United States
Department of
Agriculture

Forest Service

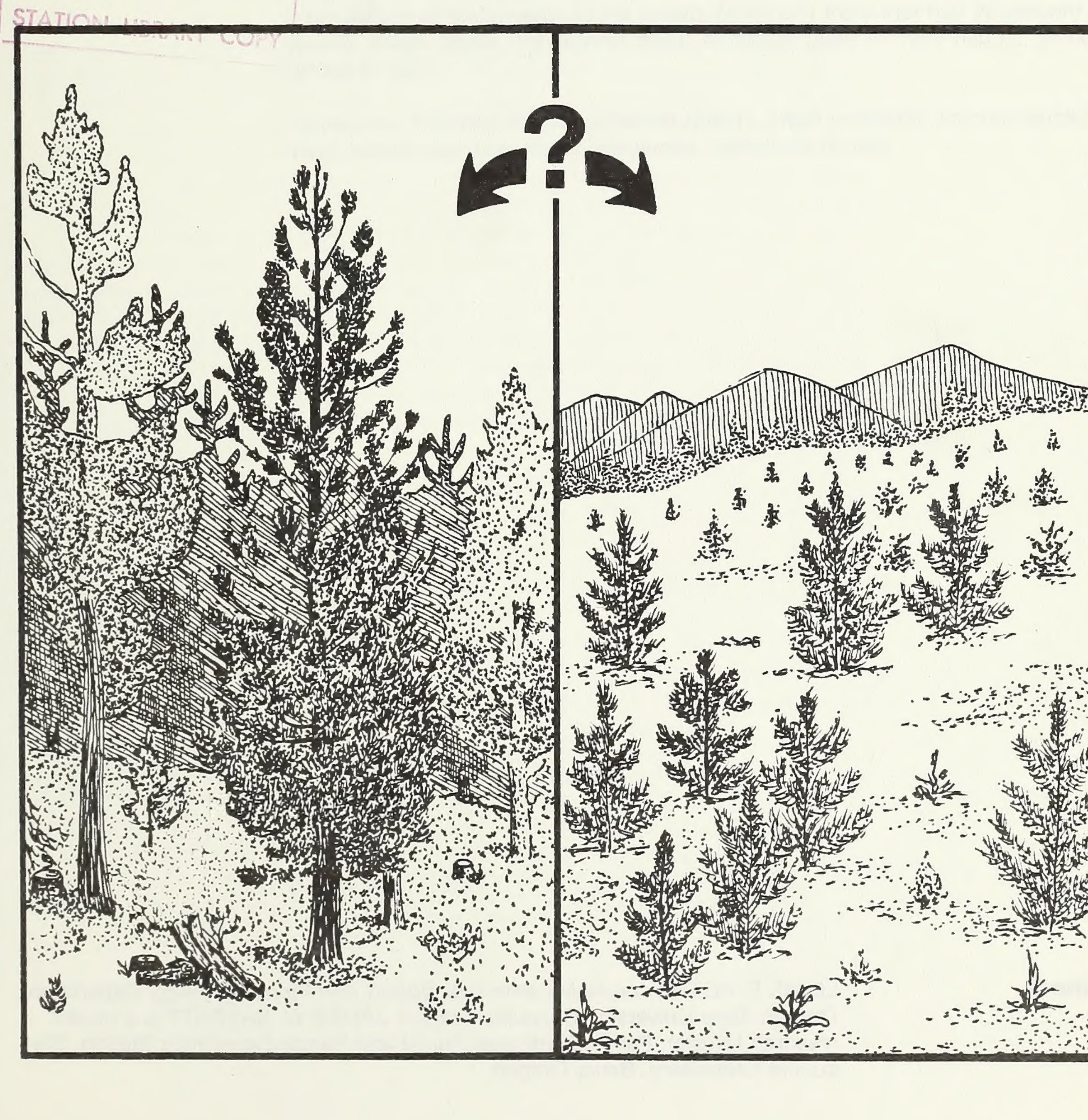
Pacific Northwest
Forest and Range
Experiment Station

Research Paper
PNW-331
January 1985

Response of Dwarf Mistletoe-Infested Ponderosa Pine to Thinning:

2. Dwarf Mistletoe Propagation

Lewis F. Roth and James W. Barrett



Research Summary

Population trends of western dwarf mistletoe were examined in 54 parasitized ponderosa pine saplings for 13 years, both before and after release of advanced regeneration by removal of the overstory and, without discriminating against trees with mistletoe, thinning the understory thickets to 250 trees per acre.

Before the stands were treated, the number of mistletoe plants increased at a slow, constant rate. After stand treatment, mistletoe propagated rapidly at varying rates. We were concerned about the effect of this rapid increase on crown development and tree growth. The variations in rate of increase resulted from removal of most of the stable seed source during stand treatment and from a flush of emergence and reproduction of previously latent plants that accompanied the excellent response of tree crowns to release.

Despite the conspicuous increase of mistletoe, the average number of plants per meter of stem decreased slowly with time after stand treatment. The decrease was marked on 19 trees, suggesting that they had substantial resistance to mistletoe. Tree crown density, but not height, increased rapidly immediately after stand release, trapping most of the mistletoe seed within the existing crown to establish new plants at the height of their parent plants, about 16 percent being in the upper crown. After height growth accelerated in the fifth or sixth year, proportionally fewer mistletoe plants established higher in the crowns. Only 1 percent of all plants were in the upper third of the crowns after 13 years. Observation four years later disclosed no plants in the upper third of the crowns of dominant trees. Dwarf mistletoe propagation relative to crown development was similar among dominant, codominant, and intermediate trees, suggesting that smaller trees can be safely kept for stocking purposes if they will truly respond to stand release. Suitability of parasitized pine stands for silvicultural treatment depends on whether trees will grow rapidly after release. Guidelines are given for identifying treatable stands and for selecting leave trees.

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Introduction

On favorable sites, healthy advanced ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) regeneration that is protected from damage during overstory harvest responds quickly to release from competition and grows rapidly (Barrett 1970, 1973, 1979). Where western dwarf mistletoe (*Arceuthobium campylopodum* Engelm.) is abundant, however, many foresters question whether thinned stands will respond favorably. The negative view may lead to excessive clearcutting of infested stands, followed by uncertain, costly reforestation, or it may lead to rejecting any silvicultural treatment for potentially productive stands.

We know that dwarf mistletoe retards growth of unmanaged pine (Childs and Edgren 1967, Childs and Wilcox 1966, Shea 1964, Shea and Belluschi 1965, Weir 1916, Wilcox 1963) and extremely heavy infestations will stunt and kill trees (Roth 1971), but we are much less certain that managed stands suffer significantly.

This paper examines the dwarf mistletoe component of stand response where infested pine regeneration on the east slope of the Cascade Range has been released by thinning, following removal of the overstory.

Dwarf mistletoes, unlike the widely distributed microscopic fungal pathogens in the forest, scatter their seeds over short and definable distances, and plants that are reproductively mature are big enough to be easily seen. These features have encouraged foresters to undertake dwarf mistletoe control by harvesting the overstory and thinning to sanitize the understory (Hadfield and Russell 1978). Removal of the overstory is profitable, of course. Where appropriate, removal of parasitized understory trees can also be economically beneficial if it is integrated with thinning for stand improvement and enhanced growth (Barrett 1979, Sassaman and others 1977, Shea and Lewis 1971).

Early efforts to control dwarf mistletoe in advanced ponderosa pine regeneration were aimed at eradication (Childs 1963, Graham 1967, Shea and Lewis 1971). This objective tended to limit control to stands that had enough trees visibly free of dwarf mistletoe to adequately stock the site after treatment.

Contrary to expectations, dwarf mistletoe frequently recurred, even where all visible plants were removed. Resurgence resulted primarily from the emergence of previously undeveloped plants already established within the bark (Shea and Lewis 1971). In stands thinned to specified densities, the average stem diameter was also greatly reduced after treatment because dwarf mistletoe is most evident in the bigger trees (Childs 1963). Accordingly, foresters either backed away from managing infested stands or they destroyed them and replanted, thus incurring reforestation costs and sacrificing the contribution of accumulated growth toward shortening the timber rotation.

Following intensive examination of dwarf mistletoe in the diverse stands of ponderosa pine on the Pringle Falls Experimental Forest on the Deschutes National Forest in central Oregon, Roth (1952, 1953) suggested that pine might suffer little damage from dwarf mistletoe if growth conditions that allowed annual height growth exceeding 10 inches could be maintained. He further suggested that, on sites of good quality, recent height increment of the better trees, along with growth response to thinning, might be better criteria for guiding and evaluating treatment than the amount of visible dwarf mistletoe. These suggestions helped prompt Barrett to establish the growth study (Barrett and Roth 1984) and guided the second thinning. This approach recognizes that after treatment most leave trees are parasitized. The amount of damage resulting from these plants is a valid concern and is examined here with respect to crown enlargement and height increment, the growth characteristics most reduced by dwarf mistletoe (Childs and Edgren 1967, Weir 1916).

When this study began, little was known about the effects of dwarf mistletoe on the growth of advanced pine regeneration. There was some difference of opinion as to whether the parasite was damaging at all. Nevertheless, abundantly parasitized, suppressed pines appear hardly to grow at all while lightly parasitized trees show no detectable reduction in growth. Between these extremes are intermediate frequencies of parasitism that damage physiological functions and must indirectly limit growth.

We understand very little of the process by which dwarf mistletoe actually damages trees. Although the parasite gets nearly all of its food from the tree, competition with the tree for nourishment seems moderate. Probably most important is disrupted translocation because the tree system, particularly the roots (Knutson and Toevs 1972), is deprived of the photosynthate formed distally to dwarf mistletoe plants (Leonard and Hull 1965, Rediske and Shea 1961). Disturbances of translocation also modify self-pruning of branches from the lower crown which may be delayed indefinitely. Such branches often distort to form brooms and, because of impaired translocation in the phloem, they contribute little to the tree's welfare. Like the parasite, they take valuable water and minerals. Such branches essentially become parasitic, and their demands—perhaps more than those of the parasite—contribute to the characteristic decline of the upper crown.

Tree growth is a direct function of crown size and photosynthesis (Grier and Waring 1974, Waring and others 1980). Consequently, we hypothesized that if crowns of infected saplings enlarge faster than the dwarf mistletoe propagates, the trees should grow productively. Since the resurgence of dwarf mistletoe is a common consequence of thinning we needed to know if it would nullify the growth benefits expected from thinning.

The Study

We examined dwarf mistletoe in crowns of advanced ponderosa pine regeneration with respect to increases in crown size and tree height. Data covered a 30-year period centered on the years 1957-58, when the experimental stand was released, then thinned to 250 trees per acre (Barrett and Roth 1985). In 1971 and 1972 when stocking was again reduced, from 250 to an average of 88 trees per acre, dwarf mistletoe plants were counted and annual increments of branchlet elongation measured by dissection of 26 intermediate, 12 codominant, and 2 dominant trees. This was more than a decade after initial thinning and long after formerly latent dwarf mistletoe plants had emerged.

Annual bud scars, which are recognizable for about 25 years back from branch tips, were used to identify points for branch dissection and determine age of dwarf mistletoe plants.

Twig growth for the previous 3 years was clipped from the tips of all branchlets and discarded as being too recent for dwarf mistletoe detection. Branches were then dissected at the bud scars and annual growth segments for all branches at each main-stem whorl were piled together by year of growth. Segments were scrutinized for dwarf mistletoe plants, measured, and their lengths totaled for each pile. Lengths for branches from all whorls were then totaled to describe each year's crown enlargement and to provide an index to crown mass. Dwarf mistletoe plants were recorded by year of origin of the supporting segment, branch whorl of their occurrence, sex, and size. This procedure included all but a few of the very oldest dwarf mistletoe plants that could not be accurately aged.

Length of the bole below the crown, length of each bole interwhorl, and length of leader were recorded. From the data a scale diagram was drafted of each tree enabling measurements of dwarf mistletoe plant locations relative to crown development and height growth (fig. 1).

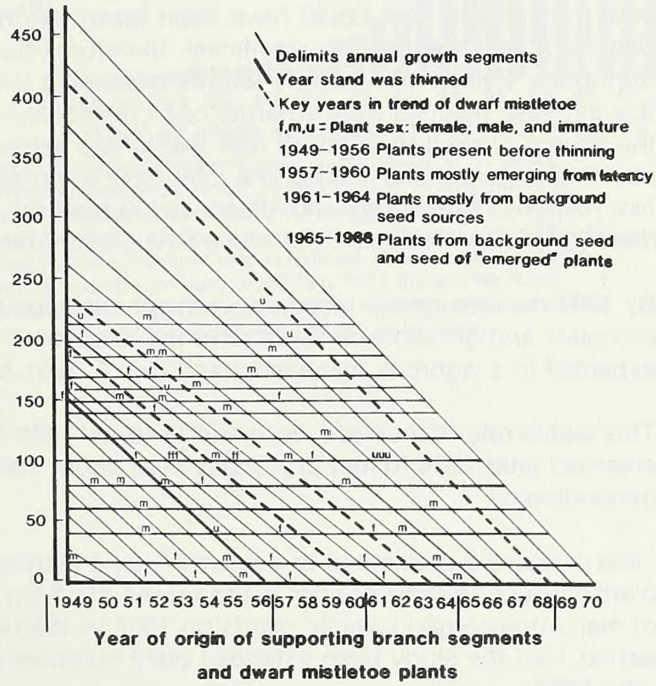

Figure 1.—Diagram of the live crown of tree 9A showing location of dwarf mistletoe plants by position of supporting branch (horizontal lines) and year supporting branch segment originated (space between diagonal lines). The vertical axis only is drawn to scale. Diagrams of 54 such trees were used to measure population trends of dwarf mistletoe and ascent in crown relative to crown development. Because of branch inclination, some plants low in the crown were slightly lower and some high in the crown were slightly higher than shown.

Initially, we assumed that if the intermediate and codominant trees from the thinnings could enlarge their crowns faster than dwarf mistletoe increased, then certainly the same relationship would be true of the better trees in these classes and of the rapidly growing dominants. As the study progressed, however, the position of dwarf mistletoe plants within the crown relative to height growth appeared increasingly important. Consequently, in 1973 and 1974, we non-destructively sampled 14 standing trees, mostly dominants. Units identical to those on the dissected trees were measured.

The 54 trees measured were taken consecutively along three irregular traverses of the thinning plots (Barrett and Roth 1985).

Results

Effect of Thinning on the Number of Dwarf Mistletoe Plants

As crowns of the saplings slowly enlarged, the number of dwarf mistletoe plants gradually increased. Values in figure 2 for the period before 1957 represent infections existing, but mostly latent and invisible, during the decade preceding overstory removal and thinning, except for infrequent plants possibly arising on still susceptible 1954-57 wood. Because of the emergence of many plants from latency the pre-1957 values—as recorded in 1971—greatly exceed values that would have been recorded if data could have been taken before the stand responded to release. It seems especially significant, therefore, that the number of visible plants during the 4 years immediately following thinning doubled (fig. 2). Nearly all of this increase resulted from emergence of previously established plants because the source of seed to establish new plants was extremely depleted by the logging and thinning operations. Also, the interval of approximately 6-years between the first response to thinning and 1964 was too brief for abundant completion of the dwarf mistletoe life cycle to produce new plants from seed.

By 1961 the emergence response of dwarf mistletoe to thinning was substantially complete and growth from seed returned to a slower annual rate that would be expected in a vigorous managed stand (fig. 2, 1961-64).

This stable rate of increase was short lived; by 1965 the many latent plants that emerged after 1958 fruited prolifically after about 1961, initiating new populous generations.

Data in figure 2 are limited to 2 years of rapid increase. As in the preceding cycle, plant production should return to the slower (1961-64) rate in 3 or 4 years. Because of many unemerged juvenile plants on 1967 to 1970 wood, values beyond 1966 are partial. Had the study been extended plant numbers would have continued to rise after 1966.

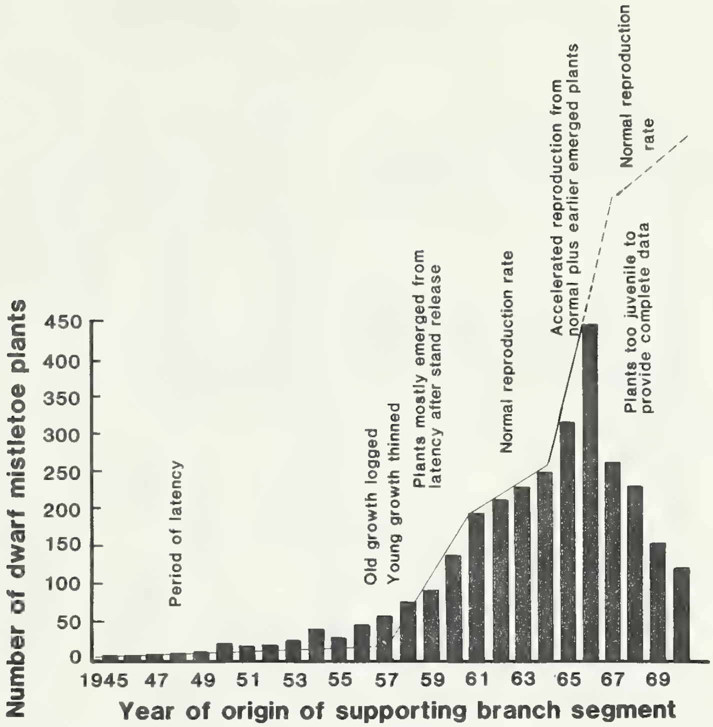

Figure 2.—Dwarf mistletoe population trends of 54 small, pole-size ponderosa pines: 14 dominants, 14 codominants, and 26 intermediates. Columns represent number of dwarf mistletoe plants originating on each successive year's shoots. Lines represent ascent rate variations of population development. Projection of bars preceding 1957 above line is an anomaly resulting from tabulation of formerly latent, invisible plants after they emerged in response to thinning.

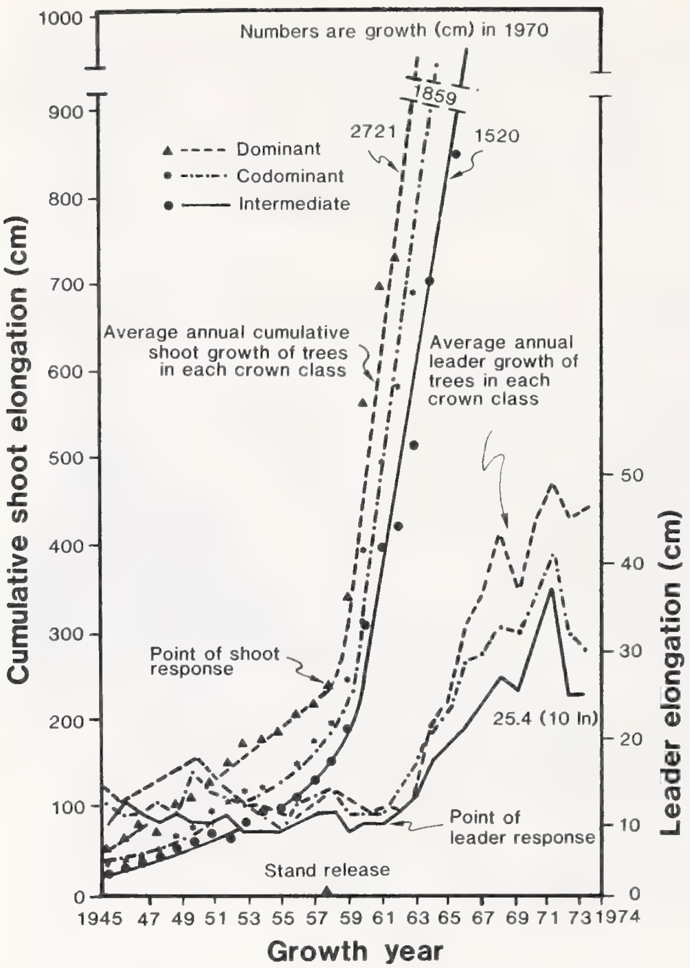

Figure 3.—Average annual shoot growth and leader elongation of 54 small, pole-size ponderosa pines. Dominants (14), codominants (14), and intermediates (26) are plotted separately. Annual leader length is graphed on data points. Visually smoothed curves are used for the annual sums of branch segment lengths.

Effect of Thinning on Crown Development and Ratio of Dwarf Mistletoe Plants to Crown Size

Crown development accelerated immediately following stand release in 1957-58 (fig. 3). Length and number of branchlets among the dominant trees quadrupled in the first growing season after thinning. The increase was even larger in subsequent seasons. During the 3 years following thinning, crowns of the intermediates enlarged nine times the pretreatment rate. An extremely rapid rate of crown enlargement was maintained by trees of all crown classes up to study termination in 1974. Height growth, notably, did not accelerate until 5 years after release (fig. 3). Trees retained in the growth study maintained an accelerated rate of crown enlargement through 1982 (Barrett and Roth 1985).

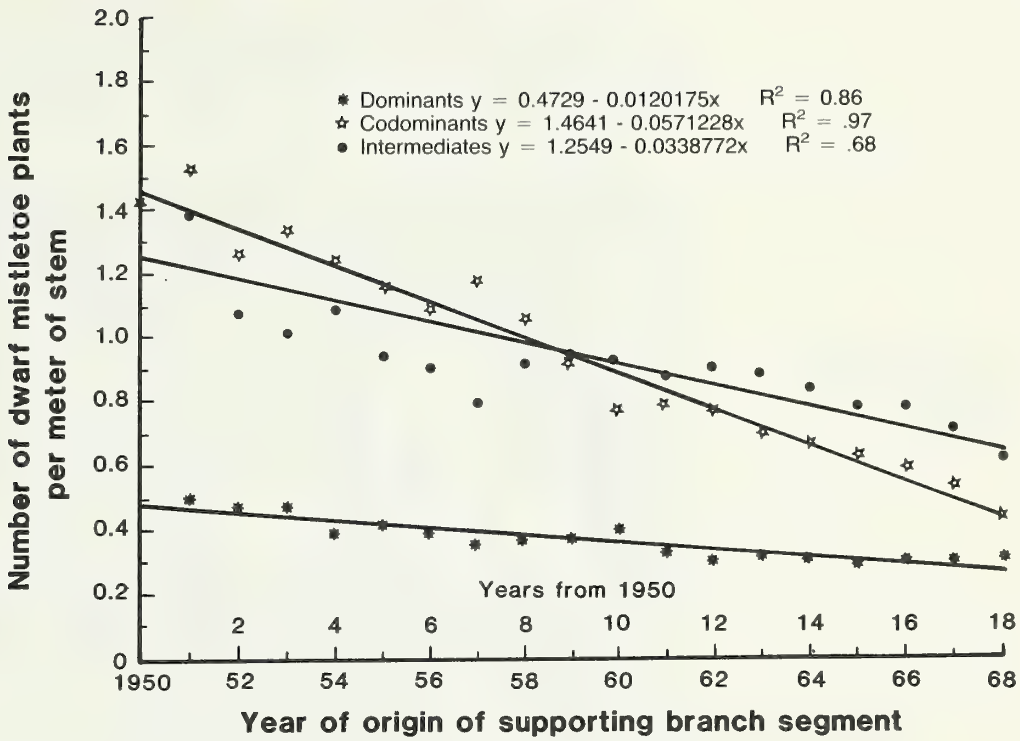

Figure 4.—Number of dwarf mistletoe plants per meter of annual growth on branches comprising the crowns of 54 pole-size ponderosa pines. Dominants (14), codominants (14), and intermediates (26) are averaged separately and plotted.

Figure 4, covering the period 1950 to 1968, shows the relationship between the increase in dwarf mistletoe and crown enlargement, expressed as the number of dwarf mistletoe plants per meter of branch. Prior to 1950 crown enlargement averaged only 0.22 m of branchlet length per tree per year. On such slow growing trees data are highly variable and even one dwarf mistletoe plant greatly influences the plant to crown ratio. Data after 1968 underestimate the amount of mistletoe because of plant immaturity on the relatively new wood (fig. 2) and are excluded from figure 4.

The number of plants per unit of stem declined from 1950 to 1968 on trees in all crown classes. This decline was slow in the dominants, fairly rapid in the codominants, and somewhat variable in the intermediates. Only in the latter was there a suggestion that fewer plants per unit of stem resulted from stand release. If thinning had influenced the ratio, the slope of lines in figure 4 would have changed after thinning in 1957-58. These changes in plant to branch ratio indicate a consistent improvement in stand condition but are not particularly convincing evidence that the treated stands have overcome their dwarf mistletoe problem.

Between 1945 and 1970 the number of dwarf mistletoe plants per meter of stem increased on 20 of the 54 trees and decreased on 19. On fifteen there was no change. A *t* test indicated that differences in height growth of trees with increasing and decreasing numbers of plants per meter during these 25 years were not significant (P = .05). At this early stage the amount of mistletoe was not influencing height growth.

In summary, while the number of dwarf mistletoe plants increased substantially after stand thinning, tree crowns enlarged correspondingly and the plant to crown ratio was little changed. The stand responded to thinning with growth equalling that of a thinned healthy stand (Barrett and Roth 1985). (fig. 3). and the amount of dwarf mistletoe had no detectable effect on tree height growth.

Location of Dwarf Mistletoe Plants in the Crown

The location of a dwarf mistletoe plant in the crown influences the plant's importance (Hawksworth 1961, Strand and Roth 1976). Because of their ability to disperse seed more widely, plants high in the crown are more threatening to the stand and perhaps more damaging to the host tree than are plants lower in the crown.

Understory trees that intercept seed from an infected overstory have limited opportunity to grow in height faster than the dwarf mistletoe establishes higher in the crown and commonly have plants relatively high in their crowns. In the absence of seed from the overstory, however, it appears that well spaced young pines can grow in height faster than the dwarf mistletoe can ascend. They may be able to do this even though dwarf mistletoe plants in understory crowns can throw seed higher than the tops of trees that bear them. The rate of dwarf mistletoe ascent depends on the height to which seed is thrown and on the probability that a given seed will establish an infection. This probability is very low (Strand and Roth 1976).

We hypothesized that sustained height growth of 10 or more inches (25.4 cm) a year would enable a tree to stay ahead of the dwarf mistletoe and would result in an increasingly larger proportion of the crown length above the mistletoe.

Tree growth is divided into the pre-thinning period of slow growth, extending from our oldest records in 1945 to 1957, and the post-thinning period of rapid crown enlargement from 1957 to 1974. The latter tree-growth period is divisible into four periods of recognizable dwarf mistletoe proliferation (fig. 2): 1957-61, when extensive emergence of latent plants combined with some normal regeneration from seed; 1961-64, when new plants arose almost entirely from seed; 1964-68, when plant regeneration from seed was excessive (the start of this period coincided with acceleration of tree height growth); and 1969-70, which was biologically similar to 1961-64 and ended with final dwarf mistletoe records from the dominant trees.

Foresters have found it useful to divide tree crowns horizontally into thirds based on equal divisions of the main stem within the crowns. Such division has biological significance as well, in that each crown part functions somewhat differently physiologically. The upper crown maintains height growth and position of the tree in the stand, the middle crown performs most of the photosynethesis and related functions, and the lower, senescent third contributes relatively little (Barrett 1968). Horizontal thirds, however, poorly represent the distribution of crown mass and, consequently, poorly reflect the size of the sections as targets for dwarf mistletoe seed. Despite this limitation, our data compare dwarf mistletoe distribution among crown thirds as of the end of the periods identified above.

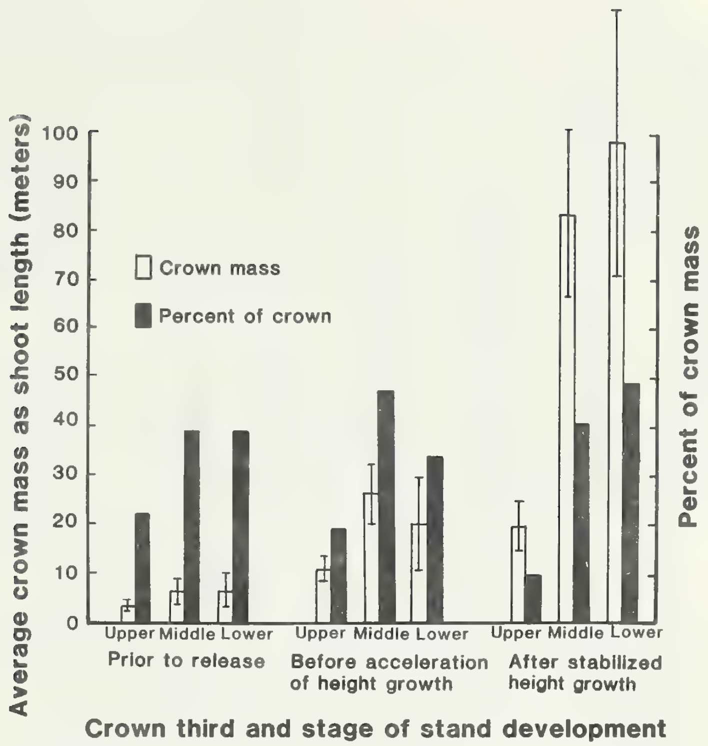

Figure 5.—Distribution of crown mass into horizontal thirds of the dominant trees at three stages of stand development: mass is represented as meters of shoot length (confidence limits P = .05).

Figure 5 shows distribution of crown mass of the dominant trees among crown thirds at the time of stand release, at the time of crown enlargement preceding accelerated height growth, and after rapid height growth stabilized.

The proportion of crown in the upper third of unreleased trees is larger than in released trees. This third, accordingly, is a proportionately larger target for dwarf mistletoe seeds. The upper crown third in fast-growing trees did not decline in relative size during the first 6 years after release and remained a comparatively large target, even though crown mass tripled. The proportion of mass in the middle crown increased somewhat during the 6 years following release but during the last period was similar to that in the first period. Consequently, there was a proportionate decrease in the upper crown, after initiation of accelerated height growth, and an increase in mass of the lower, less functional third of the crown. The distribution of dwarf mistletoe among crown thirds of the dominant, codominant, and intermediate crown classes was strikingly similar.

While the number of dwarf mistletoe plants quadrupled between 1956 and 1963, there was little change in the distribution of plants among crown thirds (fig. 6). This reflects the emergence of latent infections on old wood. New plants were similarly distributed among the enlarging crown thirds because crown configuration remained relatively unchanged during this time. After height growth accelerated in 1964, a marked and progressive difference developed in the distribution of plants among crown thirds. By 1970, 80 percent were in the lower third, and fewer than one percent were in the upper third, even though a 12-fold increase had occurred in the total number of plants. By 1974, with data available only for dominant trees, there were no plants in the upper crown third, and 87 percent were in the lower third.

The prevalence of dwarf mistletoe is frequently evaluated by a six point system (Hawksworth 1977, Hawksworth and Lusher 1956). If there are one or more dwarf mistletoe plants in a crown third, a point is recorded. If plants are on more than half the branches in a crown third (here corresponding to more than one plant on 3 m of branch) another point is added making possible a maximum total-crown rating of six points. Stands can be rated by adding values for individual trees and dividing the total by the number of trees.

Fourteen of our trees remaining after the second thinning were rated at significant times of stand and dwarf mistletoe development:

Period	Rating
1945-56	1.8
1957-60	2.3
1961-63	2.8
1964-68	2.8
1969-70	2.4

A sharp rise in rating (17 percent) occurred during the first years after thinning because latent plants emerged. This change was mostly from rating 1 to rating 2. Though sometimes conspicuous, this increase is scarcely real because most plants had been present but invisible at the first rating period. Ratings leveled off after 1961 (in spite of a great increase in total plants) until tree height growth accelerated in 1963, then ratings of all trees declined.

One tree rated 6 initially and five rated 5 or higher at intermediate periods. In 1970, however, none rated higher than 3. Since no dwarf mistletoe was found in upper crown thirds in 1974, the rating system probably overstates severity of the infestation. The nature of this overstatement is suggested by figure 7, which further relates location of dwarf mistletoe plants to crown development.

Uniformity of condition among the three crown classes is again striking (fig. 7). Through 1963 there was no detectable increase in the proportion of uninfected crown above the highest mistletoe plants. This distribution shows that directly after thinning growth of leaders was comparable to growth of other branches. There was no accompanying rise in height of the dwarf mistletoe plants because newly observed plants were primarily the latent infections emerging on old wood rather than new seedlings. By the time new plants from seed became numerous, height growth had accelerated faster than the ascent of dwarf mistletoe. So, by 1968, approximately the upper 45 percent of the crown length was above the highest dwarf mistletoe plants, and within 6 more years, 60 percent of crown length was above the highest plants.

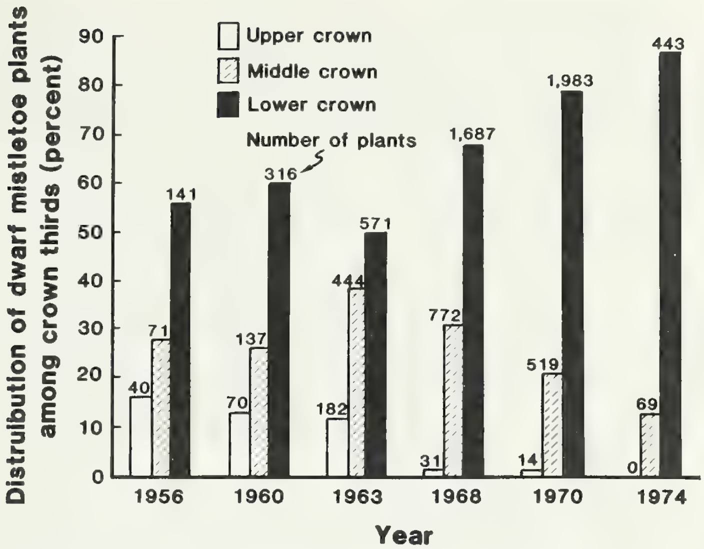

Figure 6.—Distribution, among crown thirds, of the total dwarf mistletoe plants (7,440) growing on 54 young ponderosa pines between 1945 and 1974. Plant numbers are reported just preceding stand release in 1956; when most latent dwarf mistletoe plants had emerged after stand release in 1960; immediately preceding accelerated leader elongation in 1963; when rapid leader growth had stabilized in 1968; and when data collection ended in 1970 and 1974. Data for 1974 describes dominants only. Dwarf mistletoe distribution was similar among crown classes.

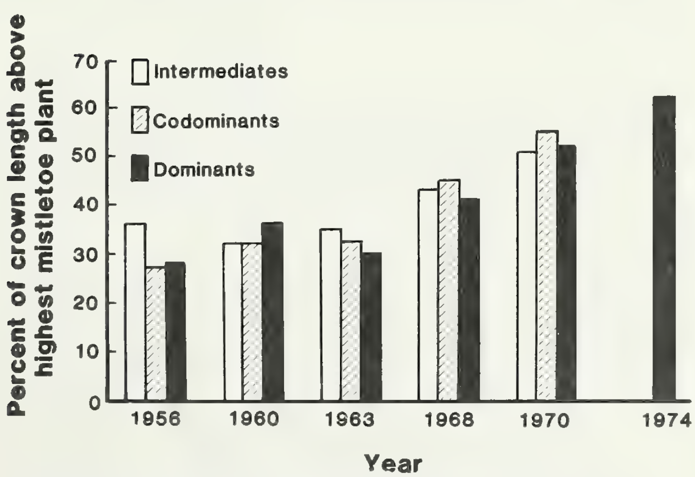

Figure 7.—Portion of crown length above the highest dwarf mistletoe plant in intermediate, codominant, and dominant trees at six key periods of stand and parasite development.

Discussion and Management Applications

The productivity of naturally regenerated, healthy ponderosa pine in the Pacific Northwest can be increased by releasing selected crop trees from competition. In the past, western dwarf mistletoe has caused various degrees of damage in much of the advanced pine regeneration. This has lead to divided opinion among foresters about the desirability of thinning infested stands.

Uncertainty about managing infested stands comes from past experience with both the poor appearance of unmanaged stands and the abundant dwarf mistletoe that recurs in managed stands. The history of control has shown regular resurgence. If the focus at decision time is on the abundance of dwarf mistletoe and accompanying tree distortion, destroying and replacing the stands will seem preferable to managing them. On the other hand, if the focus is on trees that are apparently clean and lightly parasitized, which are common in most infested stands on reasonably good sites, the decision is likely to be for stand management.

To provide a basis for making this decision we need to know how damaging the dwarf mistletoe that appears after treatment will be. Our study examined the assumption that infected trees would be productive in spite of the dwarf mistletoe, provided their crowns enlarged faster than the parasite reproduced.

To determine the ability of a tree to grow faster than its dwarf mistletoe, we annually compared number of dwarf mistletoe plants with crown mass. Mass was expressed as total length of all branches and branchlets. Data were from 40 recently felled intermediates and codominants encountered randomly along transects when the infected stand was reduced to 88 trees per acre after being thinned 14 years earlier to 250 trees per acre. Because of the lack of dominant trees in the thinnings, 12 standing dominants and 2 codominants encountered along the transects were also measured. All trees were parasitized by dwarf mistletoe, most of them for about 25 years.

Nearly all leave trees responded promptly to the first thinning. Needles increased in length and abundance. Needle color improved. Shoots proliferated and growth increased, paralleling changes in adjacent healthy stands thinned at the same time. Dwarf mistletoe also increased conspicuously. The response was similar in trees of all crown classes.

Except for the steady increase in crown mass after thinning, responses to release changed somewhat over time. The first change was the general increase in crown vigor just described. This change initiated a prompt, sustained increase in crown mass and a less prolonged increase in crown density. Crown shape remained unchanged for 5 or 6 years because all shoots, including the leader, elongate at roughly the same relative rate. We suspect that, during the first 5 years of good vigor, root development—which is distinctively poor in suppressed trees—occurred rapidly. After adequate roots developed, height growth accelerated, and crowns developed a more conical shape, with proportionately less mass in the upper third. There was no sign that this desirable growth trend would not continue through many decades.

Reproduction of dwarf mistletoe also changes with time. Within 4 years following stand release, plants appear on trees thought to be unparasitized and become conspicuous on recognizably parasitized trees. Since the main sources of dwarf mistletoe seed are removed by release cutting, plants that appear to be new are those emerging from latency in response to increased host vigor. Some years are required for plants to become fruitful. Consequently, in the absence of a major seed source, the first flush of newly observed dwarf mistletoe is followed by approximately 4 years of rather stable populations. This period precedes a period of major population increase arising from seed produced by plants of the first flush. Stand treatment thus establishes a succession of small waves of dwarf mistletoe propagation, each about 10 years long and decreasing in depth, but not in number of plants.

Since the first wave of dwarf mistletoe plants grew mostly from seed in the former overstory, and because crowns remained somewhat rounded for several years after release, a higher proportion of the dwarf mistletoe population was in the upper third of the crown than will be likely in the future. When dwarf mistletoe is evaluated by the six point severity rating system during the decade in which the stand is released, a worsening condition is recorded over time. This is a misleading representation. During this period, number of plants and their distribution on the crop trees changes very little; only the appearance of the stand, resulting from emergence of long established dwarf mistletoe plants, is altered significantly.

From about the sixth year on, the pattern of dwarf mistletoe propagation is reversed. Newly appearing plants are new seedlings originating from seed produced within the stand rather than above it. They may quickly become abundant and fruitful but do not overcome their hosts for a number of reasons. Now seed dispersal is against gravity rather than with it. Susceptible branch tips are shielded by older needles from the dwarf mistletoe located within the crown. Trees are growing rapidly in height and forming new crown above the dwarf mistletoe, which is substantially screened in situ within the old hollow crown by dense shoots and foliage that developed right after thinning. And the old crown is rapidly becoming lower crown.

In 1956, 30 percent of the crown length of study trees was above the highest dwarf mistletoe plant, and by 1974 this had increased to 62 percent in the dominants, which then comprised most of the stand. During the 1956-74 period dwarf mistletoe progressed up the crown at the rate of less than 4 inches a year. The subsequent rate will be somewhat greater as propagation begins higher in the crowns where conditions are more open and consequently more favorable to the parasite. The six-point severity rating system reflects real rather than apparent conditions in the second and subsequent decades after thinning and should reliably indicate trends. On sites appropriate for management, ratings should progressively improve for at least several decades.

In trees of all crown classes we found that with passing time, there were fewer dwarf mistletoe plants, on the average, per unit of stem. The ratio of plants to stem increased, however, on 40 percent of the trees, suggesting that factors, such as differing inherent resistance, were influencing propagation rate within individual crowns. Trees with increasing numbers of plants per unit of stem grew in height at the same rate as trees with decreasing number of plants. Height growth exceeded 10 inches a year. While growth appeared unaffected by large amounts of dwarf mistletoe in stands thinned as lightly as 250 trees per acre, we concluded that highly susceptible trees, trees developing brooms, and trees not responding to the first thinning should be removed in a second thinning.

The favorable responses to thinning that we found should occur on suitable sites throughout the region. Additional study will provide refinements, but foresters need not await verification from plots in a particular region. Good height growth is the determining factor. If thinned, healthy stands in a particular locale will grow 10 inches or more a year (after the 5- to 6-year lag period) then infested stands should grow comparably.

Our results show that selected suppressed ponderosa pine saplings parasitized by dwarf mistletoe respond to release and grow productively. Proper selection of stands and trees is the key to most dwarf mistletoe management.

Extremely severe infestations of dwarf mistletoe in ponderosa pine occur on comparatively few acres of average or better sites in the Pacific Northwest. Such stands should be completely destroyed and regenerated.

Over most of the forest infested by dwarf mistletoe, control need not be the primary consideration. The main goal on both infested and clean sites should be acceleration of tree growth, which should handicap the parasite enough to enable the stand to complete a productive rotation.

In most of the ponderosa pine region, dwarf mistletoe can be reduced through the normal practices of timber stand improvement. The principal special requirements are: (1) the overstory, including all whips, be completely removed, (2) spacing be appropriate, and (3) the trees to be left be selected properly.

Correctly evaluated infested stands can be dealt with more or less as encountered. In the absence of fire, however, and with the probability that dwarf mistletoe damage will become more severe with time, there is reason to improve infested stands before healthy stands. Since our results show that managed infested stands can grow as well as clean stands for a long time after thinning, priority treatment of appropriate diseased stands is justified. Ordinarily the worst of the diseased stands that qualify for management should have first attention.

Identifying Manageable Stands

Certain stands can be summarily rejected. These are stands with densities below the minimum stocking level or that will fall below the minimum stocking curve after treatment (fig. 8); stands on scablands or other noncommercial forest sites; and stands that are hopelessly infested (all trees growing poorly and nearly all distorted).

Identifying pine stands that appear manageable can be aided by using the plant community guide appropriate to the area.

Eastern Oregon, Southeastern Washington	Hall (1973)
Central Oregon	Volland (1976)
South-central Oregon	Hopkins (1979a, 1979b)

Site index for different plant communities is estimated in these guides, as well as relative measures of productivity in cubic feet per acre per year. Sites that produce 20 cubic feet per acre per year or more qualify as commercial timberland.

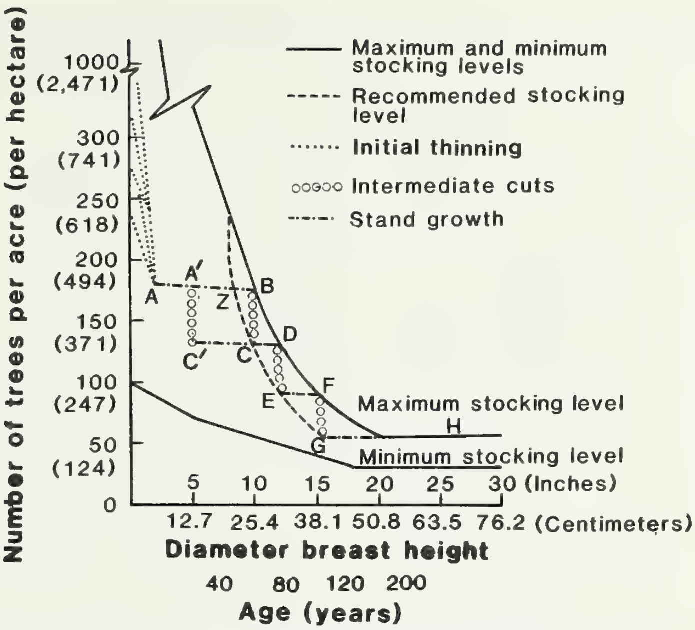

Figure 8.—Stocking level curves for healthy ponderosa pine where site index is IV or better (Barrett 1979, Meyer 1961). Optimum stand growth occurs between the recommended and maximum stocking level curves. In practice pine thickets are frequently noncommercially thinned to 180 trees per acre and an average stem diameter of approximately 2 inches or point A. Commercial tree harvests are made at points B, D, and F, and a final harvest of all trees somewhere along line H. Where dwarf mistletoe occurs, a second noncommercial thinning may be needed at point A' to remove undesirable trees to point C' before allowing the stand to grow to the maximum stocking level curve.

Since success in treating sapling stands infested by dwarf mistletoe depends largely on the ability of crop trees to grow well in height, only stands on land qualifying as commercial, with the potential of growing 10 or more inches a year, should be managed for timber production.

Determining capacity for height growth on average or poorer sites is difficult. Frequently, overstory trees have been harvested and the remaining advanced regeneration is suppressed in height, thus depriving the forester of a means for determining site index. Sometimes this dilemma can be avoided by measuring height growth for the last 5 years on advanced reproduction that is relatively free of competition. If growth of more open trees approaches 8 to 10 inches annually there is a good chance that, after thinning, crop trees selected from a dense stand also will show good growth. Hence, we can conclude that the stand is thinnable.

The next step is to determine that there are enough suitable leave trees to exceed the minimum stocking level. Where the general stand examination indicates that management is questionable because of abundant dwarf mistletoe, standards are needed for selecting leave trees.

For well stocked uniform sapling stands with or without overstories we recommend that the following categories be considered leave trees (in order of decreasing priority):

1. Unparasitized dominants and codominants.
2. Dominants and codominants with dwarf mistletoe in only the lower third of the crown.
3. Dominants and codominants with dwarf mistletoe in only the lower half of the crown.
4. Dominants and codominants with dwarf mistletoe in only the lower two-thirds of the crown.
5. Intermediates with no visible dwarf mistletoe.
6. Intermediates with dwarf mistletoe only in the lower third of the crown, or, if a tree is required for spacing, in the lower half of the crown.
7. Trees below the general canopy having high vigor, good crowns, and no dwarf mistletoe.

A crop tree should not have dwarf mistletoe on more than half the branches of any designated portion, and there should be no plants on or within 8 inches of the main stem.

Selected trees must show potential for good height growth as evidenced by a good crown and a single vertical leader that has grown well in the previous 5 years.

Stands of trees that meet the above requirements should be thinned. Small patches of qualifying trees in extensive areas of nonqualifying trees should be destroyed and regenerated along with the rest of the area—unless this conflicts with other resource management objectives.

Lightly Stocked Stands of Larger Trees

It is difficult to evaluate infested, lightly stocked stands of larger trees distributed unevenly in patches of different densities. When stocking is light, parts of the stand will be open or brushy (consult the minimum stocking level curves in Barrett 1979). If brooming is absent, dwarf mistletoe may appear less damaging than in dense stands. Growth response to thinning will be less, however, and there is no certainty that height growth will exceed 10 inches after thinning. Thinning will result in additional unproductive open space, and stands will overcome the dwarf mistletoe slowly, if at all. Brush control may stimulate adequate height growth of such stands on average sites. Sparse, uneven, infected stands, or those on below-average sites, probably should be destroyed and regenerated.

Stands of very uneven height that include infected pole-size trees are especially hard to evaluate because they have overstory/understory relationships that favor the spread of dwarf mistletoe. Diversity of size introduces the complexity of timeliness for treating such stands. Evaluating the timing of treatment involves considering stand structure, dwarf mistletoe propagation, and economics that are beyond the scope of this paper, but have been considered by Graham (1967).

Treatment of Infested Stands

Suggestions for laying out dwarf mistletoe control units to reduce perimeters, establish optimum boundaries, and achieve other desirable features are discussed by Childs (1963), Graham (1967), and Weir (1977).

Stands should be thinned to the desired level of stocking, leaving the best trees, as identified by criteria used above in examining stands for manageability. Even thoughtful application of the best procedures for selecting leave trees cannot assure that all trees will respond. Where economics will allow, thinning in two stages or follow-up cutting in 6 to 10 years is best.

While data for this paper are based on 250 trees per acre, reducing to 180 trees initially (fig. 8) will allow for later removal of trees that fail to respond to release and parasitized trees that are exceptionally damaged after thinning. Though the delay is not recommended, the second entry can be postponed until the earliest possible commercial thinning.

Pruning Considerations

Removal of heavily parasitized branches by pruning can have desirable, long-term effects. Dwarf mistletoe plants throw seed vertically for several feet and past a number of branch whorls, the distance being greater where crowns are more open. Strand and Roth (1976) found, however, that most seeds probably will not establish new plants. Moreover, once a seed is effectively placed to establish a new plant, there will be no further spread from that seed for about 6 years because of the extended dwarf mistletoe life cycle. Consequently, the rate of dwarf mistletoe ascent in the crown is slow and is directly related to the vertical distance between branches.

There is no certainty that the advantage gained by a tree over dwarf mistletoe, as a result of thinning while plants are mostly in the compact lower crown, will continue indefinitely. The facts that height growth of ponderosa pines slows again in later life and that dwarf mistletoe spreads faster in the more open crown portions (Barrett and Roth 1985). than in dense lower crowns suggest that the race between tree height growth and the upward movement of the parasite in the crown will narrow before stands reach rotation age. If changes in the crown that favor faster ascent of mistletoe are large, considerable damage can result. Much of the increase in mistletoe could be avoided by pruning the heavily parasitized dense lower crowns 10 to 15 years after thinning, before the parasite begins to propagate actively in the elongating upper crowns.

Pruning also would reduce opportunities for the formation of brooms and the damaging physiological effects mentioned earlier. It would further enhance timber quality by limiting development of large knots.

Metric Equivalents

1 centimeter = 0.3937 inches
1 meter = 3.281 feet
1 cubic meter = 35.32 cubic feet
1 hectare = 2.471 acres
1 tree/hectare = 0.4047 trees/acre

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Keywords: Thinning effects, parasites (plant), dwarf mistletoe, precommercial thinning, ponderosa pine, *Pinus ponderosa*, pathology (forest).

Propagation of dwarf mistletoe in ponderosa pine saplings is little influenced by thinning overly dense stands to 250 trees per acre. Numerous plants that appear soon after thinning develop from formerly latent plants in the suppressed understory. Subsequently, dwarf mistletoe propagates nearly as fast as tree crowns enlarge but the rate differs widely among trees. The greatest increase is in the lower third of the tree crown. Parasite abundance had no measurable effect on height growth during 21 years following thinning, and height growth was faster than ascent of the parasite in the crown. Dominant trees that had 28 percent of crown length above the highest dwarf mistletoe plant in 1956 had 62 percent above in 1974.

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Pacific Northwest Forest and Hange
Experiment Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208