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Permanent plots for measuring spread and impact of Douglas-fir dwarf mistletoe in the Southern Oregon Cascades, Pacific Northwest Region:

Results of the ten year remeasurement

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Introduction

Douglas-fir dwarf mistletoe (*Arceuthobium douglasii*) Engelm., is a parasitic, flowering plant found almost exclusively on Douglas-fir. It is widespread on Douglas-firs in the Cascade and Siskiyou Mountain ranges of Southwest Oregon. Studies have shown that heavy infection of Douglas-fir dwarf mistletoe reduces growth of host trees and contributes to an increase in mortality (Mathiasen et al 1990, Filip et al 1991). Infection also results in formation of brooms. These brooms, especially large ones, are widely used for nesting and hiding cover by a variety of wildlife species including the northern spotted owl (Hawksworth and Wiens 1996). Because Douglas-fir dwarf mistletoe is widespread and has significant impacts on its host, stand development and ecosystem functions, its impacts should be included in models used to predict stand development.

The Forest Vegetation Simulator Model (FVS) is the most widely used vegetation model in the Pacific Northwest Region. It incorporates the impacts of dwarf mistletoes using the Dwarf Mistletoe Impact Modeling System, which was written to run in conjunction with FVS. Much of the information used to develop the relationships between spread and intensification of dwarf mistletoes and tree growth and mortality in the model was derived from existing data and "best guesses" (David 2005).

In 1990 a methodology for establishing permanent plots to measure the effects of dwarf mistletoe for use in vegetation simulation models was developed for the Forest Service, U.S. Department of Agriculture Forest Pest Management (FPM) by Mathiasen (1990). The field manual describing this method (Work Plan version 2.0, 1990) was used to install permanent plots in Douglas-fir dwarf mistletoe-infested mixed conifer stands in the southern Oregon Cascades of Southwest Oregon. The data collected in these permanent plots were used to validate FVS model projections of growth and mortality of Douglas-firs in dwarf mistletoe infected stands in Southwest Oregon.

Methods

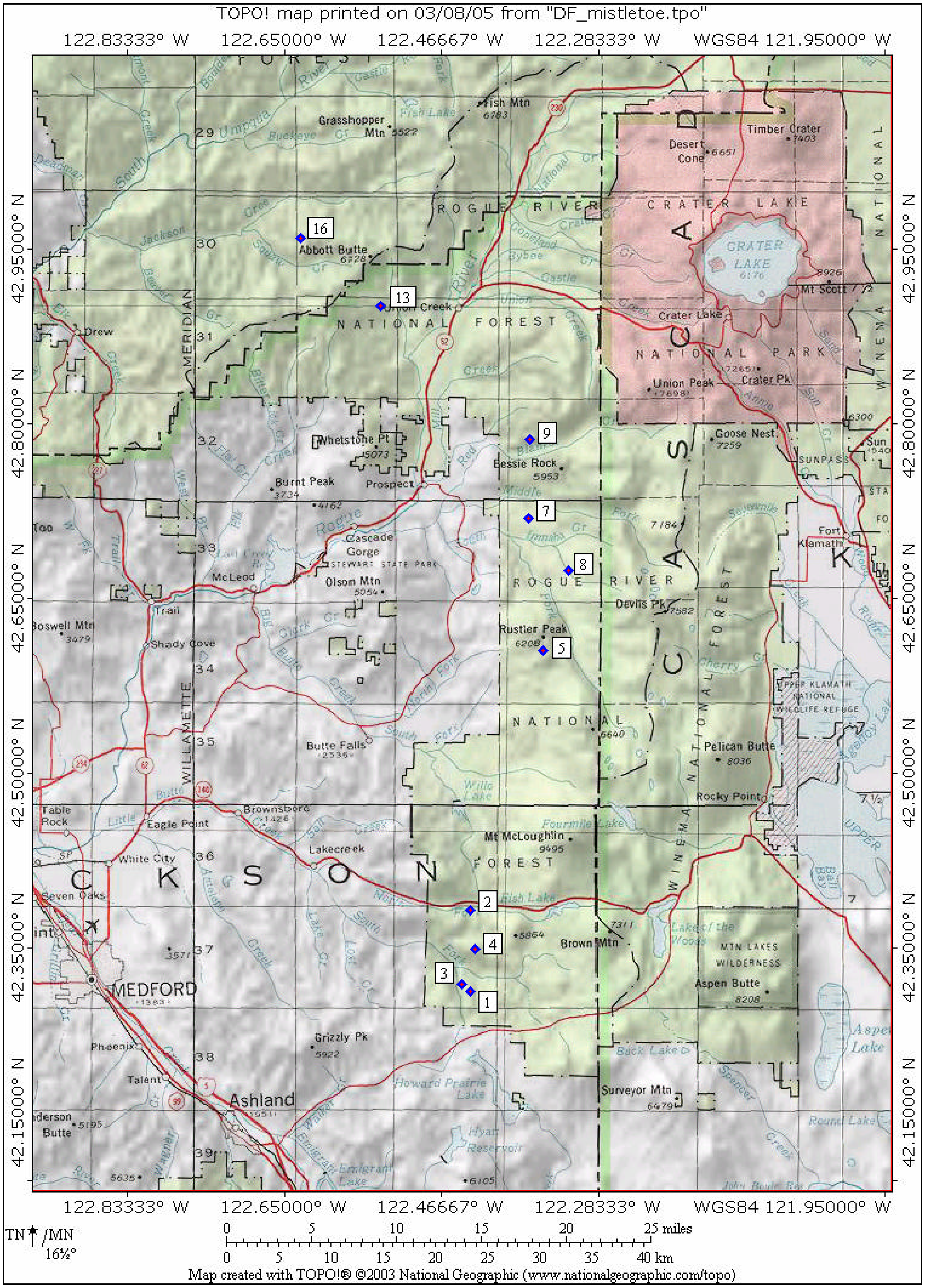
In 1992 eleven plots were installed in the southern Oregon Cascade Mountain Range on the Rogue River-Siskiyou and Umpqua National Forests (Figure 1). We followed procedures developed by Mathiasen (1990) to install the plots and collect data. Plot locations were selected to include a variety of plant associations, stand ages, structures and histories (Table 1). The plots were square and varied in size from one third to one acre. Plot size was determined by the number of trees per acre. The corners and center of each plot were monumented with fiberglass pipes and tagged, painted reference trees. Bearings and distances to the plot corners and centers were recorded on the tags and on the plot data forms.

Table 1. Summary of plot conditions

Plot[1]	Forest	Plant Association[2]	Elevation (feet)	Size (acres)	Stand Structure[3]	History	DF site index[4]
1	Rogue	ABCO-CADE27/TRLA6	4400	0.5	uneven	uncut	82
2	Rogue	ABCO-CADE27/TRLA6	3750	1.0	even	salvage	92
3	Rogue	ABCO/BENE2	3850	0.3	even	uncut	82
4	Rogue	ABCO-CADE27/TRLA6	4450	0.5	uneven	uncut	84
5	Rogue	ABCO/BENE2	5200	0.5	even	uncut	93
7	Rogue	ABCO-TSHE/BENE2/LIBOL	3600	1.0	even	thinned	115
8	Rogue	TSHE-ABCO/ACCI-BENE2	4100	0.5	uneven	uncut	90
9	Rogue	ABCO-CADE27/TRLA6	4200	0.3	even	selective	103
13	Rogue	ABCO/BENE2/ACTR	3900	1.0	uneven	selective	107
16	Umpqua	ABCO-CADE27/TRLA6	3700	0.5	uneven	selective	84

1. Plots are numbered as they were originally numbered in the field
2. From Atzet et al 1996. For a brief description of the plant associations see Appendix 1.
3. Even-aged stands < three age classes, uneven-aged stands = three age classes
4. Fifty year site index from Schumacher, Francis X. 1930.

Figure 1. Plot locations, Rogue River-Siskiyou and Umpqua National Forests



At each plot the slope, aspect, site index and plant association were determined. All live trees greater than two inches diameter at 4.5 feet (dbh) were tagged and data collected on species, dbh, crown class and damage agents. The level of dwarf mistletoe was measured using the Broom Volume Rating system, a modification of the Hawksworth six-class dwarf mistletoe rating system developed by Tinnin (1998) for rating Douglas-fir dwarf mistletoe-infected trees. Broom Volume Rating (BVR) is based on the total volume of each crown third occupied by mistletoe brooms. Total height, height to the base of the live crown, breast height age and ten-year radial growth was measured in a subsample of live trees. Species and dbh were recorded for all dead trees. The bearing and distance from the plot center to each tree was measured to create stem maps of plots 2, 7, 8, 13 and 16.

The plots were located in mid-elevation, mixed-conifer stands, both even and uneven-aged, in the white fir and western hemlock plant series (Table 1). Five of the ten plots had no evidence of logging. Five had been salvage logged, thinned or selectively logged at some time before the plots were installed. A total of 1,576 live trees were tagged. 732 (46 percent) were Douglas-firs. 327 (45 percent) of these were dwarf mistletoe infected. Initial infection levels ranged from 22 to 78 percent of the live Douglas-firs in the plots. Other tree species present were white fir (36 percent), incense cedar (nine percent), western hemlock (three percent), Pacific yew (three percent), golden chinquapin (one percent), and big leaf maple, Pacific madrone, sugar pine, ponderosa pine and Shasta red fir (each less than one percent).

In 1997 the plots were revisited and data collected on the status (live or dead) of all tagged trees. Diameter, total height and dwarf mistletoe ratings of all live Douglas-firs were measured. The results were reported in Permanent plots for measuring the spread and impact of Douglas-fir dwarf mistletoe in the southern Oregon Cascades, Pacific Northwest Region: establishment and five-year re-measurement report, SWOFIDSC-98-3, and in the Dwarf Mistletoe Committee Report, Proceedings of the 46th Annual WIFDWC (Marshall 1998). One plot was dropped in 1997. Due to the topography, understory vegetation, and the height of the trees in the plot it was too difficult to collect accurate data. In 2002, Plots 1, 2, 3, 4, 5, 7, 8, 9, and 13 were remeasured. Data collected was the same as that collected in 1992.

Plot 16 was not remeasured in 2002 due to the Crooked Fire. The Crooked Fire, part of the Tiller Complex on the Umpqua National Forest, burned through Plot 16 in September 2002 (Figure 2). Due to safety restrictions remeasurement of the plot was delayed until June 2003. According to Tiller Ranger District personnel the fire came up from below and burned through the plot with two to five foot flame lengths. No Douglas-firs in the plot were killed, but all the Pacific yews were killed, as well as 70 percent of the white firs and 40 percent of the incense cedars. Most of the dead trees were less than six inches dbh. Heat generated by slow consumption of down wood in the plot was probably responsible for the mortality. In addition to the data collected in the other plots, data were collected in Plot 16 on the percentage of bole circumference charred, the percentage of crown scorched, and the height of the scorched foliage. To avoid confounding effects from the fire, data from Plot 16 were analyzed and summarized separately from the other plots.

Figure 2. Plot 16 after the Crooked Fire

Data from the plots were analyzed using Microsoft Office 2000 Excel Data Analysis Descriptive Statistics and SPSS 10.1 (SPSS 2000). Means and standard deviations were calculated for each measured variable. One-way analysis of variance (ANOVA) was used to compare the statistical significance of differences in diameter growth, height growth and the level of mortality among BVR levels. A *P*-value of 0.05 was used to determine significance. Pairwise multiple comparisons were made using least significant difference for equal variances and Tamhane's T2 tests for unequal variances.

The stem maps were created in Arcview GIS 3.2a with the extension Fred's COGO Tools 0.01. The location of the plot centers were established using their GPS coordinates. The distance and azimuth of each tree from the plot center was used to create a line ending in a point corresponding to the location of each tree relative to the plot center. The trees were represented by symbols for their condition, dwarf mistletoe infection, and crown class.

Results and Discussion

<u>Growth</u>

Infected Douglas-firs in every diameter class grew less in diameter between 1992 and 2002 than uninfected trees (Figure 3). The difference in diameter growth between infected and uninfected trees was greatest among trees in the two smallest diameter classes and the largest diameter class. Differences in growth between infected and uninfected trees ranged from 12 percent in the 12.0 to 15.9 inch diameter class to 40 percent in the = 36.0 inch class. The only statistically significant difference in diameter growth among trees in the same diameter class was between infected and uninfected Douglas-firs in the 21.0 to 35.9 inch diameter class ($P = 0.028$).

Diameter growth of Douglas-firs in BVR classes 1 and 2 was similar to that of uninfected Douglas-firs after ten years (Figure 4). Diameter growth of Douglas-firs in BVR classes 3 and 4 was 31 percent less than uninfected Douglas-firs. Douglas-firs in BVR class 5 had 61 percent less diameter growth than uninfected Douglas-fir. Douglas-firs in BVR class 6 had 92 percent less diameter growth than uninfected Douglas-firs. The difference in diameter growth between Douglas-firs in BVR classes 5 and 6 and uninfected Douglas-firs was statistically significant (P = 0.000).

Height growth of Douglas-firs in BVR classes 1, 2 and 3 was similar to that of uninfected Douglas-firs after ten years (Figure 5). Douglas-firs in BVR classes 4 and 5 had 50 percent less height growth than uninfected Douglas-firs. Douglas-firs in BVR class 6 had no height growth. The difference in height growth between Douglas-firs in BVR class 6 and uninfected Douglas-firs was statistically significant ($P = 0.003$). When the Douglas-firs were grouped by diameter class the impact of infection on height growth was highly variable. In general, diameter growth of infected Douglas-firs was affected at lower BVR than height growth.

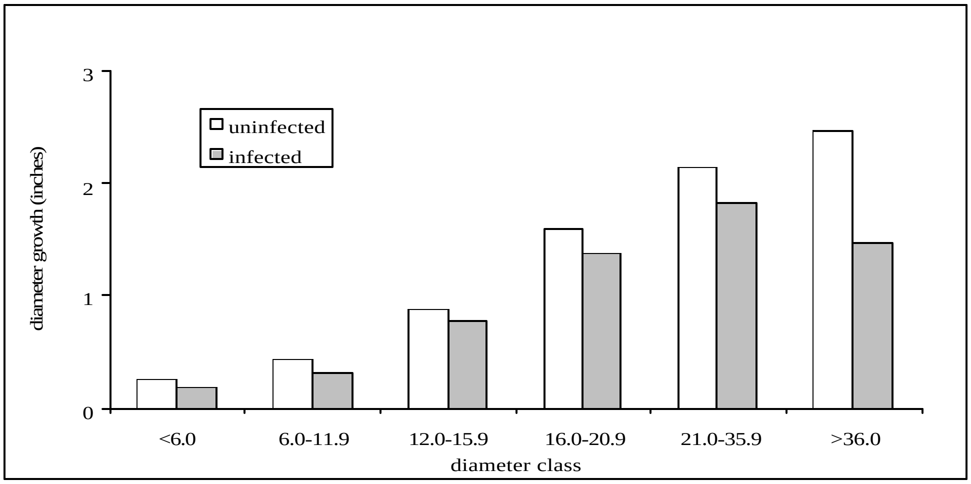


Figure 3. Ten-year diameter growth of infected and uninfected Douglas-firs

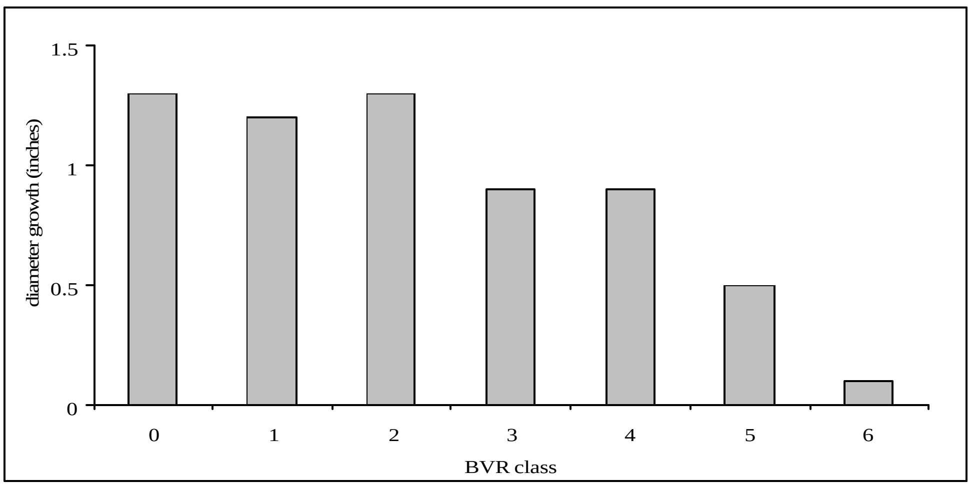


Figure 4. Average diameter growth after ten years by BVR class

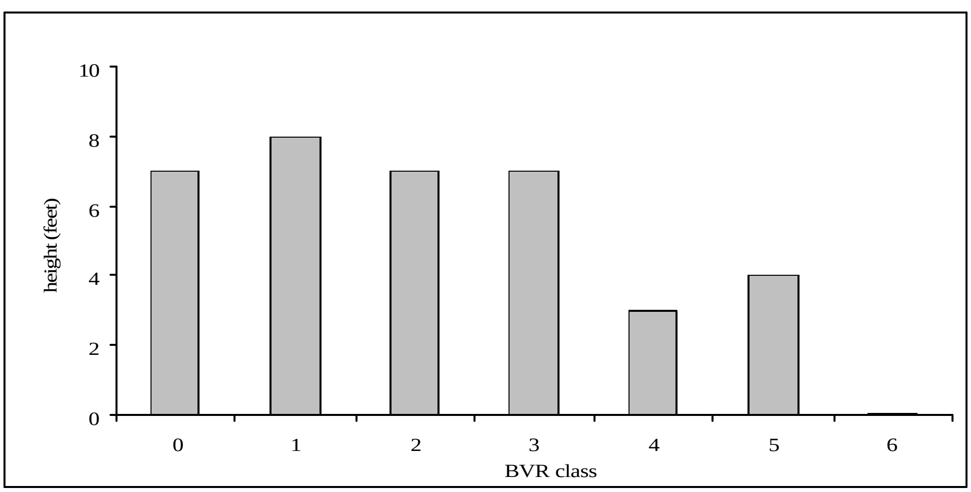


Figure 5. Average height growth after ten years by BVR class

Mortality

Sixteen percent of the Douglas-firs died between 1992 and 2002. The level of mortality of Douglas-firs in BVR classes 1, 2, 3 and 4 was similar to the mortality of uninfected Douglas-firs (Figure 6). Douglas-firs in BVR class 5 had 48 percent more mortality than uninfected Douglas-firs. Douglas-firs in BVR class 6 had 80 percent more mortality than uninfected Douglas-firs. The difference in the level of mortality between Douglas-firs in BVR class 6 and uninfected Douglas-firs was statistically significant (*P* = 0.000). The BVR class of dead Douglas-firs was significantly higher (*P* = 0.000) than the BVR class of live Douglas-firs in all diameter and crown classes (Figures 7 and 8).

Small diameter infected Douglas-firs had a much higher level of mortality than large diameter infected Douglas-firs (Figure 9). Similarly, infected Douglas-firs in the suppressed and intermediate crown classes had much higher levels of mortality than codominant and dominant Douglas-firs (Figure 10). The level of mortality, especially among smaller Douglas-firs, may have been influenced by the preponderance of drier than average years during the study period. Eight of the eleven years were drier than average. 1994 and 2001 were particularly dry years, with the weather station at Prospect, Oregon recording only 78 percent of average precipitation in each of those years.

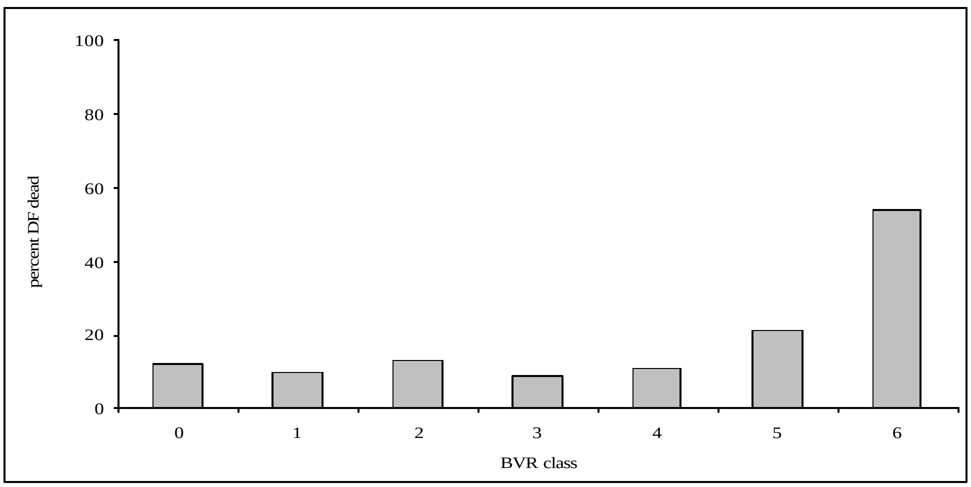


Figure 6. Percent of Douglas-firs in BVR class dead after ten years

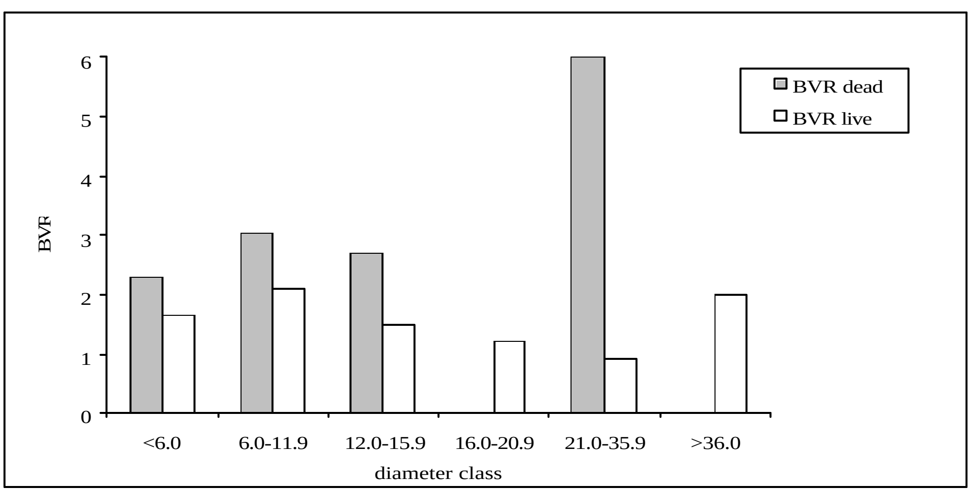


Figure 7. BVR class of dead and live Douglas-firs by diameter class after ten years

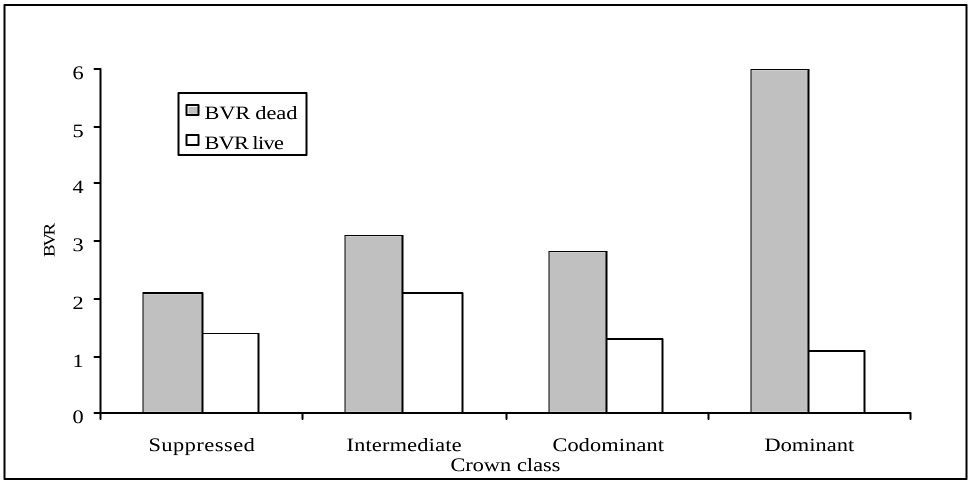


Figure 8. BVR of live and dead Douglas-firs by crown class after ten years

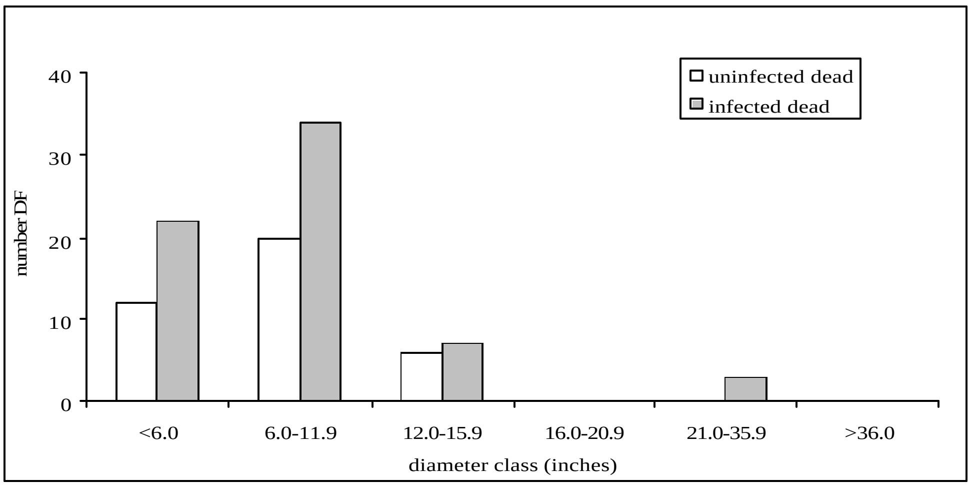


Figure 9. Mortality of infected and uninfected Douglas-firs by diameter class

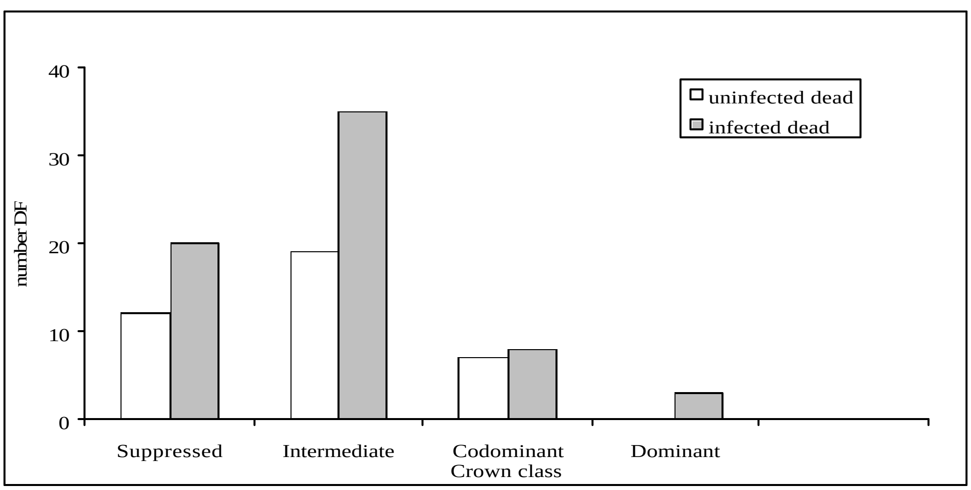


Figure 10. Mortality of infected and uninfected Douglas-firs by crown class

Spread

The number of infected Douglas-firs increased 19 percent between 1992 and 2002 (Figure 11). The greatest increases in new infections were in the 12 to 15.9 inch and the = 36.0 inch diameter classes, and in the suppressed and intermediate crown classes (Figure 12). New infections in small diameter and understory Douglas-firs are what would be expected given the ease with which dwarf mistletoe spreads from overstory to understory trees. The high percentage of new infections in large diameter Douglas-firs may have been an artifact of the sample size. There were only five uninfected Douglas-firs = 36 inches in diameter in 1992. By 2002, two of these (40 percent) had become infected.

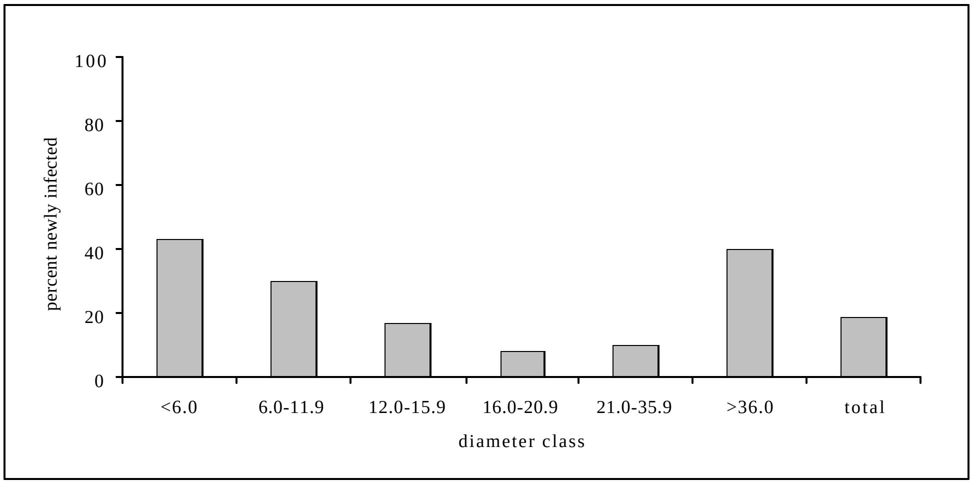


Figure 11. Douglas-fir dwarf mistletoe spread by diameter class

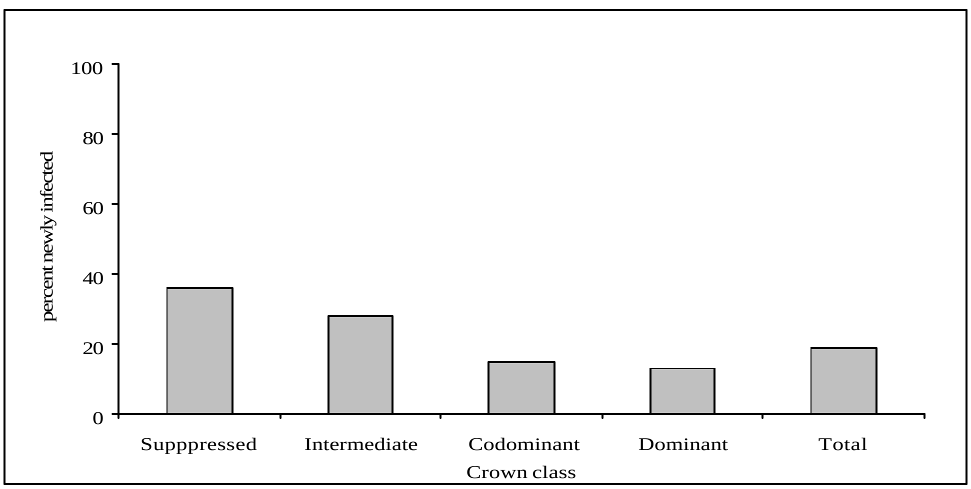


Figure 12. Douglas-fir dwarf mistletoe spread by crown class

In three of the five stem mapped plots all Douglas-firs that were newly infected in 2002 were within 25 feet of previously infected Douglas-firs (Appendix 2). In the other two plots one newly infected Douglas-fir in each plot was approximately 40 feet from the nearest previously infected Douglas-firs. All other newly infected Douglas-firs in these two plots were within 25 feet of previously infected Douglas-firs.

Intensification

Forty-five percent of the total Douglas-firs that were alive and infected in both 1992 and 2002 did not change BVR class during the ten-year period (Table 2). Forty-six percent increased one to four BVR classes. The BVR class decreased either one or two classes in nine percent of the Douglas-firs. These trees may either have lost infected limbs or grown faster in height than the dwarf mistletoe advanced upward in their crowns.

Table 2. Percent of infected Douglas-firs changing BVR class in ten years

Change in BVR	Percent of trees
+0	45
+1	28
+2	10
+3	6
+4	2
-1	7
-2	2

Table 3. Average change in BVR over ten years by diameter class (Douglas-firs infected in 1992)

Diameter class	Change in BVR
<6.0	+0.20
6.0-11.9	+0.17
12.0-15.9	+0.05
16.0-20.9	+0.19
21.0-35.9	-0.02
=36.0	+0.40

The average change in BVR ranged from a decrease of 0.02 classes in the 21.0 to 35.9 inch diameter class to an increase of 0.40 classes in the > 36.0 inch diameter class (Table 3). The relatively large increase in BVR in the = 36.0 inch diameter class may have been exaggerated by the small sample (eleven Douglas-firs) and the fact that one of these Douglas-firs increased three BVR classes in ten years. Hadfield et al (2000) predicted an average increase of one DMR class every ten years for Douglas-fir dwarf mistletoe. These data suggest a slower rate of intensification for Douglas-firs in southwestern Oregon in the situations sampled.

The greatest percentage increase in severity of infection was in the top third of the live crowns as measured by changes in average BVR over the ten-year period (Table 4). The bottom third of the live crowns had the smallest percentage increase in severity over the same period.

Table 4. Change in average BVR by crown third after ten years

	Average BVR 1992	Average BVR 2002	Percent change
Bottom	0.63	0.78	24
Middle	0.29	0.48	66
Top	0.08	0.17	113

Results by plot

Changes in growth and mortality of Douglas-firs, and degree of spread and intensification of dwarf mistletoe varied greatly among the plots (Tables 5, 6 and 7). Plot 7, the thinned plot, had no mortality, the least amount of spread of Douglas-fir dwarf mistletoe, and the highest diameter and height growth of all the plots. The greatest amount of mortality was in Plot 1. Douglas-fir dwarf mistletoe spread was greatest in Plot 3. Intensification of Douglas-fir dwarf mistletoe was greatest in plots 1, 2 and 4. It declined in Plot 8, probably due to the death of one heavily infected Douglas-fir. Tables with summary statistics for each plot are presented in Appendix 3.

Table 5. Summary of changes by plot

Plot	Douglas-firs			Dwarf mistletoe	
	Avg. diameter growth (inches)	Avg. height growth (feet)	Mortality (%)	Spread[1] (%)	Intensification[2] (BVR)
1	0.8	2.9	34	34	+ 1.00
2	0.9	3.9	13	5	+ 0.85
3	1.0	7.6	20	28	+ 0.53
4	0.6	2.6	24	22	+ 1.00
5	1.4	7.1	16	9	+ 0.28
7	2.2	13.0	0	3	+ 0.06
8	1.3	3.5	6	13	- 0.38
9	0.9	7.6	18	6	+ 0.23
13	1.4	6.8	11	12	+ 0.54
16	1.2	7.5	18	4	+ 0.56

1. Spread = percent of Douglas-firs in BVR class 0 in 1992 and BVR class > 0 in 2002
2. Intensification = average change in BVR class of Douglas-firs alive and infected in 1992 and 2002

Table 6. Summary of tree and Douglas-fir dwarf mistletoe data by plot

Plot and year	Number live trees	Number live DF	Number infected DF	Avg. age	Avg. dbh	Avg. hgt	Avg. BVR by crown third			Avg. BVR[1]	Avg. BVI[2]
							Bottom	middle	top		
1											
1992	201	44	28	91	10.8	70	1.10	0.66	0.30	2.1	3.2
2002	149	29	27		12.7	77	1.45	0.97	0.28	2.7	3.0
2											
1992	200	109	42	86	14.6	96	0.70	0.40	0.10	1.1	2.8
2002	182	95	37		16.4	109	0.70	0.50	0.10	1.3	3.4
3											
1992	131	40	23	70	13.1	89	0.90	0.50	0.10	1.4	2.5
2002	96	32	24		15.7	100	1.20	0.70	0.10	2.0	2.7
4											
1992	199	116	69	83	9.3	69	1.10	0.70	0.40	2.1	3.6
2002	160	88	69		10.8	87	1.20	1.00	0.50	2.8	3.6
5											
1992	109	55	18	80	19.0	96	0.60	0.02	0	0.6	1.8
2002	84	46	21		22.3	109	0.70	0.20	0.04	0.9	2.0
7											
1992	101	79	17	58	18.6	102	0.34	0.05	0	0.4	1.8
2002	101	79	18		20.8	115	0.34	0.06	0.04	0.4	1.9
8											
1992	88	16	9	130	25.6	129	1.10	0.80	0.40	2.4	4.5
2002	77	15	10		26.4	127	1.10	0.70	0.20	2.1	3.1
9											
1992	140	100	19	72	12.5	95	0.30	0.10	0.04	0.5	2.4
2002	106	82	16		14.1	108	0.30	0.10	0.01	0.4	2.0
13											
1992	200	101	46	98	16.4	103	0.80	0.50	0.20	1.4	3.2
2002	183	90	48		18.7	116	0.90	0.50	0.20	1.6	3.1
16											
1992	139	55	41	137	17.2	96	1.30	0.90	0.30	2.5	3.4
2003	79	45	33		19.2	106	1.40	0.90	0.30	2.6	3.5

1. Average BVR of each plot = (? BVR live DF)/number live DF
2. Average BVI of each plot = (? BVR infected DF)/number infected DF

Table 7. Number of live Douglas-firs by plot and BVR class, 1992 and 2002

Plot	Year	Total	BVR class						
			0	**1**	**2**	**3**	**4**	**5**	**6**
1	1992	44	16	6	5	6	5	0	6
	2002	29	2	8	1	7	9	1	1
2	1992	109	67	8	13	8	7	4	2
	2002	95	58	6	6	6	11	4	4
3	1992	40	17	5	7	8	2	0	1
	2002	32	8	8	4	4	6	0	2
4	1992	116	47	16	7	10	9	11	16
	2002	88	19	14	12	8	10	7	18
5	1992	55	37	4	13	1	0	0	0
	2002	46	25	10	3	7	0	1	0
7	1992	79	62	6	9	1	1	0	0
	2002	79	61	7	8	1	1	1	0
8	1992	16	7	0	1	2	1	4	1
	2002	15	5	3	0	3	1	3	0
9	1992	100	81	5	9	2	1	0	2
	2002	82	66	7	5	2	1	1	0
13	1992	101	55	7	14	6	8	5	6
	2002	90	42	12	6	10	11	5	4
16	1992	55	14	5	11	6	9	3	7
	2003	45	12	3	5	9	6	8	2

Effects of fire

The Crooked Fire scorched the crowns of five of 45 Douglas-firs in Plot 16. The degree of scorch was slight (two to ten percent of the live crown). All the scorched Douglas-firs were dwarf mistletoe-infected. The bottoms of the crowns of the scorched Douglas-firs were closer to the ground than the overall average of Douglas-firs in the same diameter, crown or BVR classes (Figures 13-15).

Forty-two of 45 Douglas-firs had charred boles. There was very little difference in the degree of char between infected and uninfected Douglas-firs. Ninety-four percent of the infected Douglas-firs and 92 percent of the uninfected Douglas-firs were charred. Infected Douglas-firs had an average of 60 percent of the circumference of their boles charred. Uninfected Douglas-firs had an average of 50 percent. The char averaged 11 feet high on the boles of infected Douglas-firs and 10 feet high on the boles of uninfected Douglas-firs. Future measurements will determine if survival and growth of fire-damaged mistletoe-infected Douglas-firs differs from undamaged infected or uninfected Douglas-firs in this plot.

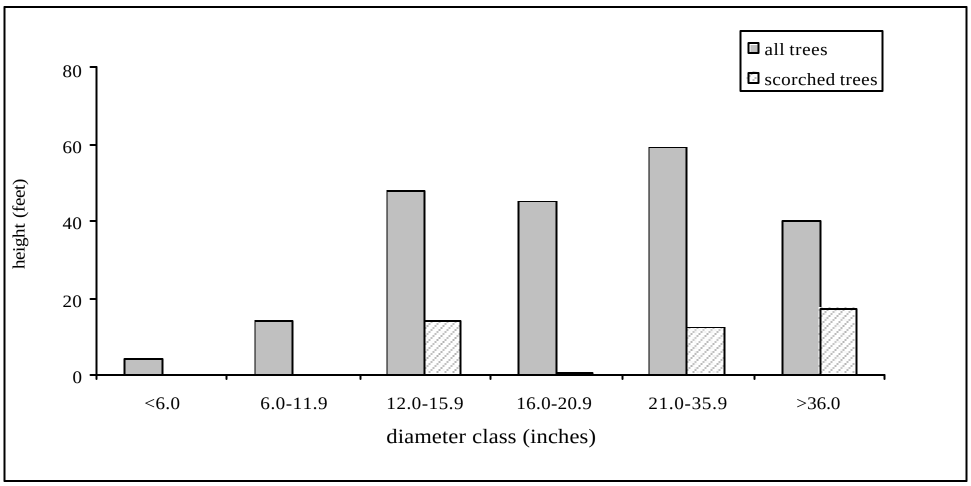


Figure 13. Scorch and height to bottom of the crown by diameter class, Plot 16

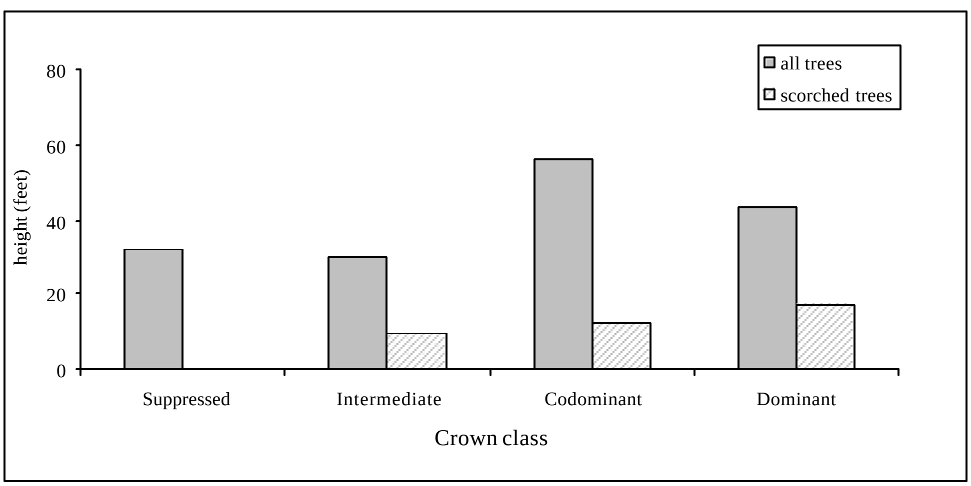


Figure 14. Scorch and height to bottom of the crown by crown class, Plot 16

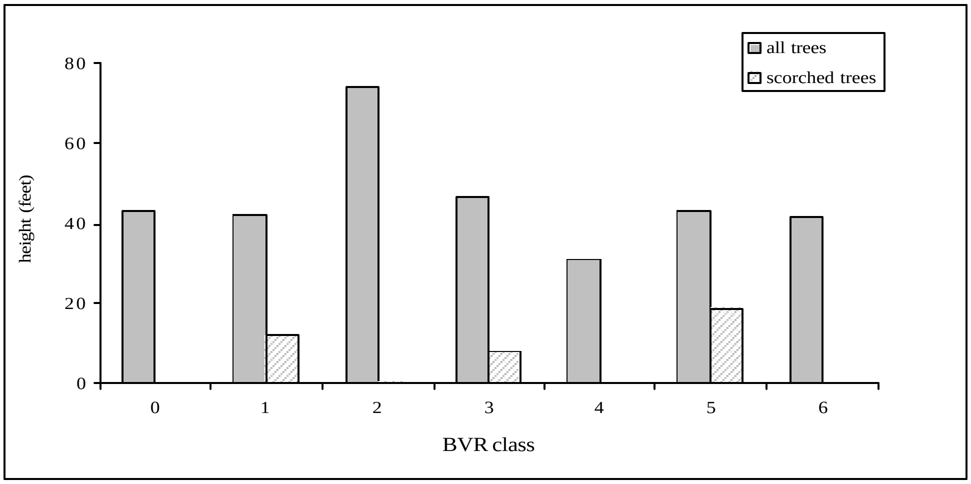


Figure 15. Scorch and height to bottom of the crown by BVR class, Plot 16

Forest Vegetation Simulator (FVS) model validation

The primary objective for installing this series of plots was to use the resulting data to validate the dwarf mistletoe impact extensions for Douglas-fir dwarf mistletoe in the West Cascades (WC) and Interior California-southern Cascades (ICSCA) variants of FVS. After the ten-year measurements were completed, the data collected in 1992 and 2002 were entered into separate FVS stand and tree data files for each plot. Individual model runs were then performed with the data from each plot for one ten year cycle. Initial processing of the files resulted in suspect diameter growth model scale factors for Douglas-fir in the calibration statistics. Subsequent runs to test the model using data sets from Rogue River and Umpqua National Forest Forest Inventory and Analysis plots (FIA) and the dwarf mistletoe plot data suggested that Douglas-fir on the Rogue River National Forest was growing more slowly than the model would predict. Further analysis indicated that this was probably not due to the dwarf mistletoe infection. Running the model with the Plant Association codes set to PSME-ABCO (Douglas-fir-white fir) for the ICSCA variant and ABAM/RHAL/XETE (Pacific silver fir/Cascade azalea/beargrass) for the WC variant instead of the FVS defaults brought the scale factors closer to 1.0. These plant associations were selected from those available in the variants because their Douglas-fir site indices were closest to what was actually measured in the plots. They were not the plant associations that were identified at the plots. The actual plant associations were not available in either of the variants.

The number of live Douglas-firs per acre, basal area, and cubic foot volume per acre predicted (P) after one ten year cycle by FVS were close to what was actually measured (M) in 2002, except in Plots 1 and 5, as determined by the ratio of P to M. In all except Plots 1 and 5, the ratio of P to M was very close to 1.0 (Table 8). In Plot 1, FVS predicted higher stocking and more volume per acre after ten years than was actually measured. Douglas-firs in this plot had comparatively low diameter and height growth, and unusually high mortality over the ten-year period, conditions which might explain why FVS overestimated stocking and volume levels. A large proportion of the Douglas-firs were mistletoe-infected. FVS predicted lower stocking and less volume after ten years in Plot 5 than was actually measured. Plot 5 was on a very productive site composed of Shasta red fir, white fir and Douglas-fir. Trees in the plot were growing very rapidly. The Douglas-fir-white fir plant association code used to run the model may have underestimated the actual site potential of this plot.

Table 8. Predicted (P) versus measured (M) stocking of live Douglas-firs after ten years using FVS

Plot	Douglas-fir per acre (n)			basal area per acre (ft^2)			volume per acre (ft^3)		
	P	**M**	**P:M**	**P**	**M**	**P:M**	**P**	**M**	**P:M**
1	81	58	1.40	72	60	1.20	3112	2419	1.29
2	103	95	1.08	159	154	1.03	7328	6707	1.09
3	76	96	0.79	177	205	0.86	9177	10726	0.86
4	198	176	1.13	156	162	0.96	6672	6702	1.00
5	53	90	0.59	184	264	0.70	8861	12060	0.73
7	77	79	0.97	193	199	0.97	9440	9159	1.03
8	27	30	0.90	130	138	0.94	7545	7935	0.95
9	230	246	0.93	273	311	0.88	11414	13396	0.85
13	90	90	1.00	198	209	0.95	9355	10094	0.93
16	96	90	1.07	201	208	0.97	9515	10196	0.93
Average	103	105	0.98	174	191	0.91	8242	8939	0.92

The number of dead Douglas-firs per acre, basal area, and cubic foot volume per acre predicted (P) after one ten-year cycle by FVS were very different in most cases from what was actually measured (M) in 2002 (Table 9). In four plots FVS predicted more dead Douglas-firs after ten years than were actually measured, and in four plots FVS predicted fewer dead Douglas-firs than were measured. The basal area per acre and total volume of dead trees after ten years was predicted to be higher than was measured in eight and nine of the plots respectively. This was undoubtedly due to the fact that FVS has no way to know when trees actually die so it gives them credit for height and diameter growth for the entire ten-year cycle before tagging them as mortality. This would affect calculations of predicted basal area and volumes.

Table 9. Predicted (P) versus measured (M) stocking of dead Douglas-firs after ten years using FVS

Plot	Douglas-fir per acre (n)			basal area per acre (ft^2)			volume per acre (ft^3)		
	P	**M**	**P:M**	**P**	**M**	**P:M**	**P**	**M**	**P:M**
1	7	30	0.23	6	20	0.30	264	835	0.32
2	5	14	0.36	6	7	0.86	262	220	1.19
3	44	24	1.83	40	7	5.71	1768	185	9.56
4	34	56	0.61	18	17	1.06	677	573	1.18
5	57	20	2.85	96	11	8.73	4291	378	11.35
7	1	0	-	1	0	-	55	0	-
8	3	2	1.50	14	11	1.27	846	552	1.53
9	70	54	1.30	83	27	3.07	3449	861	4.01
13	11	11	1.00	22	6	3.67	1005	189	5.32
16	14	22	0.64	28	23	1.22	1314	901	1.46
Average	25	23	1.06	31	13	2.43	1393	469	2.97

The Dwarf Mistletoe Impact Modeling System (DMIM): User Guide and Reference Manual Nonspatial Model 2005 Update (David 2005) describes equations used to modify FVS to account for the impacts of dwarf mistletoe. The diameter growth modification equation for Douglas-fir dwarf mistletoe was based on ten-year diameter growth potential derived from studies in eastern Oregon and Washington, Montana and the Southwest. In the Southern Oregon Cascades plots diameter growth potential was impacted more severely in BVR classes 3 through 6 than accounted for by the equation used in the model (Table 10).

Table 10. Ten-year diameter growth potential by DMR/BVR

DMR/BVR	0	1	2	3	4	5	6
DMIM (percent by DMR)	100	98	97	85	80	52	44
Southern Cascades plots (percent by BVR)	100	92	100	69	69	39	8

Similar methods were used to derive the ten-year mortality rate based on DMR and dbh to account for the impact of Douglas-fir dwarf mistletoe. Analysis of the data from the southern Cascades plots indicated that mortality of Douglas-fir < 9.0 inches dbh was much higher than accounted for by the model equation in all BVR classes. Douglas-fir = 9.0 inches in the southern Cascades plots had much higher mortality than the model would calculate in BVR classes 5 and 6 (Table 11). However, the high level of mortality observed in the southern Cascades plots, particularly among the smaller trees, may have been influenced by the series of dry years during the ten-year measurement period.

Table 11. Ten-year mortality rate (percent mortality) by DMR/BVR and dbh class

DMR/BVR	0	1	2	3	4	5	6
Dbh < 9.0 inches							
DMIM (percent mortality, DMR)	0.0	0.6	1.6	4.6	9.6	16.5	25.4
southern Cascades plots (percent mortality, BVR)	38.0	29.0	27.0	25.0	31.0	36.0	62.0
Dbh = 9.0 inches							
DMIM (percent mortality, DMR)	0.0	0.5	1.4	3.8	8.0	13.7	21.1
southern Cascades plots (percent mortality, BVR)	6.0	0.0	8.0	5.0	5.0	11.0	45.0

DMIM does not modify the FVS model to account for the impact of dwarf mistletoe on height growth. According to the data from the southern Cascades plots, ten-year height growth of dwarf mistletoe infected Douglas-fir was greatly reduced at BVR 4 and higher. Douglas-fir with BVR 6 had no height growth at all. Reduced height growth would be expected to affect volume growth.

In spite of these differences, the results of this analysis indicate that DMIM must have accounted for the effects of dwarf mistletoe on predicted stocking levels and volume of live Douglas-fir fairly well in eight of the ten plots after one ten year cycle. The one plot where FVS greatly overestimated stocking and growth had an unusually high proportion of infected Douglas-fir and high mortality, suggesting that the model may not perform as well in extreme cases.

Other problems appeared to be with aspects of the model unrelated to dwarf mistletoe. The Plant Associations available for defining habitat types in the Western Cascades and Interior California-southern Cascades variants did not fit the actual stand conditions very well. This affected the accuracy of the growth adjustment factors used in the model. Mortality created problems with growth and volume projections because FVS increased the diameter and height of trees until the end of the ten year cycle, regardless of when they actually died. Simulation models like FVS are not intended to provide plot-specific data at the end of each cycle comparable to data collected on site. Normally the model is run for multiple cycles using data from numerous plots. In this case not only was FVS run for only one ten year cycle, but only one plot was used to represent each stand in the model.

Collecting data in these plots for several more decades would provide the best information for adjusting DMIM equations for the Western Cascades and Interior California-southern Cascades variants of FVS. However, the information generated to date could be used to make some adjustments to diameter growth, height growth and mortality equations now. It would also be beneficial to incorporate the local plant associations described in Atzet et al (1996). An additional analysis that could be pursued would be to compare dwarf mistletoe spread and intensification rates predicted by DMIM with what was actually measured.

Summary

Ten permanent plots to measure the spread and impact of Douglas-fir dwarf mistletoe were installed in the Southern Oregon Cascade Mountains on the Rogue River-Siskiyou and Umpqua National Forests in 1992. They were remeasured in 1997 and 2002. Comparison of the data from 1992 and 2002 showed that after ten years Douglas-firs that were heavily infected had less growth and higher mortality than uninfected or lightly infected Douglas-firs. The number of infected Douglas-firs increased substantially in one decade. The majority of newly infected Douglas-firs were within 25 feet of previously infected Douglas-firs.

The effects of Douglas-fir dwarf mistletoe infection were particularly great in small Douglas-firs. During the ten year period between measurements dwarf mistletoe spread into more small diameter and understory Douglas-firs than into larger Douglas-firs. Infected small diameter and understory Douglas-firs also had less diameter growth and higher mortality than large Douglas-firs. The results suggested that large Douglas-firs that are currently heavily infected probably became large before their BVR reached 4. Above BVR 4 diameter and height growth decreased significantly and mortality increased significantly, reducing the likelihood that Douglas-firs would have been able to grow to large size. This suggests that widespread and severe Douglas-fir dwarf mistletoe infection is likely to adversely affect plans to grow young Douglas-firs in southwest Oregon into large old trees and have them survive for many decades unless there is some form of management intervention to reduce its impacts.

Running the FVS model using data from the plots indicated that DMIM did account for the effects of Douglas-fir dwarf mistletoe on predicted stocking levels and volume of live Douglas-fir fairly well in the majority of plots, in spite of differences between the plot data and data used to derive the equations for DMIM. The model was not as accurate in predicting numbers and volume of dead trees. Comparing the model projections to actual plot data also revealed that there are problems with the FVS model unrelated to dwarf mistletoe. Ideally these plots should be followed for several more decades. However, data collected so far could be used now to modify the equations used to predict growth and mortality in variants of DMIM used in the southern Cascades.

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References

Atzet, Thomas, D.E. White, L.A. McCrimmon, P.A. Martinez, P.R. Fong and V.D. Randall. 1996. Field Guide to the Forested Plant Associations of Southwestern Oregon. USDA Forest Service Pacific Northwest Region, Technical Paper R6-NR-ECOL-TP-17-96.

David, Lance R. 2005. Dwarf mistletoe impact modeling system: User guide and reference manual nonspatial model: 2005 update. USDA Forest Service, Forest Health Protection, Forest Health Technology Enterprise Team. Fort Collins, Colorado. Unpublished report. October 2005. 73 pp.

Filip, Gregory M., J.J. Colbert, C.G. Shaw III, P.F. Hessburg, K.P. Hosman and C.A. Parks. 1991. Some relations among dwarf mistletoe, western spruce budworm, and Douglas-fir: modeling and management implications. P. 162-164 *in* Proceedings of the symposium on interior Douglas-fir: the species and its management. Cooperative Extension, Washington State University, Pullman.

Hadfield, James S., Robert L. Mathiasen and Frank G. Hawksworth. 2000. Douglas-fir dwarf mistletoe. Forest Insect and Disease Leaflet 54. USDA Forest Service R6-NR-FID-PR-003-00. 9 pp.

Hawksworth, Frank G. and D. Wiens. 1996. Dwarf mistletoes: biology, pathology and systematics. USDA Forest Service Agriculture Handbook 709. 410 pp.

Marshall, Katy 1998. Permanent plots for measuring the spread and impact of Douglas-fir dwarf mistletoe in the southern Oregon Cascades, Pacific Northwest Region: Establishment and five year re-measurement report. USDA Forest Service, Pacific Northwest Region, Southwest Oregon Forest Insect and Disease Service Center, Central Point, Oregon. SWOFIDSC-98-3. 6 pp.

Mathiasen, Robert. 1990. Establishment of permanent plots for validation of dwarf mistletoe relationships related to growth and yield modeling: First year testing of field procedures for plot establishment, Work Plan version 2.0, May 11, 1990. USDA Forest Service Forest Pest Management, Intermountain Region, Ogden, UT. 21 pp.

Mathiasen, Robert L., F.G. Hawksworth and C.B. Edminster. 1990. Effects of dwarf mistletoe on growth and mortality of Douglas-fir in the Southwest. Great Basin Naturalist 50: 173-179.

Tinnin, Robert O. 1998. An alternative to the six-class dwarf mistletoe rating system. Western Journal of Applied Forestry 13(2): 64-65.

Schumaker, Francis X. 1930. Yield, stand and volume tables for Douglas-fir in California. University of California Agricultural Experiment Station Bulletin #491. 22 pp.

SPSS. 2000. SPSS for Windows, Release 10.1.0. Standard version. SPSS, Inc. Chicago, Illinois.

Appendix 1. Brief descriptions of Plant Associations at the plots. From Atzet et al 1996.

ABCO/BENE2, white fir/dwarf oregongrape

This association occurs over a wide range of elevations, on drier sites with moderate temperatures. Species richness is intermediate for the series. White fir and Douglas-fir are almost always present in the overstory and understory. Vine maple is dense on some sites. Other hardwoods may also be present. Shrub cover is low.

ABCO/BENE2/ACTR, white fir/dwarf oregongrape/vanillaleaf

This association occurs at intermediate elevations on sites with moderate amounts of precipitation. Total species richness is high for the series. The overstory is Douglas-fir and white fir. The understory is Douglas-fir, white fir and often incense cedar. Hardwoods are common in the understory. Shrub cover is very low.

ABCO-CADE27/TRLA6, white fir-incense cedar/western twinflower

This association occurs at intermediate elevations on sites that receive moderate amounts of precipitation. Total species richness is high for the series. Douglas-fir, white fir and incense cedar are the most frequent species in the overstory. Sugar pine is common. The understory is most frequently Douglas-fir, white fir and incense cedar. A number of hardwood species also occur in the understory. Shrub cover is low.

ABCO-TSHE/BENE2/LIBOL, white fir-western hemlock/dwarf oregongrape/western twinflower

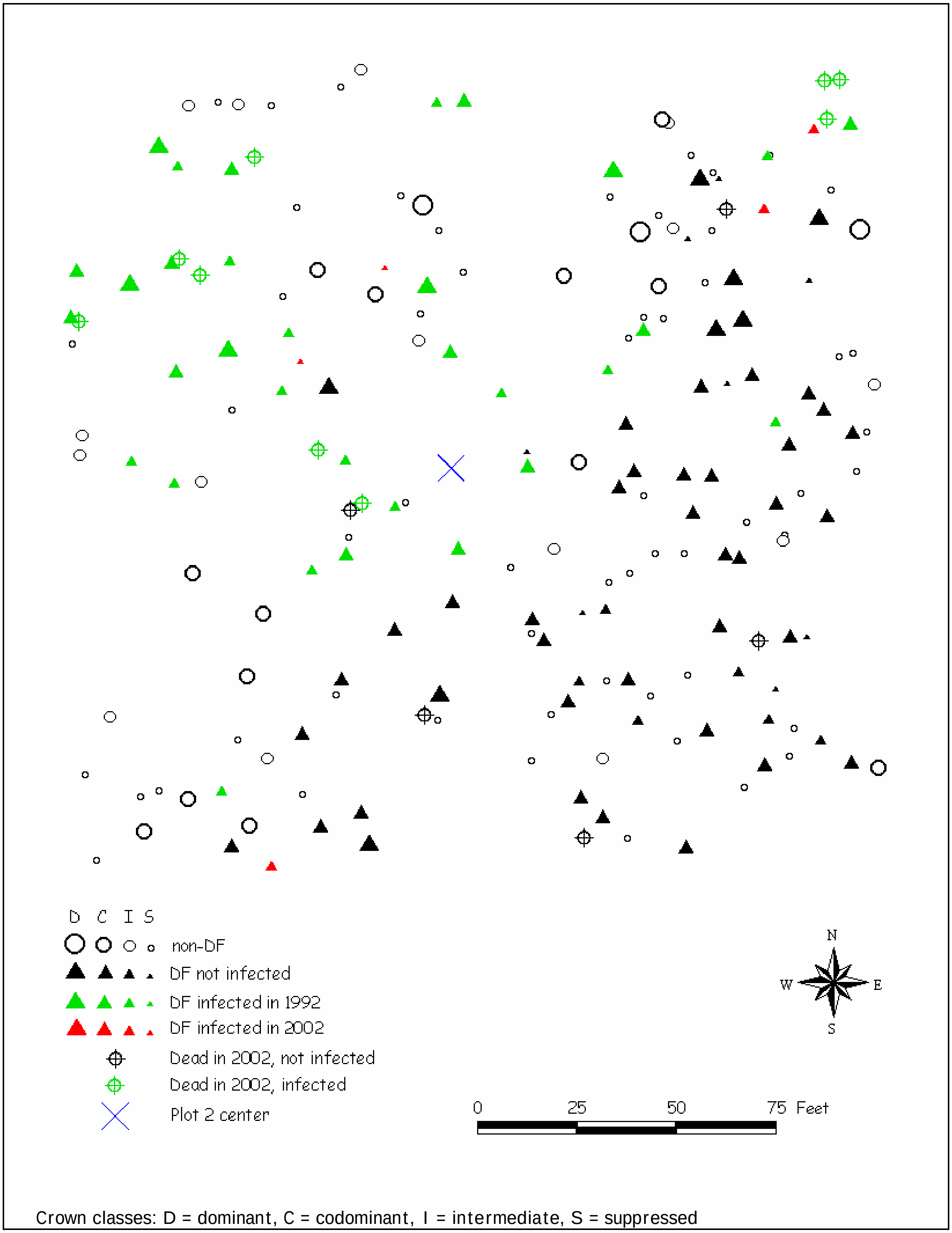
This association occurs on moist sites, often in the transition between the western hemlock and white fir series. Total species richness is high for the series. Douglas-fir is the most frequent species in the overstory. White fir is common. The understory is Douglas-fir, white fir and often Pacific yew, western hemlock and incense cedar. Hardwoods are common in the understory. Shrub cover is low to intermediate.

TSHE-ABCO/ACCI-BENE2, western hemlock-white fir/vine maple-dwarf oregongrape

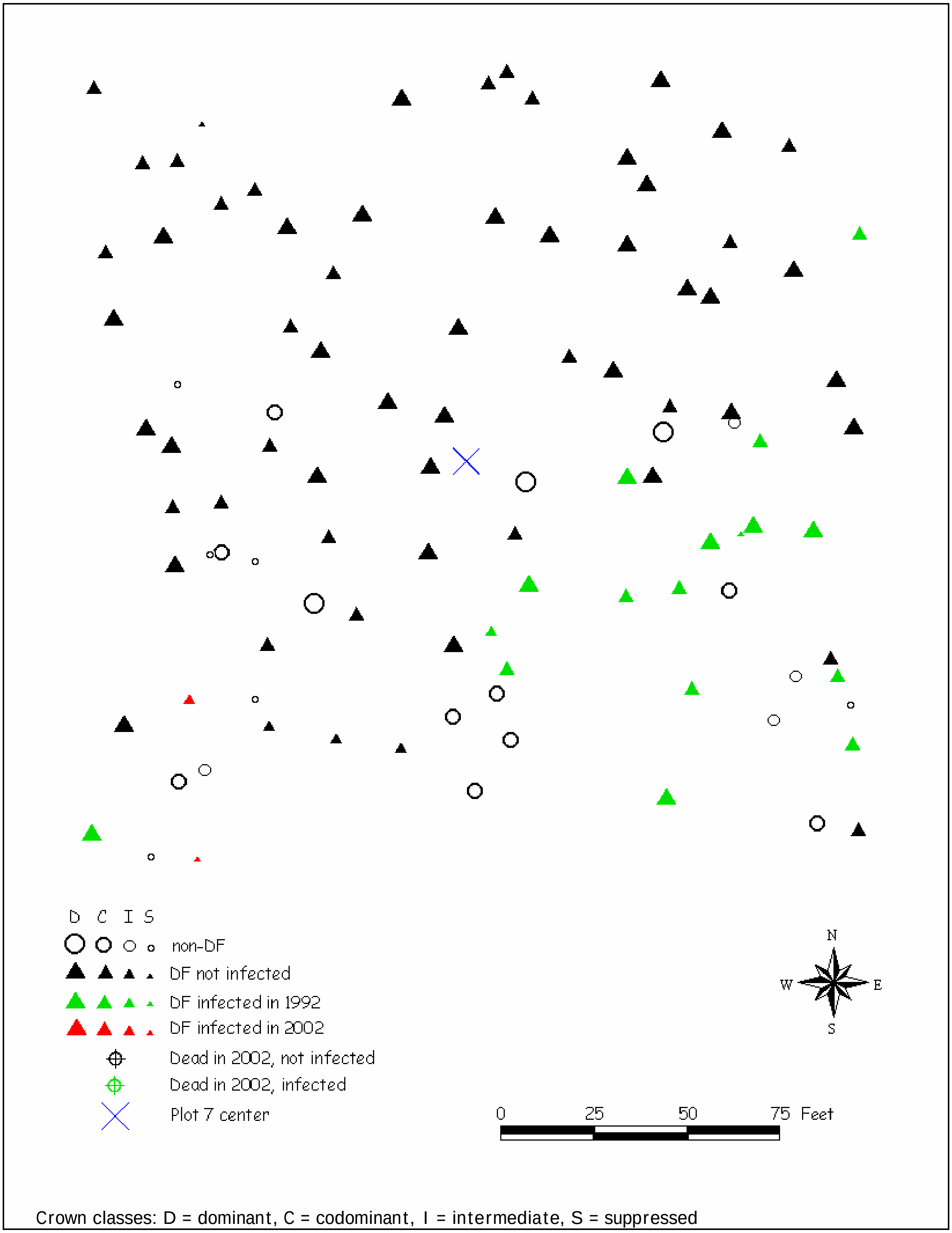
This is a cool, high elevation plant association. Total species richness is very high for the series. The overstory is dominated by Douglas-fir. White fir is usually present and sugar pine is common. The understory is western hemlock and white fir. Incense cedar and Pacific yew are often present also. Vine maple and other hardwoods can be abundant. Shrub cover is intermediate.

Appendix 2. Stem Maps

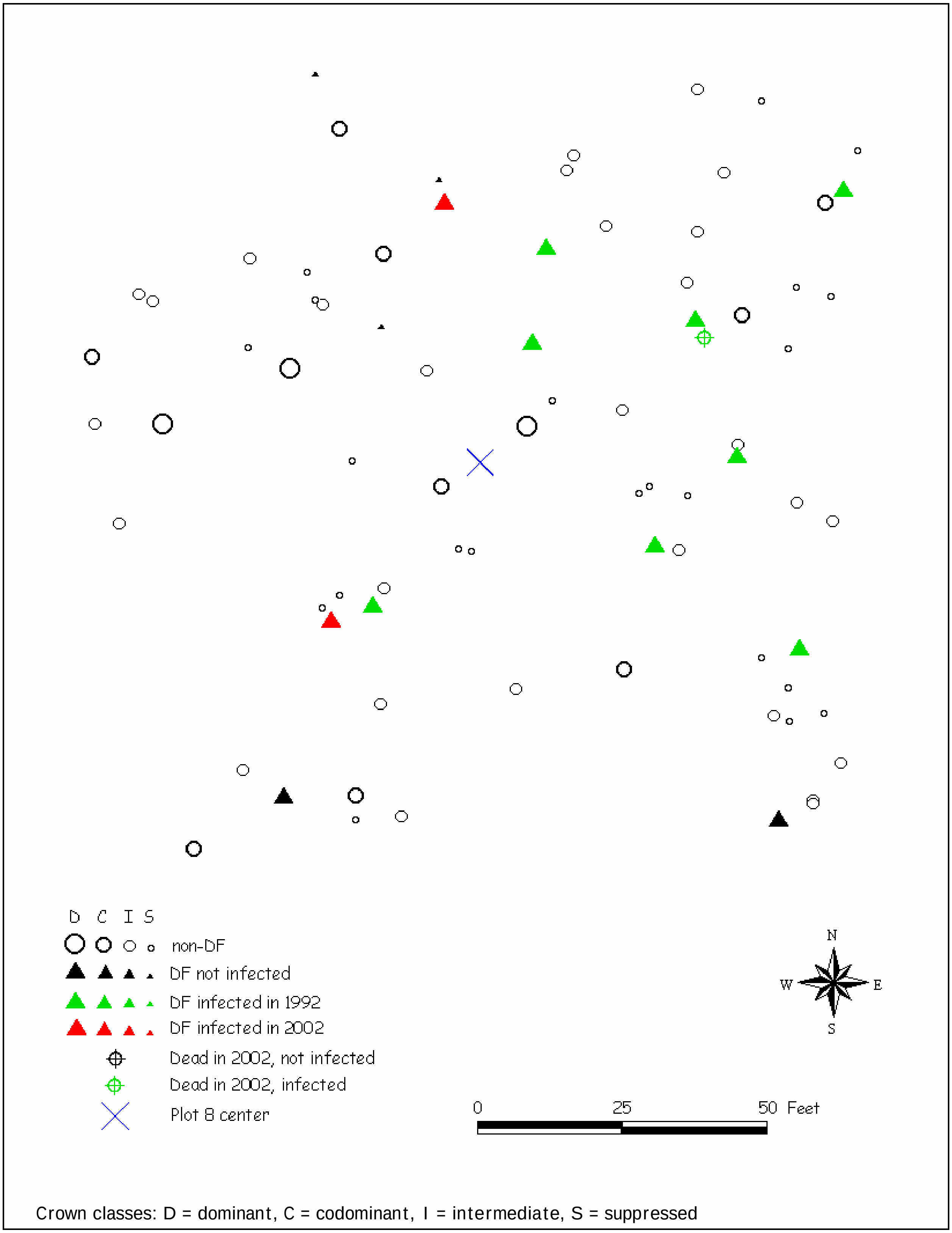
Stem Map, Plot 2.



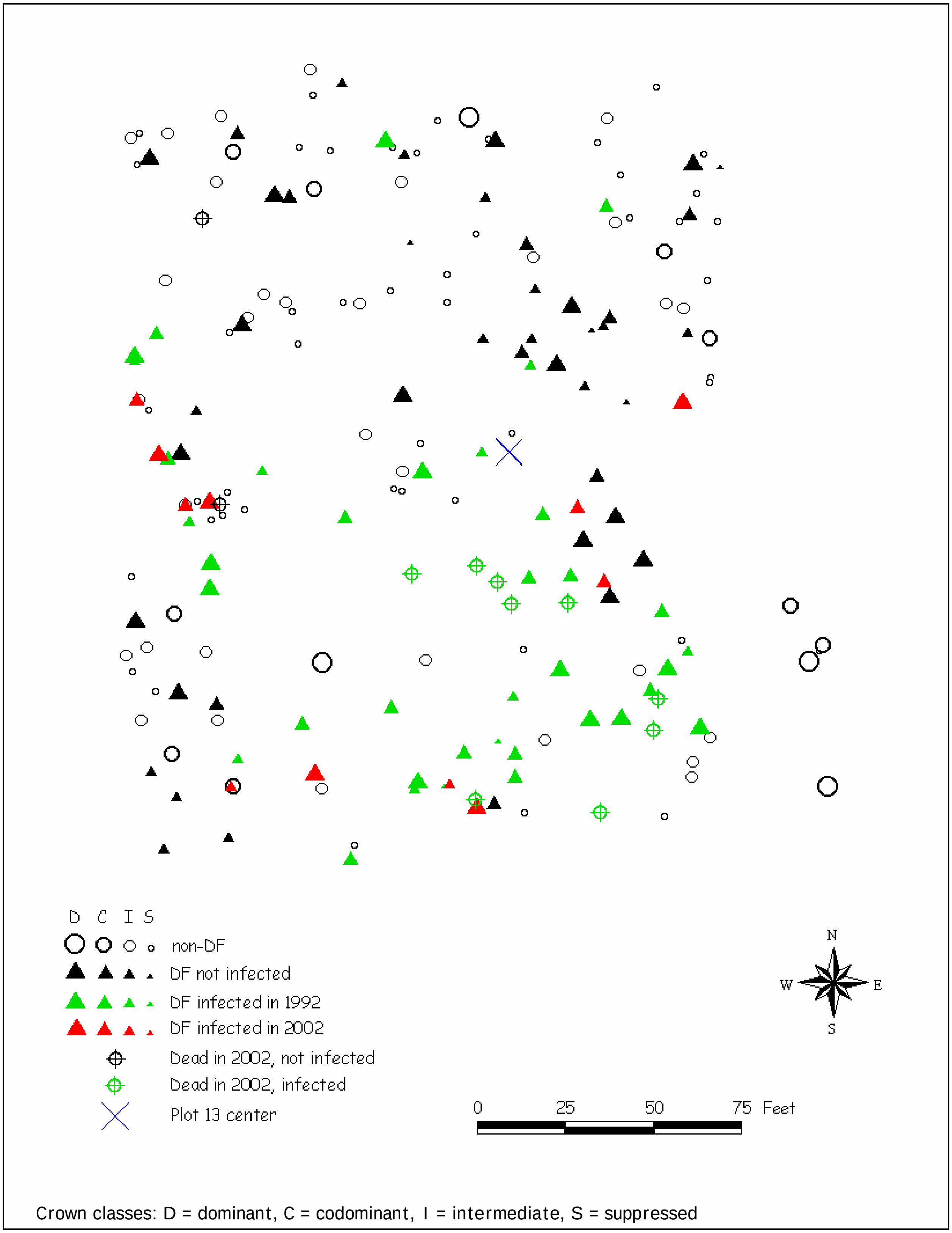
Stem Map, Plot 7.



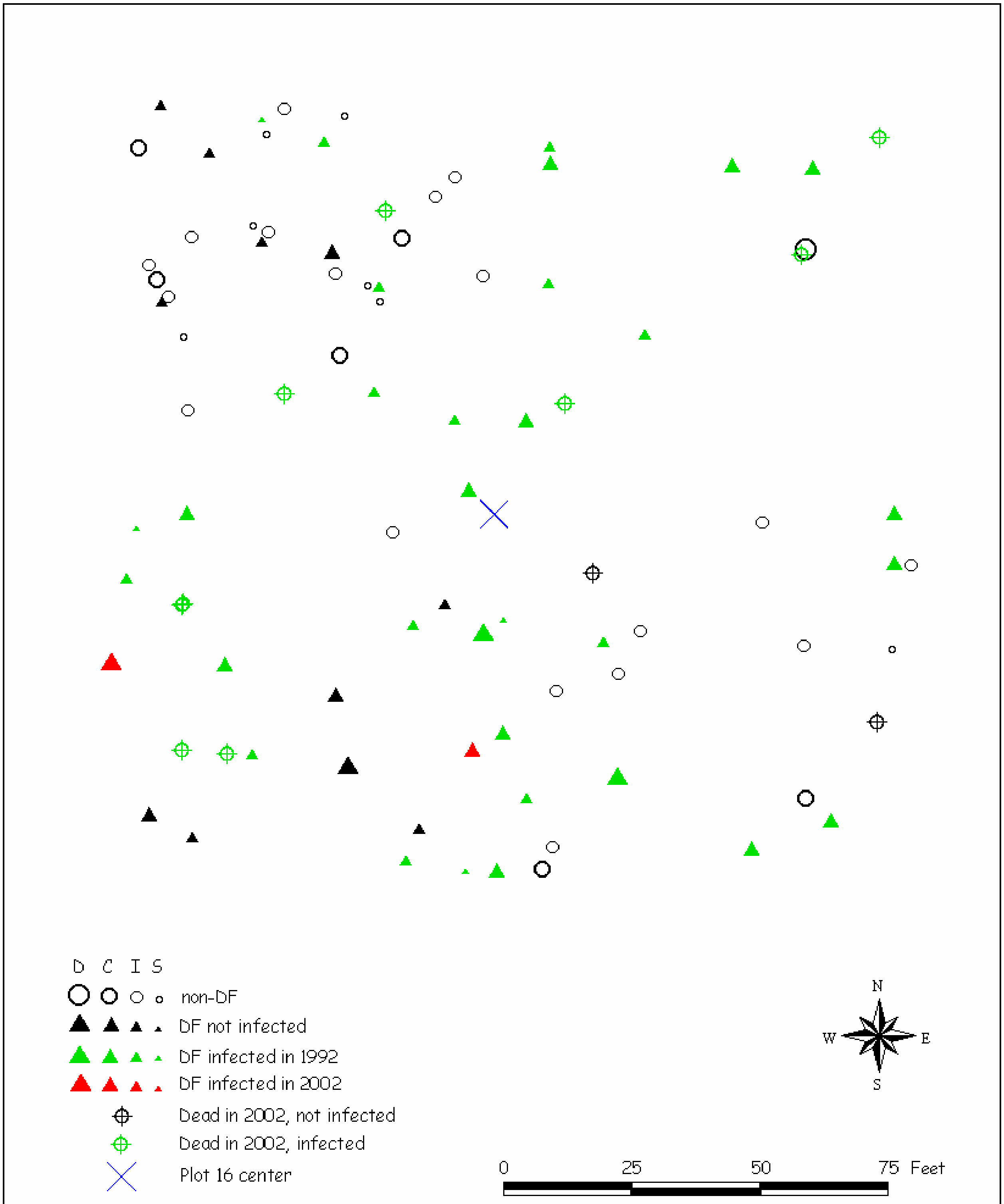
Stem Map, Plot 8.



Stem Map, Plot 13.



Stem Map, Plot 16.



Crown classes: D = dominant, C = codominant, I = intermediate, S = suppressed

Appendix 3. Summary statistics by plot

Plot 1 summary statistics	1992	2002
Number live trees	201	149
Number live DF	44	29
Number live infected DF	28	27
Live DF: mean ± SD		
Age	91 ± 48	85 ± 17
Dbh	10.8 ± 6.0	12.7 ± 5.4
Height	70 ± 35	77 ± 27
Height to crown base		38.5 ± 14.2
Total BVR	2.05 ± 2.11	2.70 ± 1.6
BVR bottom crown third	1.10 ± 0.94	1.45 ± 0.69
BVR middle crown third	0.66 ± 0.83	0.97 ± 0.78
BVR top crown third	0.30 ± 0.70	0.28 ± 0.53
BVI	3.2 ± 1.8	3.0 ± 1.43

Plot 2 summary statistics	1992	2002
Number live trees	200	182
Number live DF	109	95
Number live infected DF	42	37
Live DF: mean ± SD		
Age	86 ± 4	
Dbh	14.6 ± 5.2	16.4 ± 5.3
Height	96 ± 29	109 ± 24
Height to crown base		51 ± 19
Total BVR	1.1 ± 1.6	1.3 ± 1.9
BVR bottom crown third	0.7 ± 0.9	0.7 ± 0.9
BVR middle crown third	0.4 ± 0.7	0.5 ± 0.8
BVR top crown third	0.1 ± 0.4	0.1 ± 0.5
BVI	2.8 ± 1.4	3.4 ± 1.5

Plot 3 summary statistics	1992	2002
Number live trees	131	96
Number live DF	40	32
Number live infected DF	23	24
Live DF: mean ± SD		
Age	70 ± 15	
Dbh	13.1± 11.1	15.7 ± 12.4
Height	89 ± 46	100 ± 47
Height to crown base		53 ± 28
Total BVR	1.4 ± 1.5	2.0 ± 1.8
BVR bottom crown third	0.9 ± 0.9	1.2 ± 0.8
BVR middle crown third	0.5 ± 0.7	0.7 ± 0.9
BVR top crown third	0.1 ± 0.3	0.1 ± 0.5
BVI	2.5 ± 1.2	2.7 ± 1.6

Plot 4 summary statistics	1992	2002
Number live trees	199	160
Number live DF	116	88
Number live infected DF	69	69
Live DF: mean ± SD		
Age	83 ± 32	
Dbh	9.3 ± 6.5	10.8 ± 7.2
Height	69 ± 40	87 ± 36
Height to crown base		37 ± 13
Total BVR	2.1 ± 2.3	2.8 ± 2.2
BVR bottom crown third	1.0 ± 1.0	1.2 ± 0.9
BVR middle crown third	0.7 ± 0.9	1.0 ± 0.9
BVR top crown third	0.4 ± 0.7	0.5 ± 0.8
BVI	3.6 ± 1.9	3.6 ± 1.9

Plot 5 summary statistics	1992	2002
Number live trees	109	84
Number live DF	55	46
Number live infected DF	18	21
Live DF: mean ± SD		
Age	80 ± 10	
Dbh	19.0 ± 7.3	22.3 ± 7.16
Height	96 ± 29	109 ± 25
Height to crown base		37 ± 18
Total BVR	0.60 ± 0.91	0.91 ± 1.26
BVR bottom crown third	0.58 ± 0.88	0.67 ± 0.82
BVR middle crown third	0.02 ± 0.13	0.20 ± 0.45
BVR top crown third	0.0 ± 0.0	0.04 ± 0.21
BVI	1.83 ± 0.51	2.00 ± 1.14

Plot 7 summary statistics	1992	2002
Number live trees	101	101
Number live DF	79	79
Number live infected DF	17	18
Live DF: mean ± SD		
Age	58 ± 5	
Dbh	18.6 ± 4.8	20.8 ± 5.3
Height	102 ± 34	115 ± 36
Height to crown base		33 ± 20
Total BVR	0.39 ± 0.84	0.44 ± 0.97
BVR bottom crown third	0.34 ± 0.71	0.34 ± 0.70
BVR middle crown third	0.05 ± 0.27	0.06 ± 0.33
BVR top crown third	0.0 ± 0.0	0.04 ± 0.25
BVI	1.82 ± 0.81	1.94 ± 1.11

Plot 8 summary statistics	1992	2002
Number live trees	88	77
Number live DF	16	15
Number live infected DF	9	10
Live DF: mean ± SD		
Age	130 ± 57	
Dbh	25.6 ± 12.0	26.4 ± 12.7
Height	129 ± 55	127 ± 58
Height to crown base		45 ± 19
Total BVR	2.38 ± 2.36	2.07 ± 2.02
BVR bottom crown third	1.13 ± 1.02	1.13 ± 0.92
BVR middle crown third	0.81 ± 0.91	0.73 ± 0.88
BVR top crown third	0.44 ± 0.73	0.20 ± 0.41
BVI	4.22 ± 1.30	3.10 ± 1.66

Plot 9 summary statistics	1992	2002
Number live trees	140	106
Number live DF	100	82
Number live infected DF	19	16
Live DF: mean ± SD		
Age	72 ± 10	
Dbh	12.5 ± 4.9	14.1 ± 5.8
Height	96 ± 24	108 ± 24
Height to crown base		27 ± 17
Total BVR	0.45 ± 1.13	0.39 ± 0.95
BVR bottom crown third	0.33 ± 0.71	0.29 ± 0.66
BVR middle crown third	0.08 ± 0.37	0.09 ± 0.36
BVR top crown third	0.04 ± 0.28	0.01 ± 0.11
BVI	2.37 ± 1.50	2.00 ± 1.21

Plot 13 summary statistics	1992	2002
Number live trees	201	183
Number live DF	101	90
Number live infected DF	46	48
Live DF: mean ± SD		
Age	98 ± 36	
Dbh	16.4 ± 8.3	18.7 ± 8.94
Height	103 ± 34	116 ± 30
Height to crown base		51 ± 15
Total BVR	1.45 ± 1.94	1.63 ± 1.93
BVR bottom crown third	0.77 ± 0.94	0.93 ± 0.93
BVR middle crown third	0.49 ± 0.82	0.54 ± 0.82
BVR top crown third	0.19 ± 0.52	0.16 ± 0.47
BVI	3.17 ± 1.65	3.06 ± 1.60

Plot 16 summary statistics	1992	2002
Number live trees	139	79
Number live DF	55	45
Number live infected DF	41	33
Live DF: mean ± SD		
Age	137 ± 19	148 ± 19
Dbh	17.2 ± 6.9	19.2 ± 7.7
Height	96 ± 37	106 ± 37
Height to crown base		43 ± 26
Total BVR	2.5 ± 2.1	2.6 ± 2.0
BVR bottom crown third	1.3 ± 0.9	1.4 ± 0.9
BVR middle crown third	0.9 ± 0.9	0.9 ± 0.9
BVR top crown third	0.3 ± 0.7	0.3 ± 0.5
BVI	3.4 ± 1.7	3.5 ± 1.4
Effects of Fire on DF: mean ± SD		
Height to crown base unscorched DF (n=40)		45 ± 25
Height to crown base scorched DF (n=5)		12 ± 8
Height of scorch in crown (n=5)		16 ± 8
Percent crown scorched (n=5)		6 ± 4
Percent circumference charred (n= 42)		58 ± 28
Height of char on bole (n=42)		11 ± 5