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Stem Infection by Dwarf Mistletoe in California Firs

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Cover: White fir (*Abies concolor*) stem infected by dwarf mistletoe.

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IN BRIEF . . .

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Retrieval Terms: Arceuthobium abietinum; dwarf mistletoe; *Abies concolor*; *Abies magnifica*; white fir; red fir; stem decay; stem infection; silvicultural management

Stem infections by dwarf mistletoe (*Arceuthobium abietinum* Engelm. ex Munz.) are common in red fir (*Abies magnifica* A. Murr.) and white fir (*A. concolor* [Gord. & Glend.] Lindl. ex Hildebr.) and can result in stem defect, decay, wood borer activity, and often in breakage at the site of infection. Beginning in 1965, we studied fir trees in the central and northern Sierra Nevada in California to determine how stem infections are initiated, how they develop, and how they might affect productivity of managed, second-growth fir stands. Data were derived from 100 understory firs selected from seven plots, 20 trees selected for presence of stem infections and dissected, and data on 61 trees dissected for studies on population dynamics of dwarf mistletoe.

The percentage of trees with stem infections on the 100 trees from the seven plots ranged from 56 to 100, confirming, thereby, an earlier study (Scharpf 1969a) that indicated a high rate of stem infection in infected understory firs. Some stem infections apparently resulted from dwarf mistletoe seed deposited directly on the stem, but most entered through live, infected branches. Because all portions of the stem have live branches at some period during tree growth, stem infections occurred with similar frequency over the lower three quarters of the length of the stem. Numbers of stem infections per tree increased with either height or age of understory trees. Most stem infections occurred before infected stem segments were 22 years old, but segments as old as 87 years were liable to infection. Apparently, the stem can be invaded at any age if live infected branches are present.

Once in the stem, mistletoes grew slowly around the circumference. In small thin-barked stems, cambial killing by secondary organisms resulted in about 4 percent of the infected trees being girdled and killed above the infection. Stem swelling was pronounced in only about 38 percent of the stem infections, indicating that many probably escaped notice. Swelling was less common in fast-growing trees.

Decay of stems at the site of infections can cause cull and breakage. Decay was found in only 3 of 333 stem infections on 82 of the infected trees surveyed. On other trees deliberately selected for stem infections, 6 of 134 stem infections had decay. In all instances, decay was restricted to wood within the infection. Of the decayed infections, about 66 percent were more than 50 years old. These data indicate that decay in stem infections should not cause important loss of volume in well-managed fir stands grown on rotations of less than 100 to 120 years.

Defects associated with stem infections in second-growth firs can be reduced by normal, sound management. Removal of infected overstory trees can minimize opportunities for stem infection of young thin-barked regions of the stem. Also, thinning to improve growth can minimize stem swellings and should permit an earlier harvest before decay is appreciable. Proper thinning will also remove trees with open, bleeding, or decayed stem infections. Maintenance of optimum stocking will promote early branch pruning, thereby minimizing the opportunities for branch infections to enter the stem. In summary, control of most damage from stem infections in timber stands should be achieved through proper stocking and stand structure, rapid growth, and short rotations.

The dwarf mistletoes *Arceuthobium abietinum* Engelm. ex Munz f. sp. *concoloris* Hawksw. & Wiens and f. sp. *magnificae* Hawksw. & Wiens are widespread and damaging parasites in California stands of white fir (*Abies concolor* [Gord. & Glend.] Lindl. ex Hildebr.) and red fir (*A. magnifica* A. Murr.) (Bolsinger 1978, Byler 1978, Anon. 1968). As with most other dwarf mistletoes, these can reduce growth, deform trees, and increase likelihood of mortality. In fir trees additional damage can result from stem infection, with subsequent swelling, decay, and frequent breakage at the site of infection (*fig. 1*) (Scharpf 1964, 1969a). Choice of management alternatives for infested fir stands depends, in part, on knowledge of the incidence of stem infections and the losses resulting from them.

In a study of small red firs beneath infected overstory trees, more than 50 percent had stem infections by the time they reached 10 to 12 feet (3 to 3.7 m) (Scharpf 1969a). Release of small infected red firs, as recommended by Scharpf (1979), therefore, is likely to involve numerous crop trees with stem infections. If damage from stem infections is high, however, it may restrict management options.

Quantitative data on damage from stem infections in fir is scant. Decay found behind open stem infections—those from which bark had sloughed and exposed bare wood—was similar to that associated with other open stem wounds (Kimmey 1957, Aho and Roth 1978). No appreciable decay was associated with unopened stem infections—those with tight, firm bark. One study found no statistically significant lumber degrade associated with stem infections (Wilcox and others 1973). But studies, such as those of Piirto and others (1974), on changes in wood quality of lodgepole pine have not been made on fir. In ponderosa pines over 12.7 cm (5 inches) in diameter at the point of infection, stem-infected trees could safely be left as crop trees (Mark and Hawksworth 1974).

This paper reports a study to evaluate occurrence, development, and damage of fir stem infections by dwarf mistletoe. It relates height and age to frequency and severity of stem infections. And it discusses ways in which proper management of fir stands can reduce stem infections.

METHODS

From 1965 to 1979, trees were sampled from stands at elevations of 1700 to 2300 m (5500 to 7500 ft) on the Stanislaus, Eldorado, and Plumas National Forests in the central and northern Sierra Nevada, California.

To obtain a representative sample of stem infections in small firs that might be selected for future crop trees, we cut and dissected 100 red or white firs, which we designate as *survey trees*. The trees were distributed in seven plots of small trees exposed to overstory sources of dwarf mistletoe (*table 1*). Data were taken also on selected trees on the Plumas National Forest (*table 1*), which we designate as *miscellaneous trees*. These trees were cut and examined but not dissected. For survey trees, a single tree on each plot was arbitrarily selected as a starting point, and for additional trees, the tree nearest to the previously sampled tree was taken. Plots were not of fixed size or tree number, therefore, but were variable according to availability of trees and time. Each tree was felled and sectioned at each

Figure 1—A tree that broke at the site of a decayed stem infection.

Table 1—*Location and incidence of stem infection for survey trees*[1] *on seven plots and for miscellaneous trees*[2] *on two plots*

Plot	National Forest	Fir species	Trees					
			No.	Avg. age, std. dev.	Avg. ht. (m), std. dev.	Pct with infection	Avg. stem infection/ infected tree, std. dev.
1	Stanislaus	Red	16	81 (19.6)	8.6 (4.1)	56	4.6 (4.8)
2	Eldorado	Red	22	53 (4.7)	4.6 (2.7)	77	2.8 (1.9)
3	Eldorado	White	23	65 (20.0)	13.1 (4.1)	91	6.3 (8.5)
4	Plumas	Red	14	30 (4.5)	4.8 (2.5)	86	2.9 (2.5)
5	Plumas	Red	12	40 (20.8)	5.2 (3.8)	92	3.0 (2.2)
6	Plumas	Red	10	83 (4.5)	12.2 (3.1)	100	3.8 (2.5)
7	Plumas	Red	3	40 (7.6)	10.3 (5.3)	67	4.0 (2.8)
Misc. 1[1]	Plumas	Red	37	68 (22.9)	7.9 (2.2)	86	2.3 (1.3)
Misc. 2[1]	Plumas	Red	24	24 (3.2)	3.6 (1.1)	71	2.4 (0.8)

[1]The 100 red or white firs cut and dissected.
[2]Trees cut and examined but not dissected.

branch whorl and between whorls if swelling, shoots, basal cups, rough bark, or ring patterns indicated an interwhorl infection. For each infection, where possible, we recorded: stem height at the midpoint of the infection; the age of the stem segment at the time of infection, and the age of the infection (Scharpf and Parmeter 1966); and presence and age of any cambial killing, insect attack, or decay. For a subsample, the amount of swelling was also recorded.

To determine patterns of initiation, development, and deterioration of stem infections, we felled and dissected 12 red firs and 8 white firs with obvious stem infections, which we designate as *dissection trees*, on the Stanislaus National Forest. The trees ranged from 10 to 35 m tall, 19 to 61 cm in diameter-inside-bark (d.i.b.) at stump height (15 to 30 cm), were 50 to 200 years old, and provided a range of host growth rates and stem swelling.

Transverse discs 2 to 4 cm thick were removed from the midpoint of each infection. Where possible, we determined age of the infection and age of the stem segment at time of infection, radius of the infected and uninfected sectors of the stem, degrees of circumference infected, age of the infection at the time of the first unhealed cambial damage and amount of decay and insect activity. For most sections, these data were readily obtainable from patterns of ring swelling and appearance of the wood (*fig. 2*).

Determining accurate age, origin of infection, and similar data were not always possible. Ring swelling, especially in fast-growing trees, was not always discernible. Where stems were invaded from infected branches, ring distortions resulting from branch growth sometimes obscured mistletoe-induced distortions, again mainly in fast-growing trees. Where decay was present, some observations could not be made. When accurate determinations were precluded, data were omitted. The database, therefore, varied among the different measurements and is specified for each.

Because past experience (Scharpf 1979) and present observations indicate that red and white firs react in a similar way to mistletoe infection, data on the two species were pooled.

The terminology of stem growth units and the processes of stem infection may need to be clarified. We follow the suggestion of Kuijt (1960), as accepted by Baranyay and others (1971), in referring to that portion of a stem representing an annual increment of height growth (usually bounded by branch whorls in the *Pinaceae*) as a *segment*. In general, the number of rings in the basal segment approximates the age of the stem, with each succeedingly

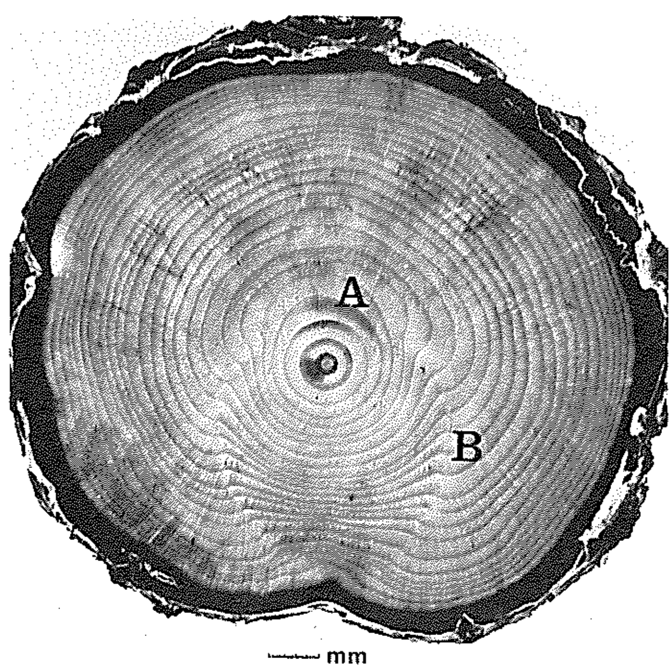

Figure 2—Cross section through the center of a mistletoe stem infection in fir, showing (*A*) initial swelling at the point of origin, and (*B*) pattern of ring distortion as the pathogen grows around the stem.

Table 2—*Stem infections as related to age and height of trees*

Tree class	Trees	Pct with infection	Avg. stem infection/infected tree
Age (yr):			
21 to 40	28	86	2.6
41 to 60	34	76	3.2
61 to 80	17	82	3.8
81 to 100	18	83	6.5
Height (m):			
1.0 to 3	10	80	1.8
3.1 to 6	36	77	2.6
6.1 to 9	12	83	3.0
9.1 to 12	18	89	4.5
12.1 to 15	11	91	5.4
15.1 to 18	11	67	4.1

higher segment containing one less ring until the terminal segment, which contains a single ring, is reached. In a 100-year-old stem, therefore, the basal segment is 100 years old, but the terminal segment is only 1 year old.

Infection designates either the process of host tissue penetration and establishment of the endophytic system or the whole mistletoe plant plus associated host symptoms (Baranyay and others 1960). The process by which the endophytic system extends from a branch into the stem is also referred to here as stem infection. It could also be called *invasion*, as distinct from *direct infection* of the stem by a germinating seed.

Age of an infection is determined by the oldest annual ring showing evidence of swelling at the infection site (Scharpf and Parmeter 1966). As far as is known, this ring is always the current annual ring at the time xylem swelling is initiated. And, dismissing the 1 or more years of latency that usually occur, we consider the first ring swelling to indicate the age of xylem infection (*fig. 2*). If the first swelling appears in the eleventh ring of a 20-year-old stem segment, we designate this as a 10-year-old infection.

RESULTS

Frequency of Stem Infection

Of the 100 survey trees, 82 percent had one or more stem infections; of the 61 miscellaneous trees, 79 percent had one or more stem infections. Numbers of stem infections per tree tended to increase with increased tree height or age (*table 2*), but percent of trees with stem infections did not change consistently within the age and height ranges studied. Infections occurred over most of the stem length. Percentages of infections in the lower, middle, upper, and top quarters of the stem were respectively 24, 24, 34, and 17. The lowest stem infection was within 4 m or less of the ground in 78 of 82 trees with stem infections; therefore, 95 percent of stem-infected trees and 78 percent of all trees had stem infections in what would be a 4-m butt log.

Initiation of Stem Infections

Of 133 stem infections on the 20 dissection trees, 73 percent originated at infected branches, 10 percent were direct infections of the stem, and 17 percent were of uncertain origin. Similar data were not recorded for survey or miscellaneous trees.

Of 430 stem infections on trees for which the age of the stem segment at the time of infection was determined, the oldest segment at the time of infection was 87 years, but more than 70 percent of the infections occurred before the stem segments were 22 years old (*table 3*).

Ages of infections were variable, also. Of 323 stem infections on survey trees for which ages were determined, 201 were 1 to 20 years old, 116 were 21 to 40, and 6 were 41 to 60. Because the survey trees averaged only 58 years, few old infections were found. Among the 20 trees dissected in detail (average age 114), infection age ranged from 2 to 116.

The number of infections by age class are the following:

Age of infection (yr)	*Number*
1 to 20	31
21 to 40	28
41 to 60	21
61 to 80	12
81 to 100	10
over 100	4

Because all available evidence indicates that the dwarf mistletoe endophytic system in stem infections dies only when the host dies, the age of individual mistletoes in stems is limited only by age of the tree.

Complete stem girdling by dwarf mistletoe was rare. Of the 98 infections examined in detail for which the degrees of circumference could be determined, only two had encircled the stem. These were 31 and 39 years old and had invaded the stems when they were young and only 2.2 and 3.2 cm d.i.b. at the point of invasion. Mistletoe growth around the stem was generally so slow that girdling was unlikely except in very slow-growing trees or in trees infected when the stem was very small—usually not more

Table 3—*Age of stem segment at time of invasion by dwarf mistletoe*

Age of stem segment at time of infection (yr)	Survey trees[1]		Dissection trees[2]	
	Stem infection	Pct infection	Stem infection	Pct infection
2 to 21	235	73	72	67
22 to 41	67	21	24	23
42 to 61	19	6	9	8
62 to 81	2	1	1	1
82+	0	0	1	1

[1]The 100 red or white firs cut and dissected.

[2]The 12 red firs and 8 white firs on the Stanislaus National Forest felled and dissected.

than 5 cm d.i.b. Multiple and overlapping infections were common. In some instances, one infection was completely contained within another.

Defect Associated With Stem Infection

Six general effects of stem infection were observed: no effect, depression of ring growth (*fig. 3*), swelling and distortion of grain, internal discoloration (mainly resulting from wetwood intrusion *fig. 4*), decay and damage from wood borers (*fig. 5*), and cambial killing by secondary fungi and insects. No attempt was made to quantify wetwood or grain distortion, but wetwood intrusion was frequent and splitting infected stem segments with wedges indicated that grain of infected wood was irregular and often "wavy."

Swelling was difficult to measure because changes in radii depended in part on age of infection, percent of circumference affected, and uniformity of swelling. Subjectively assigning stem infections to one of four classes—depressed, not swollen, slightly swollen, or markedly swollen—proved a more useful approach. Of 156 stem infections on survey trees, 5 percent were depressed, 37 percent not swollen, 20 percent slightly swollen, and 38 percent markedly swollen. Similar estimates for stem infections on the 20 dissection trees indicated that host growth rate may influence the amount of swelling. Of these 20 trees, 13 were fast growing (avg. 0.32-cm radial growth per year) and 7 were slow growing (avg. 0.15-cm radial growth per year). On fast-growing trees, 80 percent of the stem infections were depressed or not swollen; on slow-growing trees, only 38 percent were so classified.

On fast-growing trees, only 68 of 117 infections (as indicated by basal cups, shoots, or infected branches) could be confirmed by examining annual rings (Scharpf and Parmeter 1966). Even where ring patterns indicated an infection, the patterns sometimes disappeared or were too vague to be useful.

Although extreme swelling might interfere with sawing, decay is the major defect problem with stem infections. In all instances where decay was present, the bark was sloughed from an area of dead cambium, thereby providing an entrance court. Where dead wood was exposed, wood borer activity was common. Among 134 stem infections from the 20 dissection trees, only 4.5 percent contained detectable decay. These six infections were 53, 73, 75, 81, and 101 years old (one could not be aged but was contained in an 82-year-old stem segment). In all six, the decay was localized within the infected area. Decayed infections were at 1.2, 4.6, 7.6, 9.1, 13.7, and 14.6 m in trees ranging from 134 to 200 years old. An additional seven stem infections, aged 28 to 104, had unhealed cambial killing but no decay. The ages of the infections at which unhealed cambial damage occurred were 28 to 97.

Of 333 stem infections on 82 survey trees, only three had decay and two of these were within 1 m on the same tree.

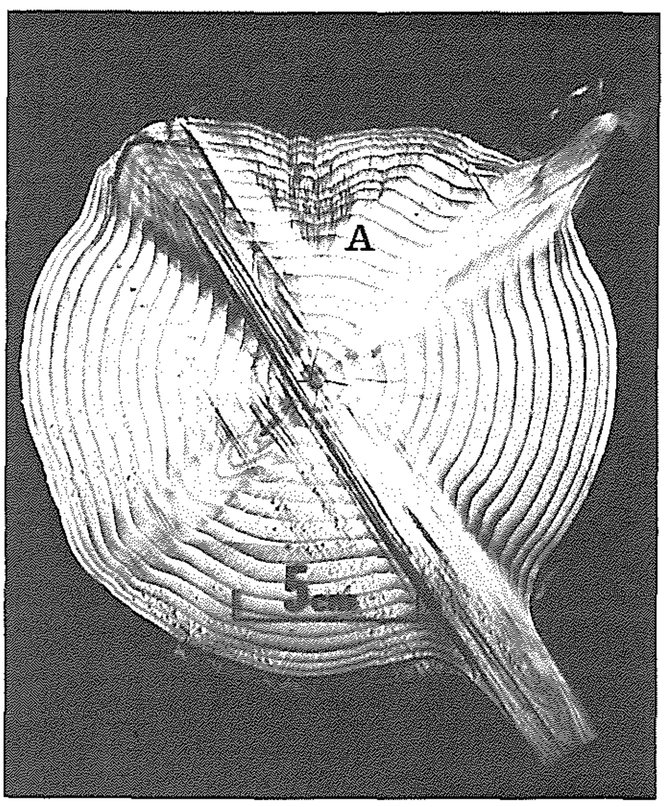

Figure 3—Cross section through a fir stem showing depression of host growth (*A*) associated with dwarf mistletoe infection.

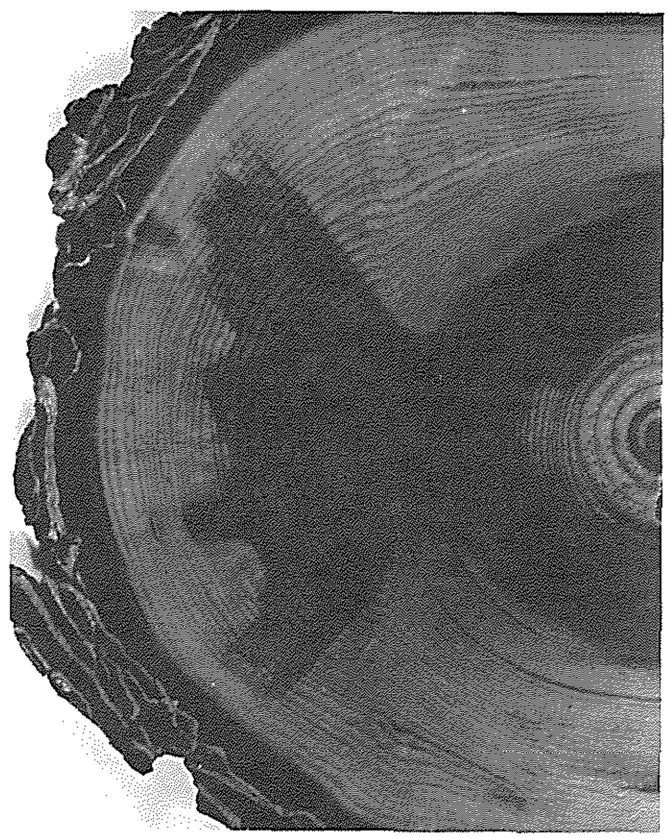

Figure 4—Cross section through a mistletoe stem infection in fir, showing the intrusion of wetwood into the infected wood.

The ages of these three infections were 15, 21 and 22; the two trees were 50 and 58 years old, and infection heights were 2.1, 4.0 and 4.9 m. Only 1 percent of the infections and 2 percent of the survey trees had decay, and decay was found only in trees more than 50 years old.

Unhealed cambial damage was found in an additional eight infections on eight *survey* trees at heights of 0.3 to 7.3 m in trees 2.4 to 9.6 m tall. In three, the stem was girdled and killed above the infection, but a side branch was assuming the position of the terminal and the trees remained alive. In five trees, one-third to one-half of the circumference was dead. Five of the above eight trees were on a single plot. All were small and thin-barked at the point of infection. Killing was thought to result mainly from the fungus, (*Cytospora abietis* Sacc.) (Scharpf 1969b, Scharpf and Bynum 1975).

DISCUSSION

Stem infections in firs arose either by direct infection of small stems or by invasion from an infected branch, the latter being far more common. Once established in the stem, the mistletoe endophytic system grew around the host circumference by small annual increments, just as with branch infections (Scharpf and Parmeter 1966). Complete encirclement of the stem was rare and occurred only when stems were infected very early or at diameters less than about 5 cm.

Stem segments as old as 87 years were susceptible to invasion. Apparently mistletoe can invade the stem at any age through live infected branches, but most stem infections (73 pct) were established before segments were 22 years old and very few (7 pct) invaded after 42 years. Likelihood of infection in older segments probably declines because nearly all infections originate on needle-bearing portions of branches (Scharpf and Parmeter 1967), and the mistletoe endophytic system must move by small annual increments down the branch to the stem. On old branches, needles are clustered at the tips, and normal branch pruning reduces the time and, therefore, the distance that mistletoes can grow toward the stem before branch death. The longer live branches are retained, the more time infections have to reach the stem.

Frequency of infection was about the same along the lower three quarters of the stem, with a slight drop in the upper quarter. The live crown becomes higher as branches die from below, while new branches grow from above. Given a uniform overstory source of inoculum, therefore, stem infections should occur at all heights, with each segment of the stem passing through a period of maximum vulnerability to infection as the tree grows. Fewer infections in the top quarter undoubtedly reflect the reduced time for infection and for growth to the stem from young branches. The oldest infections tend to be in the lower stem, with progressively younger infections at increasing heights.

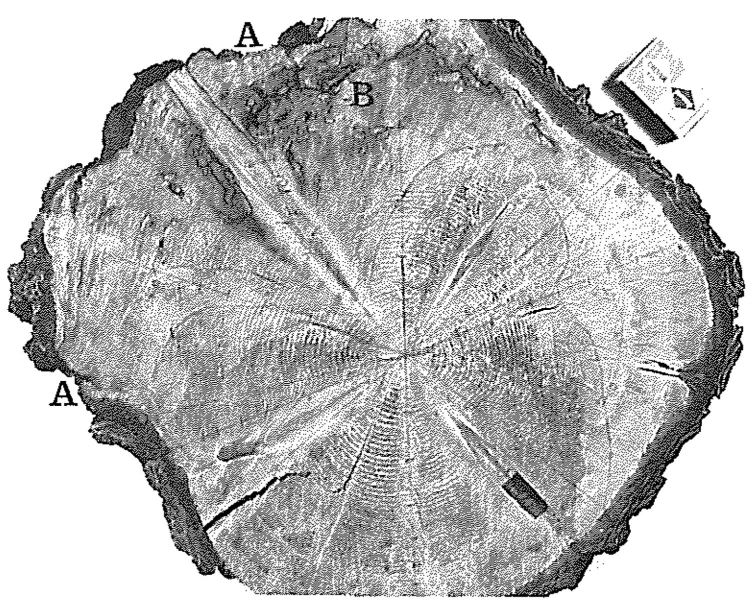

Figure 5—Cross section of a fir stem with two merging mistletoe infections, showing (*A*) bark sloughing, and (*B*) insect damage and decay. The left infection is 81 years old. The section does not go through the center of the right infection, which is 54 years old at the sectioned point.

Individual mistletoe plants vary in their capacity to affect the host. In the same tree, some stem infections can be depressed while others are swollen. Evidence (unpublished) indicates that the endophytic systems of some plants grow much more rapidly through host tissues than do others. The likelihood of swelling depends, therefore, on both the growth rate of the host and on the particular characteristics of individual mistletoe plants. Because many stem infections are not swollen, they cannot be readily detected externally in trees with thick bark. Our data suggest that prominent swelling of stem infections is more common in slow-growing trees. We hypothesize that host ring growth has width limits under any particular set of site factors. As host growth rates approach these limits, the capacity of dwarf mistletoes to induce swelling is reduced. We suggest, therefore, that in rapidly growing trees, defects associated with swelling will be relatively minor.

MANAGEMENT IMPLICATIONS

Site, stand, and dwarf mistletoe conditions are highly variable among fir stands. Samples sufficiently large to encompass this variation were beyond the scope of this study. Our results, therefore, can be used only to indicate trends. These trends provide guidelines for management, but development of additional data for local situations should be high priority for silviculturalists.

These results and those reported earlier (Scharpf 1969a) indicate that more than one-half of the understory trees in infested stands may have stem infections by the time they reach 3 m. Current recommendations include removal of infected overstory and thinning of understory (Scharpf 1968). If the infected overstory is not removed, opportunities for direct infection of the thin-barked upper stem or of short branches with needles close to the stem will continue and may lead to increased numbers of stem infections. Many of these infections will be old, the amount of circumference invaded will be large, and the interior possibly decayed by the time the trees reach merchantability. Because dwarf mistletoes spread rather slowly up through the crowns of trees with no overstory seed sources (Scharpf and Parmeter 1976), the likelihood of infection of young stem segments should be much less in properly released stands.

After overstory removal, thinning is often necessary to promote rapid growth of small firs. During thinning, where stocking and spacing requirements allow choices between two trees, marking should discriminate against stem-infected trees, especially ones with pronounced swelling, resin flow, or patches of dead bark. Our data indicate, however, that trees with stem infections on which the bark is tight can be selected as crop trees where necessary for spacing or stocking.

In precommercial thinnings, some mortality from girdling by secondary fungi may occur in small stem-infected trees. But of eight trees with such unhealed or girdling cambial damage, five were observed on a single plot. Only three (4 pct) of the trees on the other six plots showed unhealed cambial damage. Although losses from such stem damage are probably small, allowance for damage may be desirable in some areas. In commercial thinnings, trees with open stem infections should be removed, because these will likely decay and may break before the next entry.

Good management of fir stands should reduce stem infections in two ways:

- Proper spacing and fast growth will promote rapid crown closure and pruning of lower branches, thereby minimizing opportunities for mistletoe to invade stems from infected branches;
- Rapid diameter growth should minimize swelling in existing infections. Among trees deliberately selected for rapid growth, many stem infections could not be distinguished in the wood, because swelling and grain distortions were slight.

We do not expect stem infections to be a serious problem in stands of well-spaced, properly managed firs.

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Parmeter, John R., Jr.; Scharpf, Robert F. **Stem infection by dwarf mistletoe in California firs.** Res. Paper PSW-165. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982. 7 p.

In fir stands infested with dwarf mistletoe (*Arceuthobium abietinum* Engelm. ex Munz.), the majority of susceptible understory trees had one or more stem infections. Most stem infections entered through infected branches and grew slowly around the stem, resulting in small amounts of decay or stem killing. Decay was not found in trees less than 50 years old. Despite high rates of stem infection, low rates of decay and stem girdling suggest that stem infections will not lead to serious losses in well-managed young-growth stands. Overstory removal and proper spacing to promote rapid height growth and early crown closure are recommended to reduce damage from stem infection.

Retrieval Terms: Arceuthobium abietinum, dwarf mistletoe, *Abies concolor*, *Abies magnifica*, white fir, red fir, stem decay, stem infection, silvicultural management