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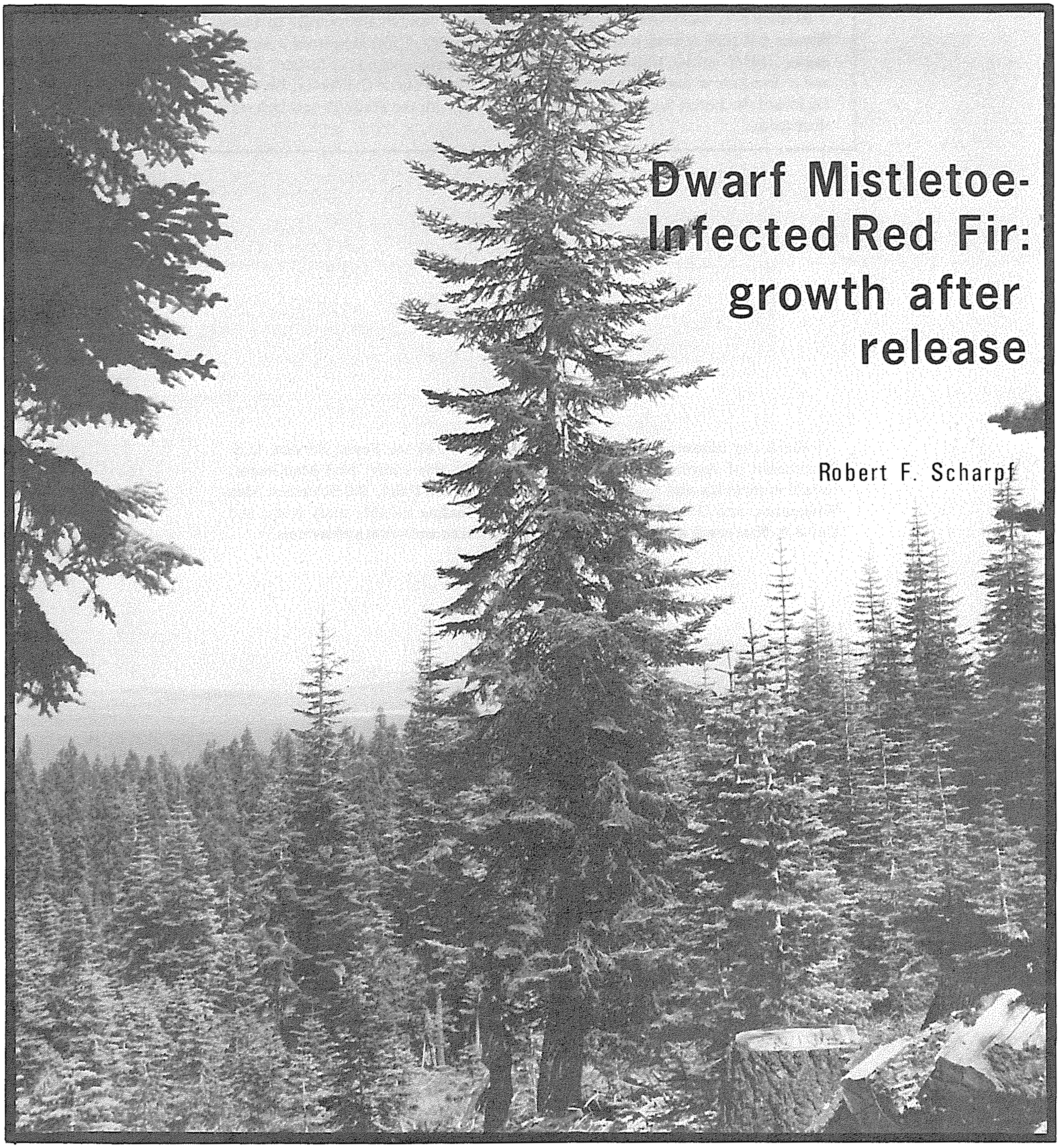

Dwarf Mistletoe-Infected Red Fir: growth after release

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RESEARCH PAPER PSW-143

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IN BRIEF...

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Release cutting—the logging of merchantable trees in stands of mixed size classes to provide growing space for smaller nonmerchantable trees—is currently a preferred method of harvest. Studies suggest that small fir trees respond well to release and that this method may have wide application for management of true firs in the Sierra Nevada and southern Cascade Ranges.

Many young- and old-growth stands, particularly red firs (*Abies magnifica* A. Murr.), however, are heavily infected with dwarf mistletoe (*Arceuthobium abietinum* f. sp. *magnificae*). Small fir seedlings and saplings in the understory are usually free or only lightly infected by dwarf mistletoe, whereas the larger poles and small sawtimber size class trees are often heavily infected. Previous research has shown that firs growing a foot or more in height will outgrow the vertical spread of dwarf mistletoe in the absence of overstory infection. In addition, trunk taper was not affected by an increase in levels of dwarf mistletoe infection in released red firs. To better manage dwarf mistletoe-infected stands in the Western United States, forest managers need answers to questions about the effects of release cutting and dwarf mistletoe on radial and height growth of infected trees.

In an attempt to find answers, field studies were begun in summer 1971 on four National Forests in northern California. The study areas represented the red fir forests of the Sierra Nevada and of the upper elevational zone of the southern Cascades. In the four forests, 2071 red firs were sampled. The following information was recorded for each test tree: (a) diameter-at-breast height, (b) live crown ratio, (c) height growth over the last 5 years, (d) mean annual radial growth the 5 years before release, (e) mean annual radial growth at 5-year intervals after release, and (f) dwarf mistletoe infection. It was expected that interacting variables—particularly tree diameter and live crown ratio—would influence growth response.

This paper reports the independent effects and interactions of release cutting, live crown ratio, diameter-at-breast height, and dwarf mistletoe on growth. Both infected and noninfected red firs responded well to release cutting: radial growth rate increased noticeably after 5 years, and essentially doubled 10 years after release. Higher rates of radial growth were achieved by trees with adequate live crown ratios and by trees with larger diameters. Dwarf mistletoe reduced radial growth significantly only at the medium-to-high levels of infection. Trees with a poor live crown ratio (40 percent or less live crown) grew less in height, and were less able to outgrow the vertical spread of dwarf mistletoe.

Release cutting is a practical method of managing dwarf mistletoe-infected red fir stands as long as adequate stocking remains after release. Selecting trees with good live crown ratios, preferably the larger, dominant trees, should be the main consideration, irrespective of the level of dwarf mistletoe infection. Results of this study should also apply to white fir (*Abies concolor* [Gord. and Glend.] Lindl.) infected with *A. abietinum* f. sp. *concoloris.*

True firs, principally white fir *(Abies concolor* [Gord. and Glend.] Lindl.) and red fir *(A. magnifica* A. Murr.), make up about one-fourth of the commercial sawtimber in California and contribute about the same proportion of growth (Oswald and Hornibrook 1966). A substantial portion of this growth and volume is in pure red fir stands. In the last decade, the stumpage value of firs has increased markedly and foresters are keenly interested in intensive management of these species.

Fir stands, particularly pure stands of old-growth red firs, were harvested in the past primarily by clearcutting. Clearcutting, especially of large blocks, required planting of trees to ensure adequate regeneration of the logged-over areas. Consistently good red fir nursery stock has not been available, and ponderosa pine (*Pinus ponderosa* Laws.) and Jeffrey pine (*P. jeffreyi* Grev. and Balf.) have been used, even though these species have not developed well on red fir sites. Where clearcutting is used today, the trend is toward cutting smaller blocks or narrow strips of mature trees to obtain natural regeneration from adjacent stands.

Many old-growth and younger merchantable fir stands in northern California contain abundant advance regeneration, or larger nonmerchantable trees. In these stands of mixed size classes, *release cutting* is usually the preferred method of harvest. The merchantable trees in stands of mixed size classes are harvested, thereby providing growing space for the smaller, residual nonmerchantable trees.

Gordon (1973) found that small firs respond well to release and that tree mortality after release is not a serious problem, even if some damage or injury to residual trees occurs. He suggested that release cutting may have wide application in the management of true firs in the Sierra Nevada and southern Cascade Ranges.

Many young- and old-growth fir stands, particularly red firs, are heavily infested with dwarf mistletoe (*Arceuthobium abietinum* Engelm. ex munz f. sp. *magnificae* Hawksworth and Wiens). Small firs in the understory (seedlings and saplings) are usually free, or only lightly infected by dwarf mistletoe (Scharpf 1969). Large, old-growth trees, the nonmerchantable larger trees, and poles remaining after release logging are often heavily infected.

Forest managers often ask questions about release of red fir stands infected with dwarf mistletoe. What is the effect of dwarf mistletoe? How fast will it spread among infected residual trees after release? Will infected trees release after logging? Will tree mortality or growth reduction be a problem over time in infested released stands?

Some of the above questions were answered recently (Scharpf and Parmeter 1976). On good sites, spread of dwarf mistletoe vertically within crowns of young, vigorous red firs and white firs not exposed to overstory infection, is slow, and the trees outgrow in height the vertical spread of the parasite by a ratio of at least 4 to 1. Dwarf mistletoe may not build up and spread throughout the crowns of young firs on good sites over the currently projected rotation ages of from 100 to 150 years. Scharpf (1977) found that trunk taper in red firs does not increase with an increase in dwarf mistletoe rating, as has been reported to occur with other dwarf mistletoe-host combinations (Baranyay and Safranyik 1970, Korstian and Long 1922). Tree taper differences, therefore, can be ignored in calculating growth and volume losses from dwarf mistletoe in true firs. Other questions regarding growth losses and mortality have not been answered to date.

This paper reports a study of the effects of dwarf mistletoe, release cutting, live crown ratio, and diameter-at-breast height on the growth of red fir. Dwarf mistletoe reduced radial growth significantly only at the medium-to-heavy levels of infection. Independent effects or interactions of the other three variables influenced the radial and height growth of both infected and noninfected stands.

METHODS

Height growth was not determined before release in this study because of the problems in determining the height of the tree at the time of release and in measuring the length of older internodes within the crown of test trees. In released trees, height growth over only the last 5 years was investigated.

Field studies extended from summer 1971 until fall 1972. Temporary plots were established on four National Forests where release logging had been done in red fir timber type *(table 1)*. The study areas represented the red fir forests of the upper elevational zone of the southern Cascades in northern California and the red fir forests of the Sierra Nevada.

Although site class was not determined for each study plot, measurements for the general areas of study ranged from site class II-150 to A-200 for dominant trees (Dunning 1942).

Size of the study plots varied, but each had to meet these research criteria:

a. About 100 or more released trees undamaged by logging and from 6 to 20 inches d.b.h. had to be available on each area after logging. Trees with broken tops, badly damaged crowns, or severe trunk wounds were rejected.

b. All trees selected for study had to be "fully" released. Whether trees were fully released was determined by the distance of the test trees to stumps of overstory trees removed during logging. Only test trees judged to have been suppressed in growth by overstory trees before release were selected for study. Groups of residual trees competing with one another, or trees not fully released after logging, were not sampled.

c. Dwarf mistletoe had to be present in all released stands studied, although not every released tree selected for study had to be infected. Trees that

Table 1—*Study area, elevation, trees sampled, and year of release cutting for released red firs in California*

National Forest and study area	Elevation *(Feet)*	Trees sampled	Year of release cutting
Lassen			
Swain Mt. Exp. Forest (T33, R8E)	6000	650	1960, 1962
Little Grizzly Creek (T26N, R5E)	6000		1955, 1966-1967
Tahoe			
Soda Springs (T16N, R14E)	7000	217	1955, 1958
Rattlesnake Creek (Sec. 22, 17N, R13E)	6500		1957-1958
Stanislaus			
Cabbage Patch (Hwy. 4, Sec. 29, T7N, R17E)	6500	642	1955-1956
Sierra			
Tamarack Ridge (Hwy. 168, Sec. 11 and 14, T9S, R25E)	6500	562	1956-1957

were within 100 feet of remaining infected overstory trees or within the margin in infested, uncut overstory were not selected as test trees.

One or more plots with arbitrary boundaries around each plot were established in each research area. All trees within a plot meeting the research criteria were sampled. For the four forests included in the study, 2071 red firs were sampled.

The following information was recorded for each test tree:

- *Diameter-at-breast height (d.b.h.).* For data analysis, trees were grouped into the following d.b.h. classes: 6.0 inches to 8.9 inches; 9.0 inches to 11.9 inches; 12.0 inches to 14.9 inches; 15.0 inches to 17.9 inches; and 18.0 inches to 20.9 inches.
- *Live crown ratio (LCR) proportion of the tree's height in living crown.* Dead and broken branches, thin portions of crown and similar irregularities were considered in the final judgment of live crown ratio. For data analysis, test trees were grouped into the following live crown ratio classes: 21 to 40 percent; 41 to 60 percent; 61 to 80 percent; and 81 to 100 percent live crown.
- *Height growth of the test trees over the last 5 years.* (This was done by measuring with a clinometer the length of the last five internodes between branch whorls.)
- *Mean annual radial growth the 5 years before release, and mean annual radial growth at 5-year intervals after release (B/A).* (If the last interval was less than 5 years, mean annual radial growth was determined from the number of growth rings that were present.) Radial growth measurements were determined from increment cores taken at d.b.h.
- *A dwarf mistletoe infection rating system (DMR).* Previously described by Scharpf (1977), the DMR was used as follows. The living crown was visually divided into thirds by height. Each third was rated as to its level of dwarf mistletoe infection: 0 = no infection; 1 = 1 to 10 percent of the primary branches infected; 2 = 11 to 50 percent of the primary branches infected; and 3 = 51 to 100 percent of the primary branches infected. The sum of the numbers listed for each portion of a tree crown gave an overall mistletoe infection rating. Trees with an overall rating of 0 were uninfected; 1 to 3 lightly infected; 4 to 6 moderately infected; and 7 to 9 heavily infected. This rating system is a modification of the 6-class dwarf mistletoe rating system commonly used today (Hawksworth 1977).

Analysis of radial growth was based on data from 1568 trees, and growth after release was based on data from the 5-to-10 year growth interval following release. For height growth, the same factors were used in the analysis of variance, except release, with results based on 2017 trees.

In addition to studying the effects of release and dwarf mistletoe on growth, it was expected that growth response would be influenced by other interacting factors, particularly tree diameter and live crown ratio. To determine if the factors investigated were significant sources of variation, the data were subjected to analysis of variance, including two-way interactions among the variables.

Table 2—*Table of F-values for independent effects and interactions of release, diameter-at-breast height, live crown ratio, and dwarf mistletoe rating on radial growth rate of red fir*

Variable	Degrees freedom	F
Independent Effects		
Before/after release (B/A)	1	371.00*
Diameter-at-breast height (d.b.h.)	4	20.47*
Live crown ratio (LCR)	3	50.56*
Dwarf mistletoe rating (DMR)	3	5.95*
Interactions		
B/A and d.b.h.	4	5.22*
B/A and LCR	3	8.09*
B/A and DMR	3	4.72*
d.b.h. and LCR	12	2.58*
d.b.h. and DMR	12	0.59
LCR and DMR	9	1.61

*Statistically significant at the 99 percent level of confidence.

RESULTS

Radial Growth

It is difficult to discuss the effect of any one factor on radial growth of red fir because analysis of the data showed that several factors influence growth. Analysis showed that the factors not only act alone but interact with one another to affect growth (*table 2*). I will attempt to point out, therefore, what I consider to be the important *independent* as well as *interacting* influences on radial growth.

Release

The most statistically significant and, perhaps, most important result of the study was that red firs responded well to release as expressed by a marked increase in radial growth rate. The magnitude of the growth response from an analysis of radial growth for all trees combined with different rated levels of dwarf mistletoe is shown in *figure 1*. Mean annual growth rates increased markedly within 5 years after release and essentially doubled after 10 years for both infected and uninfected trees. Available data was insufficient to determine precisely the growth rate 10 to 15 years after release. Preliminary results suggest, however, that growth, as influenced by release, more or less levels off in these later years.

Dwarf mistletoe was found to interact with release to affect radial growth rates in red firs (*fig. 1*). High, and to some extent, medium levels of dwarf mistletoe infection reduced growth rate. Before release, growth reduction from dwarf mistletoe may not have been as serious as after release. Under nonreleased conditions the trees (and probably the parasite) were not vigorous and were growing very slowly; thus, the effect of the parasite on growth was not pronounced. It is also possible that pronounced growth reduction by dwarf mistletoe on already weakened or severely suppressed nonreleased trees resulted in some mortality. Factors affecting mortality were not investigated in this study.

Although growth reduction from dwarf mistletoe occurred in released trees, the amount of reduction was noticeably offset by the increased growth as a result of release. It appears that increased radial growth takes place in both dwarf mistletoe infected and noninfected released red firs within 5 years of release, but that 5 to 10 years are needed before maximum growth rates as a result of release are achieved. After 10 years, no increases in growth rates were observed.

Live Crown Ratio

Next to release, live crown ratio was found to have the most significant effect on radial growth rate of red firs. It was apparent from the results that trees with good live crown ratios before and after release had better radial growth rates (*fig. 2*). This is because the capacity of a tree for photosynthesis, as expressed by the amount of living foliage, is an important factor in radial growth rate for trees growing under released stand conditions.

For released trees and probably also nonreleased trees, radial growth was related to the interaction of live crown ratio and d.b.h. In released trees, for example, radial growth generally increased with increases in live crown ratio and tree diameter (*fig. 3*). The larger, more dominant trees in a stand, on the average, had a greater live crown ratio than the smaller, suppressed understory. As a result, the larger trees had a competitive advantage because of their size, and a photosynthetic advantage because of higher live crown ratios. Because of these advantages, large trees exhibited higher radial growth rates than did smaller ones.

Results of the analysis showed that dwarf mistletoe did not interact with live crown ratio to affect radial growth, but the parasite exerted a signficant effect independently on growth rate before and after release. In released trees, for example, dwarf mistletoe reduced radial growth rate among all live crown ratio classes, especially at the level of infection rated heavy (*fig. 4*).

Even though dwarf mistletoe did not interact directly with live crown ratio to affect growth, the presence of the parasite was associated with some reduction in the live crown ratio. Heavy infection generally was found to reduce live crown ratios on an average of about 10 percent. Previous studies have shown that dwarf mistletoe-infected branches are a preferred infection site for the Canker fungus, *Cytospora abietis* Sacc., and that considerable crown reduction from branch killing occurs as a result of *Cytospora* infection (Scharpf 1964). At least part of the effect of dwarf mistletoe on radial growth in firs may be from reduction of live crown, and another part may be from the mistletoe's parasitic mode of life. The proportion that each of these two modes of action has on reducing radial growth was not determined in this study.

Dwarf mistletoe did not interact with d.b.h. to affect radial growth. In all d.b.h. classes, trees

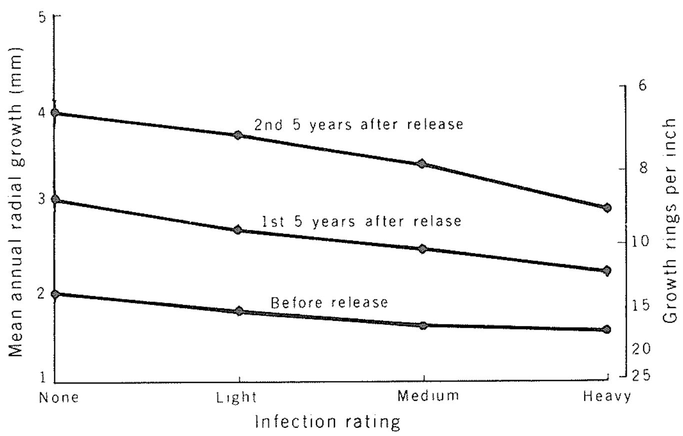

Figure 1—Red firs responded well to release as expressed by a marked increase in radial growth rate. Dwarf mistletoe significantly reduced radial growth only at the medium-to-heavy levels of infection.

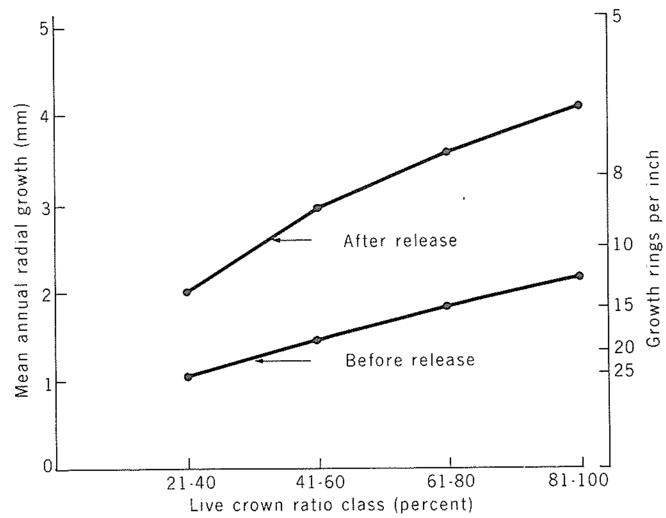

Figure 2—Next to release, live crown ratio had the most significant effect on radial growth rate of red firs. Trees with adequate live crown ratios, before and after release, had better radial growth rates.

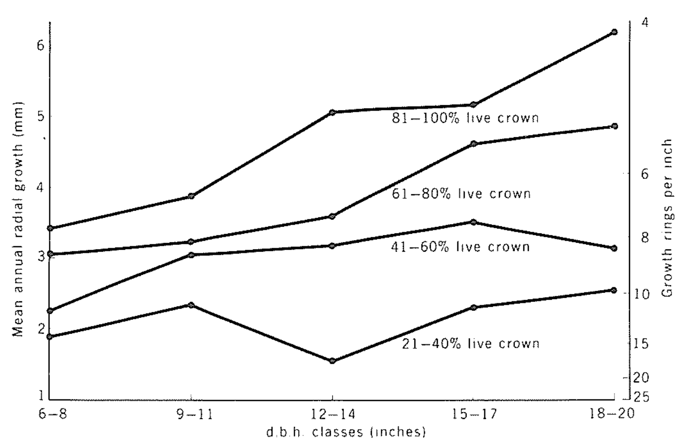

Figure 3—Live crown ratio and diameter-at-breast height interacted to influence radial growth in released red firs. Radial growth generally increased with increases in live crown ratio and tree diameter.

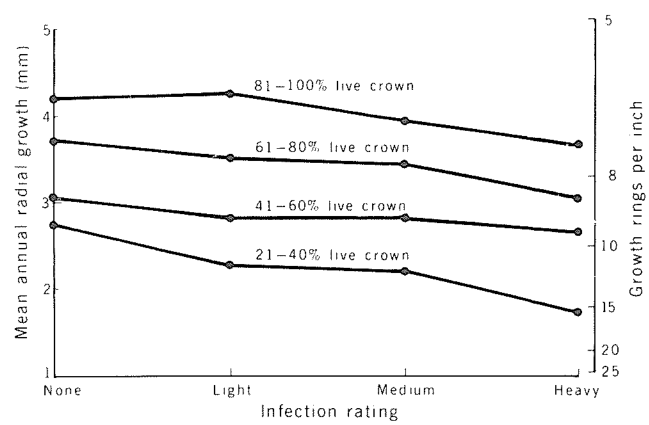

Figure 4—Dwarf mistletoe did not interact with live crown ratio but, independently, reduced radial growth rate among all live crown ratio classes in released trees, especially at the level of infection rated heavy.

Table 3—*Table of F-values for independent effects and interactions of live crown ratio, diameter-at-breast height, and dwarf mistletoe rating on 5-year height growth in released red fir*

Variable	Degrees freedom	F
Independent Effects		
Live crown ratio (LCR)	3	50.67*
Dwarf mistletoe rating (DMR)	3	23.51*
Diameter-at-breast height (d.b.h.)	4	9.14*
Interactions		
LCR and d.b.h.	12	1.39
d.b.h. and DMR	12	0.91
LCR and DMR	9	0.99

*Statistically significant at the 95 percent level of confidence.

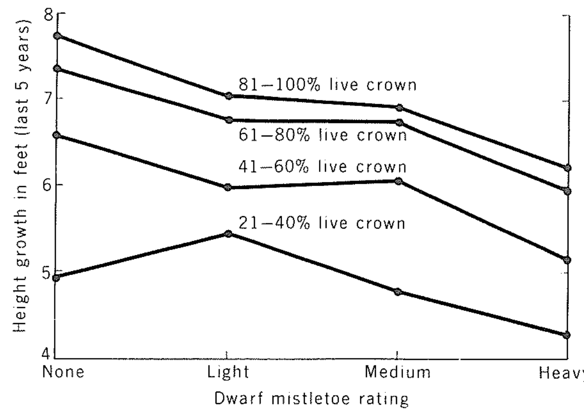

Figure 5—Most of the differences in height growth of trees resulted from differences in live crown ratio and degree of dwarf mistletoe infection. Trees with poor live crown ratio grew less in height, and were less able to outgrow the vertical spread of dwarf mistletoe.

with the highest levels of infection showed the greatest growth reduction.

Height Growth

As with radial growth, results showed that live crown ratio, dwarf mistletoe, and d.b.h. influenced height growth after release (*table 3*). None of these variables, however, interacted with one another to affect growth.

Most of the differences in height growth of trees in the study can be explained on the basis of differences in live crown ratio and dwarf mistletoe rating (*fig. 5*). Trees with poor live crown ratios, with or without dwarf mistletoe infection, on the average grew less than 1 foot a year in height. All other trees, irrespective of the level of dwarf mistletoe, were growing in height at an average of from 1 to 1.5 feet per year. In the absence of overstory infection, young trees growing in height of about 1 foot a year are able to outgrow the vertical spread of dwarf mistletoe by a ratio of at least 4 to 1 (Scharpf and Parmeter 1976). With such a ratio of growth-to-spread, infection levels and associated growth effects will diminish over time in heavily infected trees. With greater rates of height growth, infection levels and growth effects will diminish even more. Maintaining good height growth in released red firs is important in reducing future effects on growth from dwarf mistletoes.

Diameter-at-breast height was also found to be directly related to height growth. As explained previously, the larger trees are the more dominant, vigorous trees and, as such, grow taller more rapidly.

DISCUSSION

Results of this study indicate that both dwarf mistletoe infected and uninfected trees respond well to release logging. Why are infected red firs able to respond well to release and why do heavily infected trees often suffer relatively little growth impact? I suggest that several conditions are involved.

Suppressed firs have the inherent ability to respond to release and begin growth within a few years after release (Gordon 1973). This release response, expressed in particular by increased height growth, has an important bearing on effects from dwarf mistletoe. Studies on vertical spread of dwarf mistletoe in the crowns of red firs and white firs have shown that the parasite exerts little effect on growth if it is restricted to the lower portion of the crown (Scharpf and Parmeter 1976). Thus, over time, young firs on good sites "grow away" from infection and become less severely affected by dwarf mistletoe as long as adequate tree height growth is maintained.

Understory firs, even suppressed ones, often have a good live crown ratio. As this study has shown, live crown ratio had a marked effect on tree growth; however, dwarf mistletoe did not reduce the live crown ratio appreciably. Released firs, even those heavily infected by dwarf mistletoe, often have an abundant complement of foliage that is able to photosynthesize and produce the energy needed for maximum growth.

Red firs do not form brooms in response to infection, as do some other dwarf mistletoe-host species combinations. Hawksworth (1961), for example, found that reduction of radial growth was greater in broomed ponderosa pines in the southwest than in nonbroomed, infected trees, even though the nonbroomed trees may have had a higher rated level of dwarf mistletoe infection. The absence of pronounced dwarf mistletoe broom formation is probably a major reason for the lack of appreciable growth reduction on heavily infected red firs.

Is mortality a serious problem of infected red fir stands after release? Some trees could have died during that period after release, thereby adding another loss factor to those reported. Gordon (1973), however, attributed little (less than 1 percent) of the mortality which occurred in released, advance reproduction of red fir and white fir to dwarf mistletoe. I doubt if loss from mortality after release was of any consequence in this study, because trees of the size classes used that would have died within the 5 to 15 years after release would probably still have been standing on the plots, or would have fallen over in place. I saw little evidence of older or recently dead released trees on the study sites except for trees severely damaged as a result of logging. Permanent plots established at the time of the study will be used to determine mortality more precisely, as well as to assess changes in dwarf mistletoe infection rating and tree growth.

Will trunk swellings and cankers be of importance in released red fir stands? Trunk swellings and cankers caused by dwarf mistletoe in the main stem are recognized as a problem in infected red fir stands (Scharpf 1964, 1969). Considerable cull and tree breakage results from trunk infections, particularly in older trees. Recent studies suggest, however, that large swellings and cankers take many years to develop and may be of limited importance in managed, second-growth true fir stands.[1] Although verification is needed, it appears that trunk swellings have little effect on radial and height growth of released firs and that cull and tree breakage may be negligible over projected rotation ages for second-growth stands. In addition, studies have shown that, with present quality control procedures, no statistical differences were found in grade and volume of lumber cut from fir logs without dwarf mistletoe infection and from those with dwarf mistletoe trunk infections (Wilcox and others 1973).

One point must be considered in interpreting the results of this study and applying them directly to field conditions. The study was based mainly on *fully* released stand situations. Such stands may be below desirable stocking levels for particular management objectives. At any rate, the manager will be able to judge from this study the approximate range of growth he can expect from an infected red fir stand before release and from one fully released after logging. With the data given here, and with a knowledge of the general growth rate of stands of released trees in the field the manager can, within reason, predict future growth for individual fir stands with different levels of stocking. Efforts are being made to develop more precise growth and yield information for dwarf mistletoe infected and noninfected second-growth fir stands. Recent studies have shown that dwarf mistletoe has no statistically significant effect on trunk taper of released, pole-sized red firs (Scharpf 1977). Thus, the influence of dwarf mistletoe on tree form class likely will be of no consequence in determinations of growth and yield of released true fir stands.

The results of this study are not intended to suggest that dwarf mistletoe will not be a problem in released red firs. Some volume loss can be expected from growth reduction by the parasite, and unknown problems involving dwarf mistletoe may surface. It is well known, for example, that dwarf mistletoe predisposes trees to attack by bark beetles (Stevens and Hawksworth 1970). Also, the canker fungus *Cytospora abietis* often attacks and damages dwarf mistletoe-infected firs, and this fungus may become particularly serious in dwarf mistletoe infested stands when trees are injured by fire and logging, or weakened by adverse climatic conditions, such as drought stress (Scharpf 1964). The degree to which these conditions will influence released red firs infected with dwarf mistletoe, however, will be determined only from additional studies and from evaluation of permanent field plots.

The results of this study are applicable to dwarf mistletoe-infected white fir as well. The dwarf mistletoes on these two species are much alike in behavior and both red fir and white fir have similar silvical characteristics.

[1]Unpublished data by John R. Parmeter, Jr., on file, Department of Plant Pathology, University of California, Berkeley, Calif. 94720.

MANAGING RELEASED STANDS

Results of this study indicate that dwarf mistletoe-infected red fir stands can be managed by release cutting without serious losses from dwarf mistletoe. In deciding on this approach, the manager should consider:

- Release cutting implies that adequate advance regeneration will be present after logging on a given site. If this is the case, then release cutting should be considered as an appropriate management approach with or without dwarf mistletoe in the stand. If, however, release results in serious understocking, and planting or natural regeneration is required, then infected, released trees will act as a source of overstory infection. In such cases, regeneration over time will become severely infected unless nonsusceptible species of conifers seed-in or are planted. In selecting species for planting, remember that dwarf mistletoe on red fir is host specific and infects only red fir (and Noble fir in Oregon). Consider also that planted seedlings will take several years to become established and reach the initial size of the released residual trees. The growth loss that dwarf mistletoe will cause in released, understory trees over the rotation period, therefore, may be much less than the losses incurred from starting the stand anew with planted seedlings.
- It is best to leave as many uninfected or lightly infected trees or nonsusceptible species as possible to reduce volume losses that may occur over time, and to limit spread of the parasite within the residual stand.
- Live crown ratio is important to the subsequent growth response of released trees. Badly suppressed trees with poor live crown ratios show the poorest release response and suffer the most from dwarf mistletoe. Infected stands with primarily small, suppressed trees with poor live crown ratios might be managed by other methods.
- Most released trees on good sites will, after a few years, be putting on height growth faster than dwarf mistletoe can spread upward in the crown. Dwarf mistletoe infection after release and for a few years thereafter may appear serious, but with time should diminish. This change can be determined by assessing the rate of release response (annual height growth) in the residual trees. If the trees are growing well in height (about 1 foot or more per year), then the effect of dwarf mistletoe is diminishing and will become less of a problem until tree height growth slows.

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1979. **Dwarf mistletoe-infected red fir: growth after release.** Res. Paper PSW-143, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

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Retrieval Terms: Abies magnifica; release cuttings; height increment; radial growth; live crown ratio; *Arceuthobium abietinum.*

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