota limonella* forms clusters of yellow-colored mushrooms in late summer to autumn. Caps are sticky and slightly scaly. The undersurface has yellow to brown gills. Advanced decay is brown and mottled. *Stereum sanguinolentum* frequently forms thin, leathery sporophores on wounds or dead branches of living trees. Upper surfaces are gray to olive-brown; undersurfaces are gray to light brown. Advanced decay is brown, dry, and friable with white mycelial sheets in the rotted wood. *Cryptoporus valvarus* (Pk.) Shear. forms white to tan, leathery, globose annual conks that issue from insect holes in the bark, usually 6-18 months after tree death. The brown pore layer is completely enclosed by a leathery membrane.

Biology

Conks of *E. tinctorium* produce spores primarily during spring and autumn. Spores infect advance regeneration especially if trees have been suppressed for several years (fig. 18). Spores infect small (less than 0.1 inches [2 mm] in diameter) exposed branchlet stubs just before these stubs are overgrown (Aho and Filip 1982, Etheridge and Craig 1976). After spores of *E. tinctorium* have germinated and mycelia develop within the branch, fungal growth continues until branch let stubs are overgrown. Once this occurs, the fungus enters a dormant state as a resting spore that can survive for 50 years or more without causing decay. Dormant infections are activated by mechanical injuries, frost cracks, or formation of large branch stubs that allow air to enter the trunk interior. Several factors such as habitat type, tree genetics, tree age, and wound size determine the amount of subsequent decay.

Figure 18—The Indian paint fungus infects advance regeneration, especially if *trees* have been suppressed for several years. Shown is advance grand fir regeneration beneath lodgepole pine in northeastern Oregon.

Although a single suppressed tree may have several *E. tinctorium* infections, relatively few cause trunk decay because (1) infections must be within the trunk (trunk-encased branches) or immediately adjacent to the trunk in branches, (2) most infections become dormant and are not activated because wounding is too far from infections, and (3) infections probably do not survive after branch death except in branches that have become trunk-encased.

Reactivated *E. tinctorium* infections first cause elongated areas of light yellow or brown stain. Advanced decay is yellow to reddish-yellow. Extensive decay columns may occur after several dormant infections become active, cause decay, and subsequently coalesce. After extensive decay has developed, conks are produced. These appear most often at old branch stubs and occasionally at old wounds where the fungus has a continuous pathway *from* the interior to the outside of the tree.

There is some evidence that the biology of other decay fungi, particularly *Hericium abietis* and perhaps *Phellinus pini,* may resemble that of E. *tinctorium* (Aho and others 1987, Filip and others 1984). It is assumed, however, that most other decay fungi infect wounds by means of basidiospores released from conks or mushrooms. Wound infections may follow a succession of other microorganisms such as bacteria, yeasts, and nondecay fungi. Primary invaders, such as *Stereum sanguinolentum* and *Heterobasidion annosum,* are affected adversely by competing microorganisms and need previously uncolonized wood surfaces *for* successful infection (Etheridge 1969, 1973). *Fomitopsis pinicola* may attack either previously colonized or uncolonized wound surfaces on living trees. Spore infection occurs during wet, cool periods when basidiospore production is at its peak.

Management

Damage caused by stem-decay fungi in true firs can be reduced through short rotations and wound prevention. This is critical, especially if advance regeneration is already infected and some decay is present. Methods for determining this have been developed for white fir and grand fir (Filip and others 1983) and may be applicable to other true fir species, although additional research is needed (Filip 1990). If advance regeneration has low levels of infection (<20 percent of stems) and decay (<2 percent cubic decay at 100 years), these stands can be managed as usual with periodic hazard rating if future wounding occurs. Stands with either low infection rates and high decay or high infection rates and low decay should be grown on rotations of 150 years or less, and special precautions should be taken to minimize wounding of crop trees. Stands with high levels of both infection and decay should be replaced immediately, or projected losses will have to be accepted.

Because wounds either activate dormant fungal infections or provide an entry for spores, they can and should be prevented when thinning, doing prescribed burning, disposing of slash, or removing the overstory. Also, no chemical or biological method will protect trees from infection once they are injured.

The following actions can be taken--both in the planning process and during the actual operation-to prevent wounding and associated stem decay:

1. Restrict the operating season. Avoid stand operations during spring and early summer when the bark is most easily removed. Injuries during this time often result in damage to residual trees that will not occur later in the year.

2. Restrict size and type of operating equipment. Attempt to match the size and type of operating equipment with topography, tree size, residual spacing, and soil condition.

3. Mark trees to be left rather than trees to be cut. This has been shown to significantly decrease damage to residual trees.

4. Plan skid trails before logging. Straight-line skid trails should be used whenever possible, but at all times, avoid sharp turns. Clear a skid trail only slightly wider than the skidding vehicle, preferably no wider than about 8 feet (2.4 m). Leave "bump" trees or cull logs along the edges of skid trails.

5. Match log length with final spacing. Close final spacing of the remaining trees requires skidding relatively short logs; wider spacing allows longer logs to be skidded with minimal damage to crop trees. Skidding of tree-length logs increases damage to residual trees.

6. Log skid trails first. Trees on the skid trails should be felled and skidded before other timber is harvested. If trees in skid trails are felled with other trees in the stand, it becomes difficult for fallers to locate skid trails and to fell the timber in the desired direction.

7. Leave low stumps in skid trails. Stumps in skid trails should be cut as low as possible (preferably no more than 3 inches [8 cm] high) to prevent the skidder from being shunted sideways into residual trees.

8. Use directional falling. Trees should be felled either directly toward or directly away from skid trails. Trees should not be felled at angles exceeding 45° from skid trails. This reduces skidder maneuvering and load pivoting and causes less damage to residual trees.

9. Limb and top trees before skidding. Remove limbs and tree tops before logs are skidded. Limbs should be cut flush to the bole; stubs should not be left that can easily redirect a skidded tree into residual trees.

10. Remove slash from around residual trees if stands are to have the understory burned. Scorching of tree bases often leads to butt rot. Unless all woody material from the base of residual trees can be thoroughly removed, underburning of residual true fir trees should not be practiced.

11. Gain the cooperation of the operator. Operators must be convinced that most damage to residual trees is unnecessary and will not be tolerated. Contract specifications and penalties may be needed to ensure the intended results.

Dwarf Mistletoes

In Oregon, Washington, and California, about 21 percent of the true fir type is infested with dwarf mistletoes (Bolsinger 1978). Damage,. which is principally growth loss (fig. 19) and tree mortality, is greatest in grand, white, and red fir throughout the Cascade Range in Oregon and all of southern Oregon (Hawksworth and Wiens 1972). Locally damaging populations of dwarf mistletoe have been reported in noble and Pacific silver fir in Oregon (Filip and others 1979). Little or no damage has been observed in subalpine fir or in other true fir species in Washington or eastern Oregon. Dwarf mistletoe in true firs is often associated with secondary canker fungi, particularly *Cytospora abietis* Sacc.

Two species of dwarf mistletoes are damaging to true firs in Oregon and Washington (Hawksworth and Wiens 1972). Fir dwarf mistletoe *(Arceuthobium abietinum* Engelm. ex Munz) is the more destructive and infects primarily white fir, grand fir (f. sp. *con coloris* Hawksworth and Wiens) and California red fir (f. sp. *magnificae* Hawksworth and Wiens). Hemlock dwarf mistletoe *(A. tsugense* (Rosendahl) G.N. Jones) infects grand, subalpine, noble, and Pacific silver fir and can be locally damaging when associated with canker fungi (fig. 20). Fir dwarf mistletoe affects only fir, whereas hemlock dwarf mistletoe infects firs, hemlocks, and five-needle pines. A third species, *A. laricis* (Piper) St. John, occasionally will infect subalpine fir and lodgepole pine in stands mixed with larch.

Recognition

Dwarf mistletoes are seed-bearing plants with aerial parts exposed on host surfaces and rootlike systems embedded in the host (Scharpf 1964). The aerial system consists of small, leafless, jointed shoots. *Arceuthobium tsugense* differs from *A. abietinum* f. sp. *concoloris* by its smaller (2-5 inch [5-13 cm]) green to purple shoots compared (fig. 21) to the larger (4-8 inch [10-20 cm]) yellowish shoots in *A. abietinum* f. sp. *concoloris* (fig. 22).

Figure 19—Reduction in radial growth caused by dwarf mistletoe infection can be seen in the let stem section of this grand fir from central Oregon. Black dots mark 5-year radial increments. .

Figure 20—Canker fungi often attack true firs infected by hemlock dwarf mistletoe, seen here in a branch of noble fir from central Oregon.

Figure 21—Aerial shoots of hemlock dwarf mistletoe are small (2-5 inches [5-13 cm]) and green to purple; infected grand fir is shown.

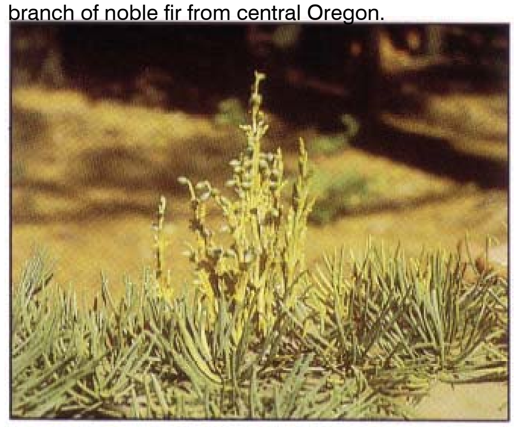

Figure 22—Aerial shoots of fir dwarf mistletoe are large (4-8 inches [10-20 cm]) and yellow; infected white fir is shown.

Shoots are the most conspicuous sign of infection by dwarf mistletoes (Scharpf 1964). On young infections, dwarf mistletoes form clumps near the center of swollen branch tissue. On old infections, they form at the margins of the swelling. On very old infections, all shoots will die, abscise, and leave basal cups at the previous point of attachment to the branch. The swellings on a branch are usually the first sign of infection. They are initially spindle-shaped but become less so with age. Witches-brooms often are associated with old infections; these are loosely arranged masses of twigs and foliage conspicuous in the lower crowns of older trees. Flags (branches with red foliage) are common in firs infected with dwarf mistletoe (fig. 23). Flags are caused by canker-forming fungi, especially *Cytospora abietis* (Filip 1984, Filip and others 1979, Scharpf 1969). Bole swellings result from infections on the main stem, especially in severely infected trees. Often the bark sloughs from old swellings and provides an entry court for decay fungi.

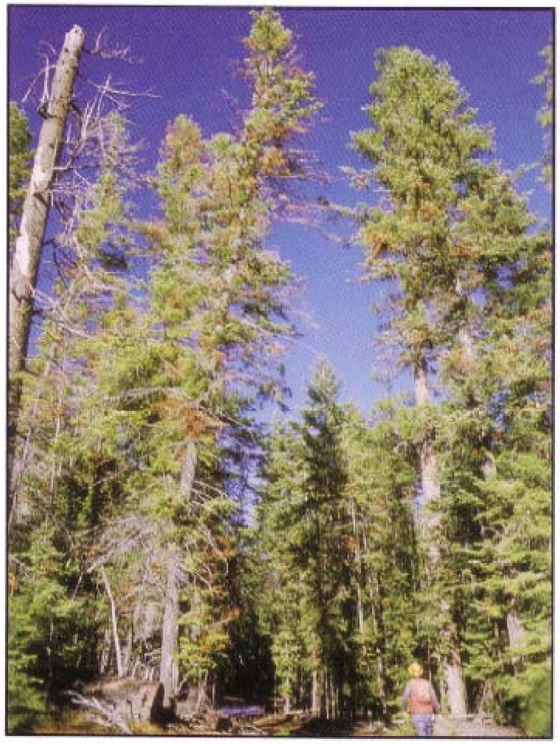

Figure 23—Dwarf mistletoe infections in true firs are often associated with secondary canker fungi, as shown by the branch flagging in this grand fir stand in central Oregon.

Biology

The main function of dwarf mistletoe aerial shoots is reproduction. Female and male flowers are produced on separate plants. Small, inconspicuous flowers form at the joints of the shoot segments. Flowers are insect pollinated and bloom in July and August for fir dwarf mistletoe and in August and September for hemlock dwarf mistletoe. After flowering, the male flowers, and often the male shoots, die and fall from the plant. The fertilized female flowers remain on the shoots, overwinter, and produce fruit the following year. Fir dwarf mistletoe disperses seed in September and October, hemlock dwarf mistletoe in late September to early November. Female shoots may persist for several years and produce more than one crop of fruit.

Spread of seeds across long distances by birds and animals is not significant. Instead, dwarf mistletoe seeds are discharged explosively from the fruit and are disseminated by the wind. Maximum horizontal dispersal distance is about 50 feet (15 m). A gluelike substance covers the seeds and allows them to stick to conifer needles. Rain softens the substance, and the seeds slide down the needle to the fascicle where they may cause infection. Germination occurs in the spring: the radicle grows along the surface until it encounters a needle base or branch fork. A specialized rootlike system develops in the bark tissues and later forms secondary structures (sinkers) that become embedded in the wood. In 1 to 2 years, a small spindle-shaped swelling develops on the branch at the infection site. After another 1 or 2 years, small yellow-green buds break through the bark and develop into aerial shoots. The cycle takes an average of 6 years.

Figure 24—Dwarf mistletoe-infected true firs with good live-crown ratios (>50 percent). as seen here in central Oregon. grow better than similarly infected firs with poor live-crown ratios.

Infection of true firs by dwarf mistletoe and subsequent attack by secondary pests including canker fungi are dynamic events that can occur during true fir development and decline (Filip 1984). These events can be categorized into five stages:

Stage 1: Seedling growth and Infection—Seedlings and saplings with good live crown ratios (>50 percent) attain rapid height growth if not overtopped. Infected trees with good live crown ratios grow better than infected trees with poor live crown ratios (fig. 24). Probability of infection by dwarf mistletoe increases with proximity to infected overstory trees and with seedling height growth.

Stage 2: Seedling growth and reinfection—Seedling height growth continues at a rate directly proportional to live crown ratios and inversely proportional to the amount of competition. New dwarf mistletoe infections occur in the expanding crown from (1) adjacent infected overstory trees or (2) old infections in the lower crown. If height growth is slow, upward vertical spread of the dwarf mistletoe will keep pace or exceed tree height growth (Scharpf and Parmeter 1976). If height growth is rapid, trees will outpace the vertical movement of dwarf mistletoe but may be reinfected if infected overstory trees are present.

Stage 3: Infection by canker fungi and branch mortality—Dwarf mistletoe-infected branches die anywhere from 3 to 48 years after infection (Filip 1984). Canker fungi, particularly *Cytospora abietis,* infect branches through older dwarf mistletoe infections and may contribute to branch mortality especially in stressed trees.

Stage 4: Tree growth, reinfection, and branch mortality—Reinfection by dwarf mistletoe, especially from surrounding trees, continues in expanding crowns. More branches die as a result of (1) shading due to crown closure by surrounding trees and (2) old dwarf mistletoe-canker fungus infections. Tree growth declines drastically if live crown ratios fall below 40 percent and dwarf mistletoe rating exceeds 4 (on a scale of 1 to 6; 1 = light infection and 6 = severe; Hawksworth 1977).

Stage 5: Secondary pests and tree mortality—Poorly growing trees may be attacked subsequently by fir engravers, first in the upper crowns resulting in top kill, then in the midcrown and lower crown, thereby contributing to further tree decline. Infection by root pathogens also may contribute to tree decline. Branch mortality continues until only recently formed adventitious branches remain. Combinations of branch mortality, fir engraver attacks, and root diseases finally kill the tree.

Two main factors affect the time interval between stage 1 and stage 5: tree live crown ratio and dwarf mistletoe rating. These two factors are in turn affected by the stocking level, either from the overstory or adjacent trees, and by the dwarf mistletoe rating of the adjacent trees. The faster a tree attains a poor live crown ratio and high dwarf mistletoe rating, the shorter the time interval between stage 1 and stage 5.

Management

Four basic steps are required to manage true fir stands potentially infested by dwarf mistletoe: detection, evaluation, prevention, and suppression (USDA 1979).

Detection can occur during normal field activities, such as timber cruising or reconnaissance, or through a special survey designed to measure presence or absence of dwarf mistletoe in a particular area (fig. 25).

Stands should be evaluated to locate infestations by severity classes and species affected. Evaluations usually can be performed during regular stand examinations where spacing of plots should not exceed 10 chains (201 m); 4-chain (80-m) intervals are ideal.

Prevention of dwarf mistletoe establishment in healthy stands is far more efficient than suppression efforts. When infected stands are clearcut, unit boundaries should be placed in uninfected stands and along natural or artificially created openings such as roads to prevent dwarf mistletoe from reinvading the plantation. Infected trees should not be within 75 feet (22.5 m) of u nit boundaries if regeneration with true firs is planned. Also, all living infected residuals should be killed before susceptible regeneration reaches 3 feet (0.9 m) tall or 10 years of age, whichever occurs first. Infected trees should not be retained to provide shade in shelterwood systems or seeds in seed-tree systems. Trees with numerous dwarf mistletoe infections produce poor quality seed and may infect susceptible regeneration. If such trees must be retained, they should be removed before susceptible regeneration reaches 3 feet (0.9 m) tall or 10 years old, or the site should be planted with another species.

Suppression is most effective when thinning 10- to 20-year-old stands. Thinning and harvesting priorities should be based on live crown ratio and dwarf mistletoe rating. First priority is to remove all trees with live crown ratios <40 percent regardless of dwarf mistletoe infection. Also, remove trees with a live crown ratio <60 percent but with a dwarf mistletoe rating of 5 or 6. Lastly, remove trees with live crown ratios >80 percent and dwarf mistletoe ratings <5. Some dwarf mistletoe can be tolerated even in young true firs if live crown ratios are good. If removal of all trees not meeting the above criteria would result in an understocked stand, then replacement should be considered. In precommercial stands, infested parts of the stand should be destroyed and replanted. Infested commercial stands should be regenerated either by clearcutting infested areas or by using shelterwood or seed-tree systems with uninfected or lightly infected trees.

Figure 25—Dwarf mistletoe infestations can be detected through special surveys such as this aerial survey of hemlock dwarf mistletoe in stands of noble fir and Pacific silver fir in central Oregon.

Silvicultural Management Strategies

In addition to root diseases, stem decays, and dwarf mistletoes, other pests such as the balsam woolly adelgid *(Adelges strobilinus* Kaltenbach), western spruce budworm *(Choristoneura occidentalis* Freeman), and Douglas-fir tussock moth *(Orygia pseudotsugata* McDunnough) affect true fir productivity. The silviculturist designing long-range management plans should consider these pests over the life of the stand. Three characteristics of the stand .can be manipulated with silvicultural treatments to minimize pest damage: stand composition, stand structure, and stand age (Twardus and others 1984).

Stand composition is probably the most important and controllable factor in minimizing future pest damage. Improving the tree species mix can ensure maximum site use and minimize pest impacts. This has been demonstrated for Douglas-fir tussock moth (Brubaker 1978, Wickman 1978) and for western spruce budworm (Carlson and McCaughey 1982) where the most shade-tolerant species, including the true firs, are the most susceptible to these defoliators. Favoring other tree species also is recommended for other pests such as root diseases (Filip and Goheen 1984, Hadfield and others 1986), dwarf mistletoes (Knutson and Tinnin 1980), and balsam woolly adelgid (Mitchell 1966).

Stand structure also can be varied to minimize pest impacts. All-age, mixed-species stands have historically been thought to be the stands safest from insect and disease activity; however, lower pest incidence has resulted more from the mixed-species than the all-age condition. In true fir stands, root diseases, stem decays, and dwarf mistletoes can be promoted by all-age management (for example, single-tree selection and salvage cutting). Harvesting of large-diameter living, but root-infected, trees may exacerbate a root disease problem by increasing inoculum potential (Filip and Goheen 1982, 1984; Hagle and Goheen 1988). Multiple entries may also create wounds on residual trees that either activate dormant decay fungi or create entry courts for other fungi (Aho 1977, Filip and others 1984). All-aged stands also perpetuate dwarf mistletoe infections from overstory trees to susceptible regeneration (Filip 1984).

Stand age affects disease impact, particularly from stem decays and, to a lesser extent, from dwarf mistletoes and root diseases. Stem decay generally increases in incidence and severity with tree or stand age. Grand fir has very little defect when less than 100 years old and considerable decay after age 150 (Aho 1977). After stands mature, the cumulative effect of increasing the number of dwarf mistletoe infections increases the incidence of secondary pests such as canker fungi, fir engravers, and root diseases. Armillaria root disease has a history of association with mortality in trees weakened by factors relating to advanced tree age.

Forest silviculturists have several options for minimizing pest-caused losses in commercial true fir stands; each of these will be discussed below, including any effects on diseases.

Type of Regeneration

Three methods of regeneration are available to the forest manager: planting, natural regenaration, and the use of advance regeneration (Seidel and Cochran 1981).

Planting of true firs is still in its infancy; either most stands are regenerated naturally or advance regeneration is used. From a pest management standpoint, planting has several advantages over natural regeneration. Pest-tolerant species can be planted in areas with known pest problems; for example, ponderosa pine can be planted in pine-grand fir stands having laminated root rot. In the future, tree genetics can be controlled so that superior seedlings potentially resistant to certain pests can be planted. On the other hand, planting is expensive, quality is difficult to control and may not be feasible on harsh sites, and stock may be poorly adapted for some sites, thus leading to pest-caused losses.

Natural regeneration is practiced in areas where local experience shows such regeneration to be sufficiently reliable to reforest the area in an acceptable time (Seidel and Cochran 1981). The chief advantages over planting are the low relative cost and good adaptation of the stock to the site. There is little or no genetic control or chance to capitalize on pest resistance. Unless tree species other than the true firs can be retained as a seed source, natural regeneration can perpetuate certain pest problems; for example, dwarf mistletoe in fir overstories may infect fir regeneration.

Figure 26—Advance regeneration, such as this stand of red fir in southern Oregon, may be effectively managed if live-crown ratios are good (>50 percent), thus assuring rapid tree growth and low probability of Indian paint fungus infection.

Advance regeneration has the advantages of little or no cost to establish and good adaptibility to the site (fig. 26). Often, a combination of planting and advance regeneration are used to offset the clumpy distribution of advance regeneration (Seidel and Cochran 1981). On some sites, this is the only way to regenerate an area because planted seedlings will not survive. Also, there is no lag time between logging and stand establishment. There is no genetic control, however, and advance regeneration may already be infested with dwarf mistletoe, root diseases, and stem decays. In addition, larger advance regeneration (over 5 ft [1.5 m] tall) may be too damaged by logging to make acceptable crop trees or to have insufficient live crown ratios (<50 percent) to ensure good release. Also, seral species usually do not regenerate under a heavy overstory, thus they are poorly represented in advance regeneration. This diminishes diversity and decreases stand health.

To diminish problems from pests, planting is recommended where site conditions are favorable. Natural regeneration, including advance regeneration, should only be used if (1) dwarf mistletoe-infected overstories can be removed before regeneration is 3 feet (0.09 m) tall or 10 years old; (2) less than 20 percent of the potential crop trees have Indian paint fungus infections, and projected decay estimates at 100 years is <2 percent of the cubic volume, and (3) root disease is not present in the stand.

Precommercial Thinning

Precommercial thinning has not been widely practiced in true fir stands, but its use is increasing (fig. 27). Several advantages can be gained when young true fir stands are thinned: (1) wounded and diseased trees can be eliminated, (2) residual trees if wounded during early thinning will develop small decay columns rather than the large columns created if thinning is done when trees are larger, (3) excellent growth response will result if live crown ratios and previous height growth are good (Seidel 1980), (4) shorter rotation ages can be used, (5) pest-tolerant species can be favored, and (6) residual trees are more resistant to certain pests because of increased vigor; for example, Armillaria root disease. Some disadvantages are (1) sunscalding on certain sites if spacing is too wide and (2) creation of slash that increases risk from fire and stem wounding (fig. 28). Because of the several advantages, precommercial thinning is recommended to alleviate pest-caused losses, especially if it is done early to avoid creating large amounts of slash (fig. 29). Closer spacings will reduce sunscalding on sites prone to this kind of damage.

Figure 27—Precommercial thinning is not widely practiced in true fir stands, but its use is increasing, as in this grand fir stand in northeastern Oregon.

Figure 28—Creation of thinning slash may increase risk from fire and stem wounding; a white fir stand in southern Oregon is shown.

Figure 29—Precommercial thinning of true fir stands is recommended to alleviate pest-caused losses, especially if done early to avoid creation of large amounts of slash, as in this thinned red fir stand in central Oregon.

Commercial Thinning

White fir stands thinned from below have been shown to display a great capacity to produce wood (Cochran and Oliver 1988). Other species of true fir may behave similarly when thinned. For pest management, commercial thinning has many of the advantages of precommercial thinning including (1) elimination of wounded and diseased trees, (2) good growth response if live crown ratios and previous height growth are good, and (3) favoring of seral, pest-tolerant species. There are some disadvantages that need to be dealt with: (1) conventional logging techniques may result in 20-50 percent of the residual trees being wounded with subsequent development of decay (fig. 30); (2) stumps created may become infected by *H. annosum* and spread to residual trees, especially if stumps are over 18 inches (45 cm) in diameter; (3) windthrow may increase, especially in root-diseased stands; and (4) sunscalding may be a problem on certain sites. The use of modified logging techniques (Aho and others 1983) reduces wounds resulting from commercial thinning to 5-14 percent of the residuals.

Heterobasidion an no sum infections can be reduced by treating fresh, large stumps with a coating of borax (Smith 1970). Areas affected by root disease and areas prone to windthrow should not be thinned at all, should be thinned to a closer spacing, or should be thinned to favor wind or root disease-tolerant species.

Prescribed Burning

Prescribed fire has been used very effectively in regenerating new stands to eliminate the fire-intolerant true fir species, especially Pacific silver fir (Pickford 1981) and grand fir (Bickford 1981). True firs are also eliminated when fire is used as a thinning tool to favor more fire-tolerant species such as larch or ponderosa pine (fig. 31). Fire can reduce dwarf mistletoe in the lower crowns of pine, but a partial burn may leave infected clumps of trees that could serve as a source to infect susceptible regeneration (Alexander and Hawksworth 1976).

Figure 30—Commercial thinning may result in 20 to 50 percent of the residual trees being wounded, as in this white fir stand, unless steps are taken to reduce damage.

Figure 31—True firs can be eliminated when fire is used as a thinning tool to favor fire-tolerant species, such as larch or ponderosa pine, as shown in this underburned stand of grand fir in northeastern Oregon.

Although prescribed burning has not been shown to directly affect root disease, leachates from ash retard growth of *Armillaria* sp. and increase populations of antagonistic microorganisms (ReaVes and others 1984).

The most important disadvantage of prescribed burning as a thinning tool where true firs are the desired crop trees is tree mortality and, even more insidious, stem decay. In underburned white fir stands in southern Oregon (fig. 32), 36 percent of the residual firs had sufficient scorch to cause partial cambial death that was associated with stained and decayed wood even 2 years after the burn (Goheen and others 1985). Prescribed burning therefore is not recommended as a thinning tool when true fir is to be maintained as a crop tree. Prescribed burning can be an effective regeneration tool where advance true fir regeneration and residuals are not desired.

Fertilizing

Very little operational fertilizing has been done in true fir stands (fig. 33). Experimental work shows increases in total gross volume growth of grand fir when fertilized with urea at 200 lb N/acre (222 kg/ha) (Moore 1988, Olson and Hatch 1981). By improving growth and vigor, fertilizing theoretically should shorten rotation ages (and decrease decay volumes) by increasing sound wood volume.

Effects of fertilizing on dwarf mistletoe and host are mostly unknown. In one study with artificially infected ponderosa pine seedlings, height growth of fertilized (300 lb N/acre) and infected seedlings was significantly greater than that of unfertilized but infected seedlings (Knutson 1973). Increasing host vigor and growth through fertilization should counteract the effects of dwarf mistletoe in true firs, also.

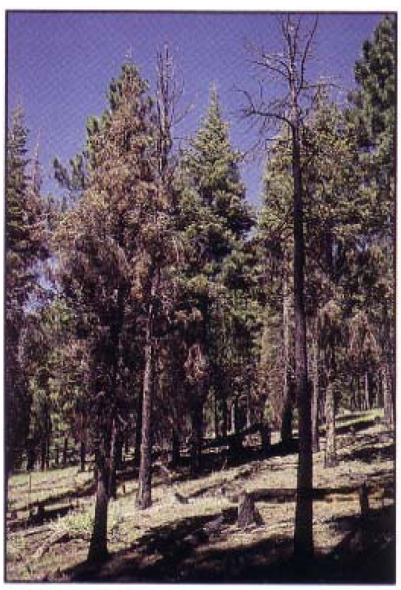

Figure 32—Prescribed burning in true fir stands often results in cambial death associated with decayed wood; shown is an underburned white fir stand in southern Oregon.

Figure 33—Very little operational fertilizing has been done in true fir stands, but indications are that fertilizer should reduce the adverse effects of dwarf mistletoe, root disease, and western spruce budworm; this theory is being tested in this application of fertilizer to an infested mixed conifer stand in northeastern Oregon.

Most of the research on fertilizer has involved root diseases. Low levels of certain soil nutrients are associated with infection - (Singh 1983) and decay (Shields and Hobbs 1979) caused by *Armillaria* sp. Other researchers have found that fertilizing with urea increases antagonistic fungi (Nelson 1975) and may increase tree resistance (Matson and Boone 1984) on sites affected by laminated root rot. There may be good reasons from a pest standpoint to fertilize true fir stands, and indications are that fertilizer may reduce future losses.

Final Harvest

Control of root disease is best achieved when stands receive a final harvest. This is true for other pests as well, because many of the affected trees or susceptible trees can be removed or destroyed. Sanitation-salvage operations traditionally have been used to harvest dead and dying trees. Although wood is used that would otherwise be lost to deterioration, salvage logging often deals with only the effect and not the cause. This is particularly true of salvaged true firs that have been attacked by fir engravers but that in most cases, are affected by root diseases. Harvesting of living but infected trees often exacerbates root diseases (Filip and Goheen 1982, 1984; Hagle and Goheen 1988). Salvage logging also increases soil compaction and creates wounds on residual trees. It is a bandage where in most cases surgery is required.

Seed tree and shelterwood systems—Seed tree and shelterwood systems are regularly used to regenerate true fir stands, especially in high-elevation stands on the east slope of the Cascade Range (Seidel and Cochran 1981) and stands in northeastern and southwestern Oregon. These systems are often recommended and are silviculturally preferred for certain grand fir plant communities. Seed tree and shelterwood systems have several advantages over clearcutting: they allow the retention of rapidly growing trees and the best seed producers. Often in mixed conifer stands, pest-tolerant species can be retained and allowed to regenerate naturally. In turn, survival rate of both natural and planted seedlings may be enhanced with seed tree and shelterwood systems, because brush and grass encroachment are slower under partial canopies. These systems reduce soil movement on steep slopes and are accepted as being aesthetically more pleasing than clearcuts.

Seed tree and shelterwood systems can promote serious pest problems if not done with pest control in mind (fig. 34). Dwarf mistletoe can spread from infected overstory trees to susceptible regeneration if the overstory is not removed before the regeneration is 3 feet (0.9 m) tall or 10 years old. In stands with root disease, susceptible species may be perpetuated if disease-tolerant species are not retained in a major portion of the overstory. Residual trees are more prone to windthrow, even in the absence of root disease. Final removal of the overstory may damage the regeneration if steps are not taken in both the planning stage and the actual harvesting operation to reduce tree wounding (Aho and others 1983).

Figure 34—-Seed-tree and shelterwood systems are common in northeastern Oregon, but these systems can promote serious pest problems if not planned with pest control in mind.

Figure—35 clearcutting has several advantages over seed-tree or shelterwood systems and may be used to remove stands with substantial disease. This Pacific silver fir stand in northwestern Washington was infected by *Echinodontium tinctorium* and *Hericium abietis.*

Clearcutting—Clearcutting of true fir stands has been done primarily west of the Cascade Range but occasionally on the east side, especially when the overstory has much decay (fig. 35), dwarf mistletoe, poor live crown ratios, low potential for seed production, and high blowdown potential and shade is not needed to protect seedlings (Rollins 1981). Clearcutting has several advantages over seed tree or shelterwood systems; it is more economical and usually has no residuals to be windthrown, to infect regeneration, or to damage regeneration upon subsequent removal (Seidel and Cochran 1981). Some potential disadvantages of clearcutting include encroachment of competing vegetation, soil movement on steep slopes, regeneration problems on certain sites and with large units, and unaesthetic visual qualities.

For pest management, clearcutting usually presents less problems than seed tree or shelterwood harvesting; however, there are some disadvantages. Regeneration may become infected by dwarf mistletoe from infected border trees or unmerchantable residuals, or root disease may spread to susceptible regeneration from infected stumps within the unit. Dwarf mistletoe can be controlled in clearcut units by designing units with as few infected edge trees as possible and removing those infected border trees and unmerchantable residuals before regeneration is either 3 ft (0.9 m) tall or 10 years old. The planting of nonsusceptible species will reduce overall dwarf mistletoe incidence in the plantation, but some natural regeneration will occur that in turn may become infected. Root disease in new plantations can be reduced by planting root disease-tolerant species in infected areas. In some cases, stump removal may be an option.

Expectations

The true firs are a valuable and expanding resource in the forests of Oregon and Washington. Because of their high susceptibility to a myriad of forest pests, the true firs need to be managed with forest pests in mind if they are to be managed at all. We hope this report will kindle an awareness in forest managers of important diseases affecting true firs and provide guidelines for managing these pests by using familiar methods.

Acknowledgments

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The true firs are important species in Oregon and Washington forests, but root diseases, stem decays, and dwarf mistletoes cause more mortality, growth loss, and cull in these species than in any other. This paper consolidates research, observations, and management techniques for diseases of true firs, especially the effects of silvicultural activities on root diseases, stem decays, and dwarf mistletoes.

Keywords: Root disease, dwarf mistletoe, stem decay, thinning.

Pacific Northwest Research Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208

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U.S. Department of Agriculture
Pacific Northwest Research Station
319 S.W. Pine Street
P.O. Box 3890
Portland, Oregon 97208