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The Relationship of Douglas-fir Dwarf Mistletoe (*Arceuthobium douglasii*) to Stand Conditions and Plant Associations in the Southern Cascade Mountains, Oregon

Abstract

Douglas-fir dwarf mistletoe (*Arceuthobium douglasii*) is a parasitic plant widely distributed on Douglas-fir (*Pseudotsuga menziesii*) in southwestern Oregon. This study examined the relationship of frequency of occurrence and severity of Douglas-fir dwarf mistletoe with stand conditions and plant associations in the southern Cascade Mountains in Oregon. Data were collected from a subsample of existing permanent plots. Fifteen stand variables and the level of dwarf mistletoe infection in all live Douglas-fir were measured at each plot. Douglas-fir dwarf mistletoe occurred most frequently in the white fir (*Abies concolor*) series. It occurred least in the Douglas-fir series. It occurred in plots at significantly higher elevations, with lower mean annual temperatures and lower mean annual and dry season precipitation than plots where it was absent. Occurrence of Douglas-fir dwarf mistletoe was also significantly associated with steeper slopes, andesite and basalt soil parent materials, lower basal area, and lower percentage of Douglas-fir in the stand. The average plot Dwarf Mistletoe Rating did not differ significantly among climax series. Average plot Dwarf Mistletoe Rating did increase significantly as total basal area decreased and age of the oldest canopy layer increased. Our study suggests that climax series could be used as indicators of the relative frequency of Douglas-fir dwarf mistletoe in the southern Cascade Mountains in Oregon.

Introduction

Douglas-fir dwarf mistletoe (*Arceuthobium douglasii* Engelmann) is a parasitic plant found almost exclusively on Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). It causes one of the most widespread diseases of Douglas-fir in the forests of southwestern Oregon (Hadfield 1985) and the interior West (Hawksworth and Wiens 1996). Severe infections cause significant losses in Douglas-fir growth, increased tree mortality, and increased fire hazard (Hawksworth and Wiens 1996). The weight of the brooms caused by Douglas-fir dwarf mistletoe infection can predispose branches to breaking, posing serious hazards in developed recreation sites (Hadfield 1999). However, the brooms caused by Douglas-fir dwarf mistletoe infection are an important component of the habitat of several birds and mammals including northern spotted owls (*Strix occidentalis* var *caurina* Xantus de Vesey), northern goshawks (*Accipiter gentilis* Linnaeus) and many of their prey species (Parks et al. 1999).

All aspects of forest management including recovery plans for the northern spotted owl, habitat management for other sensitive species, watershed restoration programs and timber production require accurate prediction of stand development to prescribe activities that will achieve desired future conditions. Stand development is affected by the frequency and severity of diseases such as Douglas-fir dwarf mistletoe. Information on the relationships between dwarf mistletoe frequency and severity, and forest conditions could be used to guide management plans at both stand and landscape levels. For example, silvicultural methods employed to encourage rapid tree growth that also favor mistletoe spread may be poor choices where the frequency of mistletoe is high. However, some areas where Douglas-fir dwarf mistletoe is frequent and severe may be best used to manage wildlife species that use the large brooms formed in severely infected trees (Parks et al. 1999).

Information about relationships that may exist between plant associations and the frequency of occurrence and severity of Douglas-fir dwarf mistletoe is useful because land stratification based on vegetation potential is a system that is widely used, can be mapped, and incorporates much of the information about site conditions. Areas with the same plant association can be expected to show the same general successional response to disturbance, including disturbance caused by pathogenic organisms such as dwarf mistletoes (Layser 1974, Cooper et al. 1991).

Previous studies have shown that there are relationships between the occurrence and severity of dwarf mistletoes, and stand conditions. Hawksworth (1959, 1968), Larson et al. (1970), Acciavatti and Weiss (1974), and Gottfried and Embry (1977) found that the occurrence and severity of several dwarf mistletoe species were associated with aspect, slope, elevation, site and topographic factors. Smith (1972), Hanks et al. (1983), Mathiasen and Blake (1984), and Merrill and Hawksworth (1987) found that the occurrence and severity of dwarf mistletoes differed by habitat type. However, the specific relationships found in these studies varied widely. The variations may have been due to differences in study designs, but it also suggests that these relationships vary according to local conditions and probably differ among geographical areas, hosts, and dwarf mistletoe species. Our study examined the relationship among stand conditions, plant associations, and the occurrence and severity of Douglas-fir dwarf mistletoe in the southern Cascade Mountains in Oregon (Marshall 1995).

Methods

Study Area and Data Collected

The study area was in the southern Cascade Mountains west of the Cascade crest on the Rogue River and Umpqua National Forests in Oregon (Figure 1). We used an existing network of permanent plots established by USDA Forest Service ecologists to identify the plant associations (Atzet and McCrimmon 1990). The locations of these permanent plots were selected by driving along roads throughout the two Forests and sampling mature, relatively undisturbed stands adjacent to the roads. The plot center was determined by walking into the stand the distance necessary to eliminate edge effect from the road, usually 15 to 60 meters. Presence or absence of disease was not a factor in stand selection and was unknown until the plot center was established (T. Atzet, USDA Forest Service, 1999, personal communication).

In 1992, we collected data from a random subsample of the permanent plots to determine the variability in the occurrence and level of Douglas-fir dwarf mistletoe infection (severity) among individual plant associations in the study area. The variability in occurrence and severity was so great that not enough existing plots were available in most of the plant associations for a statistically valid sample. Therefore, the plant associations were grouped according to their climax series: the *Abies concolor* (white fir) series, the *Pseudotsuga menziesii* (Douglas-fir) series, and the *Tsuga heterophylla* (western hemlock) series. These three series cover 75 percent of the study area and have a high constancy of Douglas-fir (Atzet and McCrimmon 1990).

Our preliminary data also showed that, on average, where infection was present, at least one mistletoe-infected Douglas-fir was tallied by the time nine live Douglas-fir closest to the plot center were tallied. Eighty-six percent of the time, the most severely infected Douglas-fir tree in the area was tallied by the time fifteen live Douglas-fir closest to the plot center were tallied. Based on this information, fifteen live Douglas-fir per plot were judged adequate to assess both the occurrence and severity of Douglas-fir dwarf mistletoe in these three climax series.

In 1993, we sampled a total of 168 plots in the three climax series: 40 plots in the Douglas-fir series, 85 plots in the white fir series and 43 plots in the western hemlock series. A sample plot was placed at each selected permanent plot. Sample plots were circular, varied in size, and were just large enough to include the nearest fifteen live Douglas-fir at least 12.7 cm dbh (diameter at breast height, 1.5 meters above ground level). The level of Douglas-fir dwarf mistletoe in each Douglas-fir tree was determined using the Hawksworth six-class dwarf mistletoe rating (DMR) system (Hawksworth 1977). The climax series, elevation (m), mean annual temperature (°C), mean annual precipitation (cm), dry season precipitation (cm, May through September), and soil parent material (andesite, basalt, granite, pyroclastic, sedimentary) of each plot were derived from data from Atzet and McCrimmon (1990). We measured ten additional variables from each plot center: 1) site index (average height (m) at 100 years of three to five dominant, uninfected Douglas-fir in or near the plot using site class tables prepared by McArdle et al. 1961), 2) aspect (north, east, south, west), 3) slope (percent), 4) topographic position (lower, middle, upper), 5) topographic shape (convex, concave, flat), 6) total stand

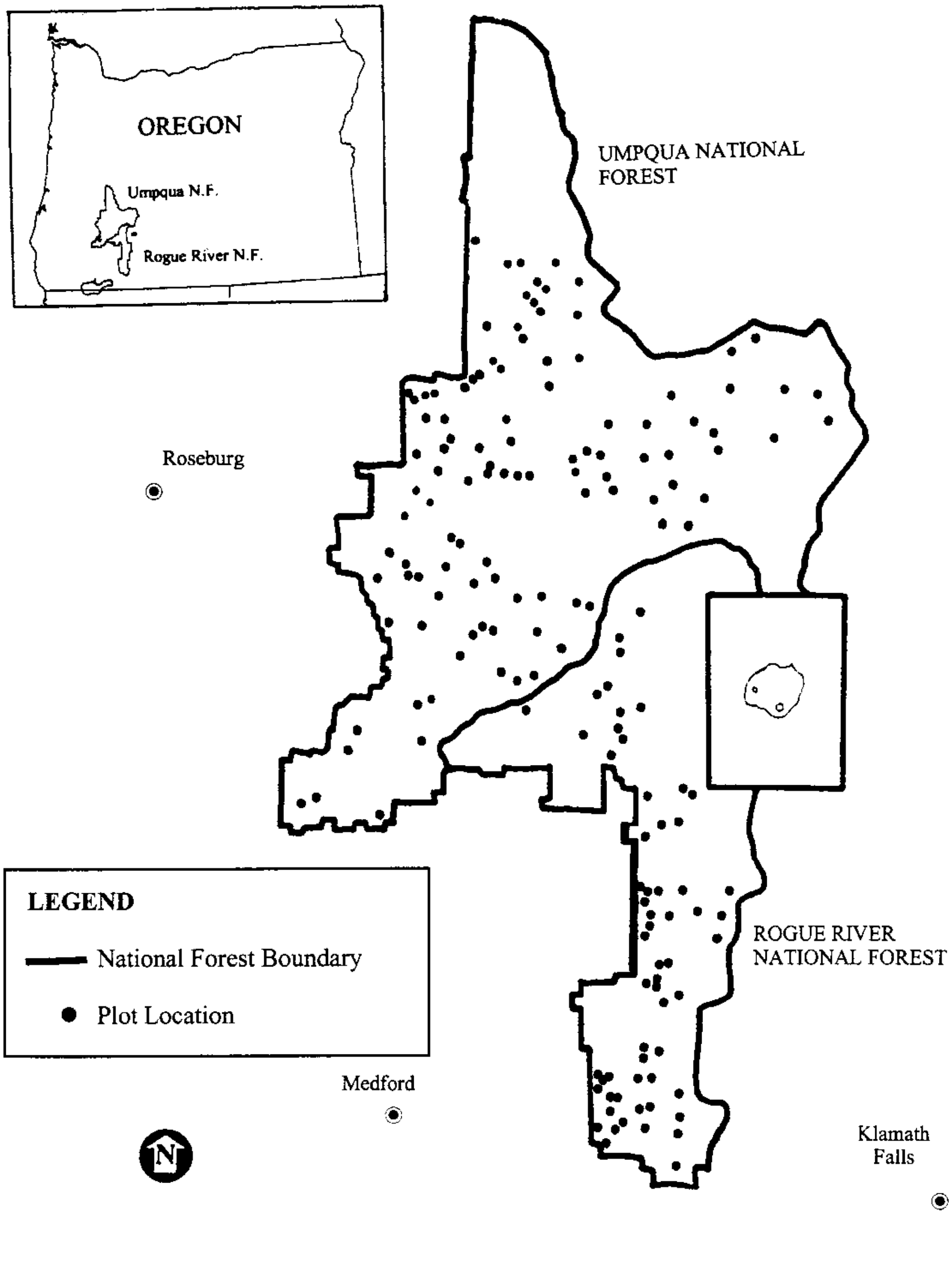

Figure 1. Location of study plots in the southern Cascade Mountains, Oregon.

basal area (cross-sectional area of tree boles at 1.5 meters above ground level, m^2/ha), 7) Douglas-fir stand basal area (m^2/ha), 8) Douglas-fir dbh (cm), 9) number of tree canopy layers, and 10) the age of each canopy layer (years). The percentage of Douglas-fir in each plot was calculated by dividing Douglas-fir stand basal area by total stand basal area.

Statistical Analysis

Analysis of the data was on a per plot basis, due to the variable size of the plots. Infected plots were those containing one or more infected Douglas-fir. The frequency of occurrence of Douglas-fir dwarf mistletoe was defined as the percentage of infected plots. T-tests (Ramsey and Schafer 1997) were used to test for significant differences ($P \leq 0.05$) in the means of the continuous variables between plots with and without infected Douglas-fir. Chi-square (Ramsey and Schafer 1997) was used to test for significant differences ($P \leq 0.05$) in the percentage of plots with infected Douglas-fir among the climax series and other categorical variables.

The average plot dwarf mistletoe rating (mean DMR), or severity of Douglas-fir dwarf mistletoe in each plot, was calculated from the sum of individual DMR of each live Douglas-fir (including uninfected Douglas-fir) divided by the number of live Douglas-fir. The ratio of highest to lowest mean DMR was greater than ten, causing this data to be non-linear. A LOG (base 10) transformation was used to make the mean DMR data linear (Stafford and Sabin 1994). Only infected plots (mean DMR>0) were used to analyze severity. During data collection we discovered that some plots had been disturbed in the past, particularly by harvest of scattered individual trees. Since disturbance is known to affect the severity of dwarf mistletoes (Parmeter 1978), those plots were also omitted, leaving 20 uncut, infected plots for this analysis. Stepwise multiple regression (Ramsey and Schafer 1997) was used to analyze the relationship between LOG(mean DMR) and the continuous variables and then to derive an equation that would best explain the variation in LOG(mean DMR). One-way analysis of variance (ANOVA) was used to test equality of LOG(mean DMR) among the climax series and other categorical variables. Relationships were considered significant with P-values≤ 0.05.

Results

The white fir series is the most widespread in the study area. In general, it is cooler and wetter than the Douglas-fir series and cooler and drier than the western hemlock series. Only the western hemlock series is more productive. The western hemlock series is most widespread on the Umpqua National Forest portion of the study area, but is also common in the northern part of the Rogue River National Forest. It has more precipitation (both mean annual and summer) than the other two series and is intermediate in temperature. This series has the highest productivity of all series in the Cascade Mountains. The Douglas-fir series occurs in the hottest, driest forest environments in southwest Oregon (Atzet and McCrimmon 1990). It is generally the hottest and driest of the three series in the study, although some Douglas-fir series plots in the northern part of the study area were wetter than white fir plots further south. Series characteristics are summarized in Tables 1 and 2.

Dwarf Mistletoe Frequency

Thirty-eight percent of the plots in the white fir series contained Douglas-fir dwarf mistletoe-infected trees, compared to 19 percent in the western hemlock series and three percent in the Douglas-fir series. Actually, infection occurred in only one plot in the Douglas-fir series (Table 3). Chi-square comparison showed significantly more Douglas-fir dwarf mistletoe in the white fir series than in the Douglas-fir series ($P<0.001$). However, the contribution of mistletoe frequency in the western hemlock series to the comparison was not significantly different from that of the other two series. The six warmest plant associations had no Douglas-fir dwarf mistletoe (Figure 2). Three of these associations were in the Douglas-fir series, two were in the western hemlock series and one was in the white fir series. They were the warmest associations in each of their respective climax series. All were moderately wet associations.

Plots with infected Douglas-fir were at significantly higher elevations than plots with no infected Douglas-fir in the white fir and western hemlock series (Table 4). All of the plots with infected Douglas-fir were above 1000 meters in elevation.

TABLE 1. Mean values and standard deviations of continuous variables by climax series in the study area

Series		Elev (m)	Matemp[1] (°C)	Maprecip[2] (cm)	Dsprecip[3] (cm)	Site Index (m/100yr)	Slope (%)	Total BA (m^2/ha)	DFBA[4] (m^2/ha)	% DF[5] (%)	Canopy Layers (no.)	Canopy Age (yr)	Mean dbh[6] (cm)
Douglas-fir	Mean	848.8	9.0	134.3	18.3	34.3	43.7	73.4	63.5	85.9	2.5	195.9	42.2
	SD	211.7	1.1	28.4	2.4	6.4	18.9	17.6	19.3	15.4	0.6	88.3	13.7
white fir	Mean	1215.7	7.1	136.7	18.4	36.9	27.7	74.4	46.3	60.9	2.6	238.4	63.7
	SD	214.1	1.0	25.6	2.9	7.1	18.6	16.8	25.5	27.9	0.5	105.0	25.2
western hemlock	Mean	1014.2	8.0	156.5	20.6	37.1	36.5	77.2	49.8	63.1	2.9	338.7	76.5
	SD	277.7	1.4	19.4	2.6	8.4	21.9	15.3	21.0	20.2	0.3	129.0	19.8

[1]Matemp = mean annual temperature
[2]Maprecip = mean annual precipitation
[3]Dsprecip = dry season precipitation (May through September)
[4]DF BA = basal area that is Douglas-fir
[5]% DF = percent Douglas-fir
[6]dbh = diameter breast height

TABLE 2. Number of plots in each level of categorical variables by climax series in the study area

Series	Soil parent material[1]					Aspect				Topographic position			Topographic shape		
	and	bas	gran	pyro	sed	north	east	south	west	lower	middle	upper	concave	convex	flat
Douglas-fir	10	7	3	20	0	1	5	22	12	5	15	20	12	26	2
white fir	35	31	8	10	1	17	19	27	22	17	30	38	47	32	6
western hemlock	12	15	3	12	1	10	10	9	14	19	5	19	20	22	1

[1]Soil parent material: and = andesite, bas = basalt, gran = granitic, pyro = pyroclastic, sed = sedimentary

TABLE 3. Occurrence of Douglas-fir dwarf mistletoe in plots by climax series in the study area

Series	Number of plots	Number of plots infected
Douglas-fir	40	1
white fir	85	32
western hemlock	43	8
All plots	168	41

Within the white fir and western hemlock series, plots with infected Douglas-fir had significantly lower mean annual temperatures than plots without infected Douglas-fir (Table 4). All of the plots with infected Douglas-fir had mean annual temperatures between 6° and 8°C (Figure 2). No Douglas-fir dwarf mistletoe was found in plots with mean annual temperatures greater than 8°C.

Within the white fir series, plots with infected Douglas-fir had significantly lower mean annual and dry season precipitation levels than plots without infected trees (Table 4), although some plots with infected trees were found at all but the highest levels of both mean annual and dry season precipitation. Plots with infected Douglas-fir had mean annual precipitation levels of 76 to 190 cm, and mean dry season precipitation levels of 15 to 25 cm. There were no significant differences in mean annual or mean dry season precipitation levels among plots in the western hemlock series. Since only one plot in the Douglas-fir series was infested, plots within this series could not be compared statistically. However, the plot that did have infected Douglas-fir occurred on a relatively high elevation, cool, dry site at 1066 m elevation, with 8°C mean annual temperature and 76 cm mean annual precipitation (Figure 2).

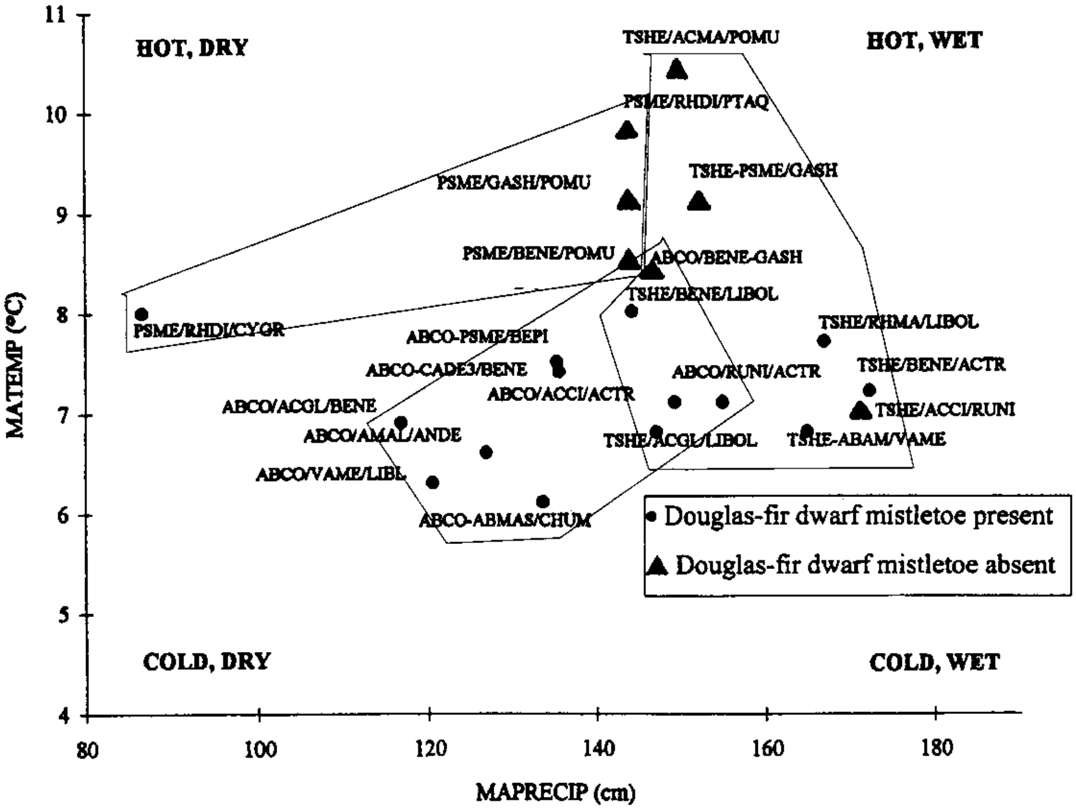

Figure 2. Ecograph of plant associations[1] by mean annual temperature and mean annual precipitation of the sampled plots in southern Oregon.

[1]ABAM = *Abies amabilis*, ABCO = *Abies concolor*, ABMAS = *Abies magnifica shastensis*, ACCI = *Acer circinatum*, ACGL = *Acer glabrum*, ACMA = *Acer macrophyllum*, ACTR = *Achlys triphylla*, AMAL = *Amelanchier alnifolia*, ANDE = *Anemone deltoidea*, BENE = *Berberis nervosa*, BEPI = *Berberis piperiana*, CADE3 = *Calocedrus decurrens*, CHUM = *Chimaphila umbellata*, CYGR = *Cynoglossum grande*, GASH = *Gaultheria shallon*, LIBOL = *Linnaea borealis longifolia*, POMU = *Polystichum munitum*, PSME = *Pseudotsuga menziesii*, PTAQ = *Pteridium aquilinum*, RHDI = *Rhus diversiloba*, RHMA = *Rhododendron macrophyllum*, RUNI = *Rubus nivalis*, TSHE = *Tsuga heterophylla*, VAME = *Vaccinium membranaceum*.

Occurrence of Douglas-fir dwarf mistletoe was also significantly associated with slope, Douglas-fir basal area, and the percentage of Douglas-fir (Table 4). Plots with infected Douglas-fir had both significantly less Douglas-fir basal area and a smaller percentage of the total basal area in Douglas-fir than plots without infected Douglas-fir. The average slope of plots with infected Douglas-fir was significantly less than the average slope of plots without infected Douglas-fir. However, plots with infected trees were found on all but the steepest slopes.

Douglas-fir dwarf mistletoe occurred in a significantly smaller percentage of plots with soil derived from pyroclastic or sedimentary parent materials than in plots with other types of soil parent materials (Table 5). Basalt and andesite parent materials had the highest percentages of plots with infected Douglas-fir.

There were no significant associations between the occurrence of Douglas-fir dwarf mistletoe and aspect, topographic shape, topographic position (Table 5), or site index, total basal area, the number of canopy layers, the age of the oldest canopy layer, and the mean dbh of Douglas-fir (Table 4).

Dwarf Mistletoe Severity

There was no significant difference in mean DMR between the white fir and western hemlock climax series (P=0.86). The Douglas-fir series could

TABLE 4. Mean values of continuous variables between plots with and without Douglas-fir dwarf mistletoe in the study area

Variable[1]	Mistletoe Occurrence	Mean	SE	*P*
Elev	No	1000.1	23.8	
	Yes	1314.2	18.8	>0.01
Matemp	No	8.2	0.1	
	Yes	6.6	0.1	>0.01
Maprecip	No	145.4	2.2	
	Yes	128.2	4.1	0.0002
Dsprecip	No	19.3	0.3	
	Yes	18.0	0.5	0.009
Site Index	No	36.3	0.6	
	Yes	36.4	1.1	0.91
Slope	No	35.8	1.8	
	Yes	27.3	3.1	0.02
Total BA	No	75.5	1.4	
	Yes	73.1	2.8	0.42
DF BA	No	54.5	2.0	
	Yes	41.6	4.2	0.003
% DF	No	71.6	2.1	
	Yes	54.3	4.3	0.0001
Canopy layers	No	2.7	0.1	
	Yes	2.8	0.1	0.15
Canopy age	No	256.6	10.8	
	Yes	245.6	17.6	0.61
Mean dbh	No	60.4	2.2	
	Yes	66.5	3.8	0.17

[1]For description of variables and units of measure, see Table 1.

TABLE 5. Occurrence of Douglas-fir dwarf mistletoe by level of four categorical variables in plots in the study area

Variable	Level	Number of of plots	Number of plots infected	*P*
Aspect	north	27	11	
	east	35	8	
	south	57	10	
	west	49	12	0.14
Topographic position	lower	41	6	
	middle	50	16	
	upper	77	19	0.16
Topographic shape	concave	79	23	
	convex	80	16	
	flat	9	2	0.40
Soil parent material	andesite	57	19	
	pyroclastic	42	2	
	basalt	53	18	
	granitic	14	2	
	sedimentary	2	0	0.004

not be included in the comparison because the only infected plot in the series had evidence of past cutting. There were no significant relationships between mean DMR and any of the categorical variables ($P \geq 0.17$).

Stepwise multiple regression showed that the following equation best explained the variation in severity in uncut, infected plots (*P*-to-enter≤0.05):

$$\text{LOG(mean DMR)} = -2.086 + 0.006(\text{ELV}) - 0.034(\text{MAP}) - 0.045(\text{TBA}) + 0.0065(\text{AGE})$$

where ELV = elevation (m), MAP = mean annual precipitation (cm), TBA = total basal area (m^2/ha), AGE = mean age of oldest canopy layer (years), and adjusted $R^2 = 0.93$. The direction of the terms in this equation, negative MAP and TBA, and positive ELEV and AGE indicates the relationship between mean DMR and these four variables. It suggests that the most severe Douglas-fir dwarf mistletoe occurred in plots located in old, open stands on high, dry sites.

Discussion

Douglas-fir dwarf mistletoe occurred significantly more often in the white fir series than in the Douglas-fir series. This suggests that in the southern Cascade Mountains in Oregon, the presence of these climax series could be used to identify the relative frequency of Douglas-fir dwarf mistletoe at the landscape scale. Douglas-fir dwarf mistletoe also occurred significantly more often in plots on the highest, coolest, and driest sites within the white fir series. This suggests that high, cool, dry white fir plant associations might be useful indicators of the relative frequency of Douglas-fir dwarf mistletoe in the white fir series.

The trend for Douglas-fir dwarf mistletoe to be on sites at higher elevations and with lower mean annual temperatures mirrored the elevations and mean annual temperatures of the white fir series. The white fir series, which had the highest frequency of Douglas-fir dwarf mistletoe, occurs on higher, cooler sites than the Douglas-fir series, where the lowest frequency of dwarf mistletoe was found. Although not statistically significant, the only plot in the Douglas-fir series where the mistletoe was found was in the plant association with the lowest mean annual and dry season precipitation levels of all associations in the study. The frequency of occurrence of Douglas-fir dwarf mistletoe in the western hemlock series was not significantly different from either of the other two series. Plots in the western hemlock series had a greater range of elevations and mean annual temperatures than the other two series, but tended to have higher mean annual and dry season precipitation. This suggested that the western hemlock series may encompass environmental conditions associated with both frequent and infrequent occurrence of Douglas-fir dwarf mistletoe. These trends are similar to those reported by Merrill and Hawksworth (1987). They found that the ecological factors associated with high frequency of southwestern dwarf mistletoe (*A. vaginatum* subsp. *cryptopodum* Engelmann) in Colorado were the same ecological factors associated with the habitat type where that mistletoe was most common. They concluded that the similarities in these trends are due to the fact that dwarf mistletoes are obligate parasites. Therefore, they are directly affected by environmental conditions and other ecological factors that affect their host.

The association between occurrence of Douglas-fir dwarf mistletoe and plots with significantly lower Douglas-fir basal area and smaller percentages of Douglas-fir was consistent with the higher frequency of mistletoe infection in the white fir and western hemlock series than the Douglas-fir series. Both the white fir and western hemlock series contained less Douglas-fir basal area and smaller percentages of Douglas-fir than the Douglas-fir series (Table 1). Acciavatti and Weiss (1974) found similar results in the White Mountains of Arizona, where the frequency of *A. microcarpum* Engelm. on Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) was highest where it grew in mixed, rather than pure stands. However, pure stands of Engelmann spruce in the White Mountains are found at higher elevations than mixed stands, unlike Douglas-fir in our study area, which is found at lower elevations than the other conifer species. This suggests that in both cases, conditions that favor dominance by the host trees might be too extreme or otherwise unfavorable for the respective dwarf mistletoes.

Many plots throughout the study area had been disturbed by partial cutting of large Douglas-fir 10 to 50 years ago. Removing large trees can (1) stimulate latent dwarf mistletoe infections in understory trees by increasing light to the remaining crowns and (2) favor mistletoe spread by reducing stand density (Baranyay and Smith 1972, Parmeter 1978). Partial cutting in our study area appeared to be concentrated on shallower slopes accessible with ground equipment. Dwarf mistletoe-infected Douglas-fir were found more commonly on shallow slopes than on steep slopes. The mistletoe most likely was on site prior to disturbance, but would have been stimulated by it. We therefore speculate that partial cutting may have been largely responsible for the significant associations among Douglas-fir basal area, slope, and the frequency of occurrence of Douglas-fir dwarf mistletoe that we observed.

Douglas-fir dwarf mistletoe occurred most frequently on andesite and basalt-derived soils which are generally described as productive, deep and fertile. Soils derived from pyroclastic materials (where Douglas-fir dwarf mistletoe was least common) are young, shallow and infertile (Atzet and McCrimmon 1990).

At the beginning of the study, we anticipated that the Douglas-fir series would have the highest frequency of Douglas-fir dwarf mistletoe. Where Douglas-fir is the climax species it was expected that the presence of overstory and understory trees of the same species would facilitate spread of the mistletoe. In fact, the Douglas-fir series turned out to have the lowest frequency of the mistletoe. One factor that could be responsible for this is fire. In the southern Cascade Mountains in Oregon, the Douglas-fir series has historically been subject to more frequent disturbance by fire than any other series (Atzet and McCrimmon 1990). Surface fires of varying intensity are common and crown fires also occur (Agee 1993). Intense surface fires tend to destroy mistletoe-infected trees and crown fires eliminate both host and mistletoe from burned areas. Reestablishment of host trees usually occurs much more rapidly than re-invasion of mistletoe. This can result in large areas that are free of mistletoe for long periods of time (Alexander and Hawksworth 1975). In the Douglas-fir series, fire may have had an important role in limiting the frequency of Douglas-fir dwarf mistletoe. Fire may also have been a factor that prevented or eliminated Douglas-fir dwarf mistletoe infections in the three plant associations in the western hemlock and white fir series where no Douglas-fir dwarf mistletoe was found. Data from Atzet and McCrimmon (1990) indicates that fires were frequent in these two western hemlock associations and infrequent but intense in the white fir association. If we continue suppressing fires in the future, Douglas-fir dwarf mistletoe could occur more frequently in the Douglas-fir series because once established it would infect each succeeding generation of Douglas-fir. However, after a very long time, frequency of *A. douglasii* in the white fir and western hemlock series might diminish because here Douglas-fir is a seral species and will gradually disappear if there is no disturbance.

Douglas-fir dwarf mistletoe was most severe on high, dry sites in the white fir and western hemlock series where the total basal area was low and where the age of the oldest canopy layer was greatest. These stand conditions are similar to conditions in which Tinnin et al. (1976) found isolated, severe infections of Douglas-fir dwarf mistletoe along the Cascade crest north of the study area. They hypothesized that these conditions may have provided refugia for the mistletoe because open conditions and sparse vegetation would have prevented most fires from carrying through those stands.

The relationship between increasing severity of dwarf mistletoes, decreasing basal area and increasing stand age is well documented (Merrill and Hawksworth 1987, Hawksworth and Johnson 1989, Mathiasen et al. 1990). A number of factors may account for these relationships. Stands with low basal area may be exposed to more sunlight, which would promote both shoot and broom development (Kuijt 1955). Open stands have higher levels of mistletoe seed production and greater opportunity for unobstructed seed flight among trees (Baranyay and Smith 1972). According to Parmeter (1978), in old trees with minimal height growth, mistletoe will advance in the crowns until the trees are completely parasitized.

Our study suggests that occurrence of the white fir and Douglas-fir series could be useful indicators of the relative frequency of Douglas-fir dwarf mistletoe at the landscape scale in the southern Cascade Mountains in Oregon. Since Douglas-fir dwarf mistletoe was most frequent in the white fir series, stands in this series may be the best candidates to manage as habitat for wildlife species that use Douglas-fir dwarf mistletoe brooms (Parks et al. 1999). However, where individual tree vigor and rapid growth are important objectives, stand structures and silvicultural regimes that favor dwarf mistletoe spread may be inadvisable. The significant increase in severity associated with decreasing basal area and increasing age raises concerns about partial cutting in portions of the study area where Douglas-fir dwarf mistletoe occurs. Partial cutting often results in stands with low basal areas and is often prescribed to retain or develop large, old trees. If these trees are infected, conditions would favor development of severe dwarf mistletoe infestations.

More information is needed on the underlying cause of differences in Douglas-fir dwarf mistletoe distribution observed today to understand the potential for the spread of infection in the future. Studies of site-specific fire history might provide information about the extent to which fire regulated Douglas-fir dwarf mistletoe distribution and severity in the past. If theories about the relationship between fire regimes and Douglas-fir dwarf mistletoe are correct, continued fire suppression may allow Douglas-fir dwarf mistletoe to become more common in areas where it is currently rare or absent. This would be of most immediate significance in areas of the white fir and Douglas-fir series that historically had frequent fires. Greater understanding of the interaction between fire and dwarf mistletoe infection is also needed to understand the impact of periodic prescribed underburning in dwarf mistletoe-infested stands.

Research is also needed on the differences in rates of spread and intensification of Douglas-fir dwarf mistletoe under various stand conditions before we can actively manage the level of infection to provide habitat for wildlife species that use Douglas-fir dwarf mistletoe brooms. The information gained from these and other studies will be useful to guide future management of the many stands with Douglas-fir and Douglas-fir dwarf mistletoe in the southern Cascade Mountains in Oregon.

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