Three-Year Survival and Growth of Douglas-Fir Seedlings Under Various Vegetation-Free Regimes

R. Rose, J.S. Ketchum, and D.E. Hanson

ABSTRACT. Responses of Douglas-fir seedlings were studied for 3 yr following eight vegetation-control treatments in three western Oregon clearcuts. The objectives were to determine seedling growth response to different areas of spot vegetation control and to determine the relative influence of early woody and herbaceous competition on seedling growth. Herbicide treatment areas varied in size from those receiving no control to full control (9.3 m^2). Controlled areas were maintained free of herbaceous vegetation for 2 yr and all woody vegetation was controlled for 3 yr. Two additional treatments, complete control of woody vegetation only and complete control of herbaceous vegetation only, were also examined. On two sites (Summit and Marcola), seedling growth parameters were maximized at or near full vegetation control with a tree spacing of 3 m × 3 m. On the third site (Pedee), maximum growth response occurred between 5 and 6 m^2 of control. Herbaceous vegetation control resulted in increased seedling growth at all sites while woody vegetation control yielded increased seedling growth only at the Pedee site. Cumulative 3 yr herbaceous cover accounted for 68% and 41% of the variability in stem volume at Summit and Marcola, respectively. Adding cumulative 3 yr woody cover to the model accounted for an additional 18% and 49% of the variability in stem volume at Summit and Marcola, respectively. At Pedee, neither herbaceous nor woody cover significantly influenced 3 yr stem volume, suggesting that factors other than vegetation cover were responsible for differences measured. FOR. SCI. 45(1):117–126.

Additional Key Words: Vegetation management, spot herbicide application, competition, forest weed control, reforestation, herbaceous vegetation.

VEGETATION CAN LIMIT GROWTH and sometimes survival of conifer seedlings on sites that span a range of soil moisture availability in the Pacific Northwest. More than 200 studies (described by Stewart et al. 1984) on the effect of different vegetation competition show that early control leads to increased growth and survival of several conifer species over a large range of environments. Clearcuts in Oregon west-side forests are initially dominated by herbaceous vegetation, although woody species usually dominate sites within 5 yr of harvest (Isaac 1940, Dyrness 1973, Malavasi 1978, Schoonmaker and McKee 1988). Traditionally, western foresters have ignored early herbaceous vegetation on harvested sites and have concentrated control efforts on woody vegetation. However, they are recognizing that early herbaceous control may increase seedling growth; for example, it has been shown to enhance the growth of loblolly pine (*Pinus taeda* L.) (Cain 1991, Miller et al. 1991, Creighton et al. 1987).

Several studies hint that such early herbaceous control may be important as well to establishment and growth of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) planted in the Pacific Northwest (Petersen and Newton 1983, Cole and Newton 1987, Newton and Preest 1988, Wagner et al. 1989). However, the cost–benefit relationship is not clear because spatial requirements for maximum seedling growth are not well understood. Trees systematically planted where there has been efficacious broadcast vegetation treatment should have greater potential for growth, and we may assume

R Rose is Associate Professor and Director of the Vegetation Management Research Cooperative—Phone (541) 737-6580; Fax: (541) 737-5814; E-mail: roser@fsl.orst.edu; J.S. Ketchum is Assistant Director of the Vegetation Management Research Cooperative, Department of Forest Science, Oregon State University, Corvallis, OR 97331—Phone: (541) 737-6086, Fax: (541) 737-5814; ketchumj@fsl.orst.edu; and D.E. Hanson is Research Assistant, Department of Forest Science, Oregon State University, Corvallis, OR 97331—(541) 737-6083, Fax: (541) 737-5814 hansone@fsl.orst.edu.
This is Paper 3224 of the Forest Research Laboratories, Oregon State University, Corvallis.

Manuscript received December 17, 1997. Accepted September 29, 1998.

that some vegetation-free area around a tree may provide maximum response. But the impact of herbaceous vegetation on conifer survival and growth and associated plant communities must be quantified for accurate assessment of the cost–benefit relationship. To that end, we systematically manipulated vegetation types (woody, herbaceous, both) to produce a range of vegetation-free zones around Douglas-fir seedlings such that the effects on their growth potential could be ascertained.

The objectives of this study were to determine seedling growth response to different areas of spot vegetation control and to determine the relative influence of early woody and herbaceous competition on seedling growth.

Materials and Methods

Study Sites

The experimental design was repeated on three western Oregon sites near the towns of Summit, Marcola, and Pedee. The study sites are separated by relatively large distances and have distinct differences in rainfall and soil characteristics. The Summit site is located on hummocky ground in the central region of the Oregon Coast Range 32 km west of Corvallis. Slopes range from 2% to 20%, and aspect differs dramatically, depending on plot location. The site is on the Apt soil series, which consists of deep, well-drained soils that formed in colluvium weathered from sedimentary rock. Site index is 41 m (base age = 50 yr). Rainfall averaged 1676.4 mm/yr over the 3 yr of the study. This hardwood conversion site was dominated by bigleaf maple (*Acer macrophyllum* Pursh), alder (*Alnus rubra* Bong.), and cherry (*Prunus emarginata* Dougl.) before harvest. After harvest in the summer of 1992, slash was raked off, and the ground was scarified with ripper blades. The site was also subsoiled with a winged blade that ripped the soil behind a D-6 Caterpillar tractor to a depth of approximately 60 cm, laterally fracturing it and reducing its bulk density. Douglas-fir 1+1 seedlings were planted in January 1993.

The Marcola site is located in the western Cascade Mountain foothills east of Springfield on a gentle south-southeast slope of less than 10%. Soils of the Nekia series, well-drained and moderately deep, are on foothills and higher rolling uplands. They were formed in colluvium and residuum weathered from basic rock. Site index for Marcola is 37 m (base age = 50 yr). Rainfall averaged 1674.4 mm/yr over the 3 yr of the study. The Marcola site was logged by processor and shovel in 1992 and was scarified and ripped in September that same year. Slash was piled and left on the site. Before harvest the stand consisted of 65 yr old Douglas-fir. The site was planted in February 1993 with Douglas-fir 1+1 seedlings.

The Pedee site, considered a Willamette Valley fringe site, is located in the transition zone between the flat lowland Willamette Valley and the hilly Oregon Coast Range. It is situated on a relatively steep slope that ranges from 15% to 75% over the study area. Soils are in the Peavine series, a moderately deep silty clay loam that is well drained and formed in fine-textured colluvium and residuum weathered from siltstone and shale. Site index for Pedee is 37 m (base age = 50 yr). Annual precipitation over the 3 yr of study averaged 1752.6 mm. After harvest in late spring 1992, the ground was scarified and slash was piled and burned. Before harvest, the stand consisted of a near monoculture of 50 to 60 yr old Douglas-fir with a small component of bigleaf maple. The site was planted with Douglas-fir 1+1 seedlings in February 1993.

Experimental Design

Each site was installed as a completely randomized design of treatments on 24 plots such that each treatment was replicated 3 times per site. The perimeters of the sites were fenced to prevent confounding of results from deer damage. Eight vegetation-control treatments were designed to provide vegetation-free zones of different types and sizes (Table 1).

Each treatment plot was a 21.3 × 21.3 m area (0.045 ha) in which 49 treatment seedlings were planted in a 3.048 × 3.048 m grid (9.29 m^2) surrounded by a similarly spaced buffer strip of 2 tree rows. The plots were laid out contiguously, where possible, before planting. Spot herbicide applications were centered on each tree, the "spots" in this case being square areas of vegetation control that differed in size.

Treatments

All treatments in year 1 consisted of hexazinone at 1.68 kg ha^{-1} (ai), and in year 2, hexazinone at 1.12 kg ha^{-1} (ai) and sulfometuron at 0.07 kg ha^{-1} (ai). The herbicides were applied from a backpack with a gas-powered boom sprayer. The nozzles on the boom were adjusted for the treatment sizes given in Table 1. Applications were made in early spring before budbreak in years 1 and 2. Treated areas were maintained throughout the first two growing seasons by periodic directed applications of glyphosate in a 1% aqueous solution

In addition, on all plots except those requiring herbaceous control only, woody vegetation was controlled over the entire area by a directed spray application. For control of woody vegetation, we used 3% triclopyr in diesel applied as a directed basal spray before budbreak in the spring of each year of the study. Care was taken to avoid spraying trees, but several were damaged by accidental drift on the Summit site in year 2 on plots receiving woody-vegetation control only Because of weather and operational constraints, the Pedee site was not treated in year 3.

Table 1. Specifications for vegetation-control treatments on plots planted with Douglas-fir 1+1 seedlings.

Treatment (area or type)	Treatment dimension (m)
Area of woody and herbaceous control	
No herbicide	0 × 0
0.375 m^2	0.61 × 0.61
1.49 m^2	1.22 × 1.22
3.35 m^2	1.83 × 1.83
5.95 m^2	2.43 × 2.43
9.63 m^2 (full vegetation control)	3.05 × 3.05
Selective control	
Woody vegetation only	3.05 × 3.05
Herbaceous vegetation only	3.05 × 3.05

Measurements

Douglas-fir variables measured immediately after planting (in year 0) and annually in years 1 through 3 after onset of dormancy were stem diameter (in millimeters at 15 cm aboveground) and total height. These measurements were made on all 49 treatment trees per plot. Conical stem volume for individual Douglas-fir seedlings was calculated as $D^2\pi H/12$ (cm^3) where D is diameter and H is seedling height in cm. The height–diameter ratio was calculated for third-year data as H/D, where H is seedling height in cm and D is diameter at 15 cm in cm. In year 3, we divided the number of dead trees on each plot by the number originally planted and then multiplied the quotient by 100 to determine the percentage of mortality.

Vegetation data excluding Douglas-fir were collected in July of each of the 3 yr at or near peak vegetation development. Four competition-measurement subplots (0.0036 ha, 6m × 6m) were located within each main plot. The first was randomly located between 9.6 m and 14.6 m of the edge of the plots in both X and Y directions, and the other three were located 10 m between centers. Each subplot was further divided into quadrants. In years 1 and 2, estimates of total cover of all species in the quadrants were assessed. In year 3, two of the four quadrants were chosen at random and cover of all species were assessed.

Mean vegetation cover for each plot in each year of the study was calculated by summing the cover for individual plant species within each subplot quadrant, then averaging quadrant values within the plot. This procedure allows for cover values that can be greater than 100% due to overlapping of foliage by different species. The means for 3 yr were added by plot in order to determine cumulative vegetation cover.

Statistical Analyses

The treatments were designed to address two issues: response to increasing area of vegetation control and response to controlling herbaceous versus woody vegetation. Regression analysis was used to evaluate the influence of area of vegetation control. A combination of analysis of variance and linear regression techniques were used to evaluate herbaceous versus woody control. The data from the three sites were analyzed independently on the assumption that site characteristics would influence seedling response. All regressions were performed with the REG procedure in the software package SAS and Analysis of Variance was performed with the GLM procedure in the same software.

Plot means of third-year stem diameter, seedling height, stem volume, percent mortality, and height–diameter ratio for Douglas-fir seedlings in each plot were regressed against the area of vegetation control using a linear model. Plot mean initial stem volume was used as an additional independent variable as were the higher order polynomial terms area^2 and area^3. All parameters that were significant at the $\alpha = 0.05$ level were included in the final model. Residuals were assessed to assure that the data fit the assumptions required for these analyses, and no transformations were required.

Data for the herbaceous only, woody only, complete vegetation control and no herbicide treatments were analyzed as a 2 × 2 factorial design using Analysis of Variance. Plot means of third-year stem diameter, seedling height, stem volume, percent mortality, and height–diameter ratio for Douglas-fir seedlings were analyzed as dependent variables with herbaceous and woody control as the main effects. In an effort to model the effect of herbaceous and woody competition on third-year stem volume, means for third-year stem volume were regressed against cumulative herbaceous cover and cumulative woody cover using a linear model of first order. Third-year cumulative cover was used because it represents an index of the competition faced by seedlings over the entire three year growing period.

Results

Area of Control

Stem diameter, height, and stem volume all increased with increasing area of vegetation control on all three sites. However, the shape of the regression curves for growth and area of vegetation control differed among the sites. At Summit, the seedling growth parameters increased linearly with control area accounting for 85% of the variability in seedling stem volume observed (Figure 1). At Marcola and Pedee the response was not linear and the area^2 term in the regression model resulted in a significantly better fit. At Marcola, seedling growth increased with area of control and peaked at roughly 6 m^2 of control. A similar response was measured at Pedee but here growth peaked near 4 m^2. Differences in control area accounted for 82% of the variability in seedling stem volume at Marcola and 56% at Pedee (Table 2).

Mortality was low at both Summit and Marcola and did not vary significantly with area of vegetation control. In contrast at Pedee, mortality was high across the entire site and declined as vegetation control area increased up to 4 m^2 after which it no longer declined. Overall, seedlings performed poorly at Pedee, and we suspect poor stock quality and/or improper planting may have been the cause.

Height-diameter ratio decreased with increased area of vegetation control at all sites. This decline was linear at Summit and Pedee while curvilinear at Marcola. Area of vegetation control accounted for more variability in height-diameter ratio at Summit and Marcola (44% and 46% respectively) than at Pedee (27%). The data suggested that a function other than linear or curvailinear may result in a better fit. Attempts to fit other relatively simple curves such as a negative exponential function to the data were no more successful than using the original linear and curvilinear functions.

Selective Control Treatments and Third-Year Seedling Size

At no site was there a significant interaction between the herbaceous and woody control treatments. Among the selective control treatments, herbaceous control only resulted in significantly larger third-year stem diameter, height and stem volume at Summit and Marcola (Table 3). At Pedee herbaceous control yielded significantly greater stem diameter but not height or stem volume. Woody control treatments did not affect seedling size at Summit or Marcola but did result in significantly larger stem diameter and volume but not height

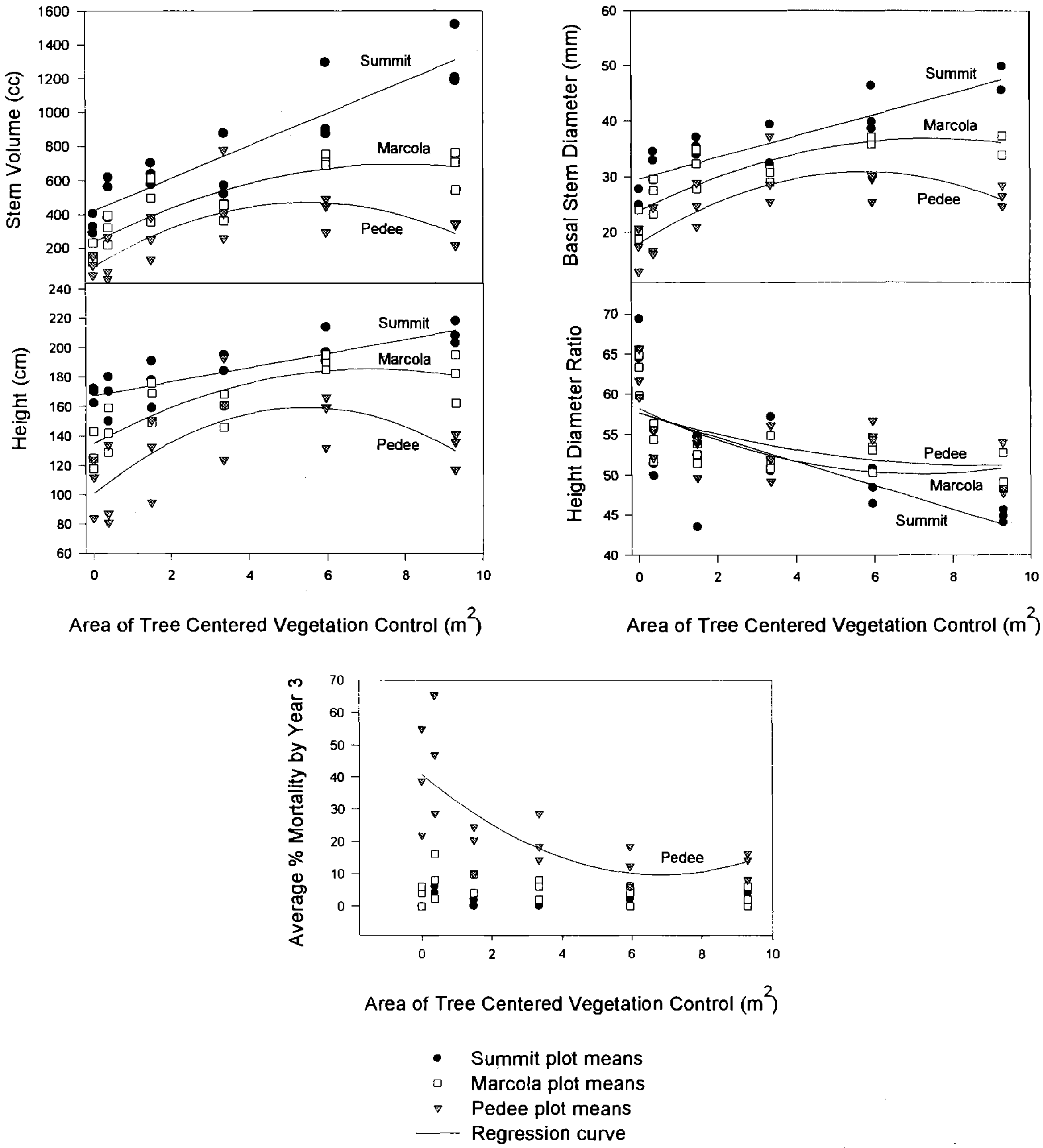

Figure 1. Summit, Marcola, and Pedee regression curves for stem volume, height, basal stem diameter, height-diameter ratio and mortality by area of vegetation control. Regression curves were not included for Summit and Marcola mortality because area of vegetation control did not account for a statistically significant portion of the measured variation.

at Pedee. Mortality was low and not significantly influenced by either the herbaceous or woody treatments at Summit or Marcola. At Pedee the herbaceous treatment significantly reduced mortality whereas the woody treatment had no significant impact. Across all the sites, the height-diameter ratio was lower if either the herbaceous or the woody treatment was administered.

Three-year cumulative herbaceous cover and cumulative woody cover significantly influenced variabilty in stem volume at Summit and Marcola (Table 4). Surprisingly, these two cover variables did not explain a significant amount of the variation measured in volume at Pedee, suggesting other unmeasured factors may have had greater influence. At Summit and Marcola variation in cumulative herbaceous cover alone accounted for 68% and 41% of the variability in stem volume, respectively. At neither site did cumulative woody cover significantly influence stem volume. However, when cumulative woody cover was added to the linear regression model including cumulative herbaceous cover, both parameters were found to be significant ($P \leq 0.05$), and the models explained a larger amount of the variability in stem volume at both sites. At both sites, the absolute value of the regression coefficients for cumulative herbaceous cover was greater than that of cumulative woody cover, suggesting that herbaceous cover had a more pronounced effect on stem volume than woody cover.

Table 2. Regression parameters and statistics for describing plot means of mortality, stem volume, diameter, height, and height-diameter ratio for Summit, Marcola, and Pedee.

Independent variable	Dependent variable				
	Mortality %	Stem vol	Stem diam at 15 cm	Height	Height–diam ratio
	Regression coefficients (B_i) and statistics				
Summit[1]					
Intercept	—	422.8	29.6	167.6	57.7
Area	—	95.1	1.92	4.8	−1.5
R^2	—	0.82	0.78	0.65	0.42
P-value	—	0.0001	0.0001	0.0001	0.0022
Marcola[1]					
Intercept	—	−132.4	16.6	89.4	56.9
Area	—	105.6	3.27	12.7	−0.83
$Area^2$	—	−5.9	−0.23	−0.8	—
Vol_{t-0}	—	73.48	—	9.24	—
R^2	—	0.79	0.71	0.71	0.36
P-value	—	0.0001	0.0001	0.0001	0.0052
Pedee					
Intercept	0.35	102.32	18.05	137.76	58.2
Area	−0.03	12.68	0.418	2.22	−0.90
$Area^2$	—	−0.109	−0.0034	−0.019	—
Vol_{t-0}	—	—	—	−5.24	—
R^2	0.37	0.5642	0.6372	0.6085	0.24
P-value	0.0045	0.0001	0.0001	0.0001	0.0221

1 Regression statistics are not shown if the regression equation did not significantly ($P \leq 0.05$) explain the variation in a measured parameter.

Table 3. Third year mean measurements of Douglas-fir seedlings planted on three sites by the type of vegetation controlled.[1]

Site/treatment	Stem vol (cc)	Diam at 15 cm (mm)	Height (cm)	Height–diam ratio	Mortality (%)
Summit site					
Woody control					
Yes	817	37	180	52.0	6.8
No	648	34	187	57.4 *	2.7
Herbaceous control					
Yes	1129	44	203	46.6	3.7
No	336*	26*	160*	62.8*	5.8
Marcola site					
Woody control					
Yes	424	29	154	54.7	3.2
No	420	28	157	57.9†	4.3
Herbaceous control					
Yes	671	36	183	51.6	3.7
No	173*	22*	129*	61.0*	3.4
Pedee site					
Woody control					
Yes	242	24	128	54.6	16.0
No	140†	19†	112	60.2†	27.2
Herbaceous control					
Yes	238	24	124	52.3	14.2
No	144	19†	116	62.4*	28.9†

1 Within a column and for each site and for each growth habit type (woody or herbaceous) values associated with a * or ** are significantly different at P-values of 0.05, and 0.001 respectively.

Table 4. Means for percentage of vegetation cover of common herbaceous and woody plants and means grouped by growth habit for the Summit, Marcola, and Pedee sites over the first 3 yr after planting Douglas-fir.[1]

Site and regression model	Regression coefficients B_0	B_i(herbaceous)	B_i(woody)	R^2	P-value
Summit[1]					
Herbaceous cover alone	1563	-6.83	—	0.68	0.0005
Woody cover alone	—	—	—	—	0.1241
Both included in the model	1770	-6.5	-4.5	0.83	0.0002
Marcola[1]					
Herbaceous cover alone	681	-3.75	-	0.41	0.0210
Woody cover alone	—	—	—	—	0.1024
Both included in the model	1052	-4.47	-2.67	0.88	.0001
Pedee[1]					
Herbaceous cover alone	—	—	—	—	0.5706
Woody cover alone	—	—	—	—	0.3344
Both included in the model	—	—	—	—	0.0897

[1] Means of growth habit and total cover of all vegetation can be greater than 100 because cover was estimated by individual species and plant foliage commonly overlaps.

Selective Control Treatments and Vegetation Cover

The herbaceous treatments substantially reduced herbaceous cover compared to the check and woody treatments at all three sites for the first 2 yr (Table 5). Herbaceous treatments were not applied in year three, and, subsequently, levels of herbaceous cover greatly increased in year 3. The woody control treatments had only a limited effect on woody cover for the first 2 yr. At Summit, woody cover was slow to establish, while at Marcola and Pedee the woody species present were only partially controlled by the herbicides used. In addition, a major component of the woody cover at Marcola consisted of bracken fern (*Pteridium aquilinum* [L] Kuhn). Bracken fern has a growth habit that does not fit easily into either the herbaceous or the woody category and is often difficult to control with the herbicides applied for both these treatments. The herbaceous treatments also reduced woody cover to a limited extent at Summit and Marcola, confounding differences measured in vegetation cover by treatment. At Pedee, early herbaceous control actually resulted in increased woody cover by decreasing competition providing for less competitive exclusion of primarily blackberry (*Rubus* spp). By year three, woody cover had increased markedly at all sites especially in the check and herbaceous control treatments.

After the treatments were applied, many of the same principle herbaceous species were prominent at all sites. The most prominent herbaceous species were bull thistle (*Cirsium vulgare* [Savi] Ten.), tall willow herb (*Epilobium paniculatum* Nutt.), woodland groundsel (*Senecio sylvaticus* L.), and several grass species. By year three, grass was the most predominant herbaceous vegetation type at Summit and Pedee. At Marcola, no one herbaceous species dominated the site. Blackberry and bracken fern were major woody competitors at all three sites. However, the principal woody competitor was different at each site: wild cherry (*Prunus emarginata* [Dougl.] Walp.) at Summit, salal (*Gaultheria shallon* Pursh) and bracken fern at Marcola and blackberry at Pedee.

Discussion

This study suggests that to achieve maximum Douglas-fir seedling growth with seedlings planted at a 3 m × 3 m spacing, a weed-free area of or near complete vegetation control is needed. Increases in vegetation control areas resulted in increases in growth up to near complete vegetation control at the Summit and Marcola sites. However, on the Pedee site, maximum growth occurred with only 5 to 6 m^2 of vegetation control. In addition, at the maximum levels of vegetation control, growth actually declined at Pedee. Apparently competition was not the driving factor on the Pedee site; possibly other limiting factors such as the steep southern exposure and prolonged drought limited the response of seedlings to increasing areas of vegetation control. The inherent variability of seedling growth across the Pedee site suggests confounding from other site or microsite factors as well.

Most studies that have investigated competition and early Douglas-fir growth have evaluated the effects of broadcast treatments (Preest 1977, Wagner and Radosevich 1991, White and Newton 1989). An exception was a study (Cole and Newton 1987) on the influence of inter- and intra-specific competition that incorporated a Nelder design: trees were grown with intra-specific competition that was carefully controlled by tree spacing. Seedlings grown at the closest spacings grew least, and as spacing increased to 1.22 m (1 49 m^2), seedling biomass increased linearly. Our findings agree with those of Cole and Newton (1987). Our results suggest that increases in the vegetation free area beyond 1.49 m^2 [the maximum area investigated by Cole and Newton (1987)] can result in continued increases in Douglas-fir growth. In addition, the impact of inter- and intra-specific competition on early seedling growth appears to be similar, although direct comparisons cannot be made because their third-year data were not reported.

The findings raise the question, "At what point does an increase in the area free of vegetation fail to elicit more seedling growth?" There is some evidence that an area greater than 9.3 m^2 may lead to further increases. Second-

Table 5. Regression parameters and statistics for describing plot means of stem volume for Summit, Marcola, and Pedee. Three models are represented: using only 3 yr cumulative herbaceous cover, using only 3 yr cumulative woody cover, and using 3 yr cumulative herbaceous and woody cover.

	No herbicide (%) 1993	Herbaceous vegetation only (%) 1993	Woody vegetation only (%) 1993	Full vegetation control (%) 1993	No herbicide (%) 1994	Herbaceous vegetation only (%) 1994	Woody vegetation only (%) 1994	Full vegetation control (%) 1994	No herbicide (%) 1995	Herbaceous vegetation only (%) 1995	Woody vegetation only (%) 1995	Full vegetation control (%) 1995
Summit												
Cirsium spp	3.2	0.5	3.0	1.1	13	0.1	9.1	—	0.7	0.4	6.7	0.8
Epilobium spp	—	—	0.1	—	0.1	—	—	0.1	—	27.6	0.3	32.1
Grass	7.9	0.1	0.1	0.1	28.0	0.6	0.6	1.0	64.6	14.9	81.7	19.8
Montia spp	18.8	0.2	6.5	5.2	—	—	0.1	0.1	—	—	—	—
Phacelia heterophylla	1.3	0.1	0.7	1.0	6.4	—	—	—	—	—	—	—
Senecio sylvaticus	7.6	—	9.8	2.2	0.5	—	2.6	—	—	7.4	0.8	20.4
Stachys rigida	4.3	0.2	3.9	3.5	5.8	0.8	4.8	0.7	1.5	0.5	0.3	0.3
Corylus cornuta	1.1	0.1	—	0.1	0.7	0.1	0.1	—	—	1.0	0.2	—
Prunus emarginata	5.0	1.4	—	—	4.9	2.8	2.8	0.5	38.8	19.8	13.5	0.1
Pteridium aquilinum	0.6	0.9	0.8	0.3	1.1	1.8	3.0	—	2.8	2.8	7.9	—
Rubus spp	0.2	0.9	0.1	0.5	5.1	5.9	2.0	0.6	26.5	27.9	4.9	1.3
Herbaceous cover	46.3	3.7	35.4	3.8	55.4	4.6	58.0	2.5	77.9	53.4	101.3	75.3
Woody cover	7.5	4.6	1.9	2.0	13.4	14.8	9.4	1.1	71.3	62.9	30.0	2.3
Total cover	53.8	8.4	37.3	5.8	68.8	19.4	67.4	3.6	149.2	116.3	131.3	77.6
Marcola												
Cirsium spp	0.9	0.1	1.8	0.1	1.6	—	1.6	—	1.0	0.5	5.6	0.5
Epilobium spp	0.7	—	0.8	0.1	5.8	0.2	1.9	—	1.3	6.4	2.6	13.8
Grass	0.4	—	1.1	—	8.5	0.1	5.6	—	5.9	2.7	15.4	1.3
Hypochoeris radicata	0.3	—	2.6	0.2	2.5	—	17.2	0.8	3.8	0.8	27.1	9.0
Iris tenax	—	—	—	—	0.9	2.2	0.7	1.4	1.5	3.4	1.5	6.2
Senecio sylvaticus	21.6	0.1	20.4	0.1	—	0.7	0.3	0.2	0.2	1.3	0.1	3.0
Corylus cornuta	2.5	2.5	0.6	1.7	3.9	2.2	0.1	0.4	8.3	8.3	0.5	0.6
Gaultheria shallon	10.9	11.9	3.6	3.9	13.4	21.4	1.1	2.2	10.8	32.3	4.5	9.4
Pteridium aquilinum	22.8	5.6	10.1	12	38.9	1.5	25.6	7.5	33.5	7.4	33.3	22.9
Rubus spp	1.9	1.1	0.2	1.4	4.7	0.8	0.6	0.2	13.8	2.4	2.1	1.7
Symphoricarpus albus	2.0	0.6	1.6	0.5	5.0	1.0	1.0	0.8	10.0	2.9	4.5	2.2
Herbaceous cover	29.9	3.5	36.3	1.5	20.6	5.9	30.5	4.5	20.7	20.6	56.2	35.3
Woody cover	41.7	22.7	18	20.6	68.2	34.4	28.5	12.8	119.2	61.6	45.4	37.7
Total cover	71.5	26.2	54.3	22.1	88.9	40.5	59.1	17.3	93.2	82.2	101.6	73.0
Pedee												
Cirsium spp	7.5	0.7	6.5	0.4	4.9	—	4.8	—	5.3	0.4	6.5	1.6
Chrysanthemum leucanthemum	—	—	—	—	10.4	—	2.5	—	5.5	—	4.5	0.2
Epilobium spp	0.3	0.1	0.1	—	0.2	—	—	—	0.2	24.4	—	23.0
Grass	5.7	0.4	3.9	0.1	24	0.7	56.7	0.1	35.3	9.0	83.3	4.4
Senecio sylvaticus	6.6	—	13.5	0.1	0.6	—	3.6	—	—	—	—	2.0
Corylus cornuta	0.2	0.4	0.2	0.5	0.3	0.8	0.1	0.2	0.8	3.2	0.2	0.7
Pteridium aquilinum	1.4	2.9	2.5	4.9	1.3	0.9	2.2	0.6	3.3	1.3	3.8	0.8
Rubus spp	10.2	17.3	8.2	11.5	13.2	39.7	7.2	11.8	37.2	75.3	22.7	68.3
Symphoricarpus albus	1.7	1.9	0.2	2.0	4.1	0.4	0.4	0.1	12.7	2.6	0.5	0.6
Herbaceous cover	30.6	4.2	41.2	2.9	52.5	3.0	73.3	0.7	44.4	42.6	96.6	32.5
Woody cover	17.8	23.5	11.6	20	24.1	44.5	13.3	13.7	100.3	83.2	31.6	74.1
Total cover	48.4	27.7	52.8	22.9	76.6	47.5	86.6	14.4	144.7	125.8	128.2	106.6

[1] Regression statistics are not shown if the regression equation did not significantly ($P \leq 0.05$) explain the variation in a measured parameter.

year results for Douglas-fir seedlings grown on two sites in southern Oregon with 4.6 m^2, 18.7 m^2, and 42 m^2 of vegetation control showed significantly greater stem diameter than trees growing with none (Jaramillo 1988). On one of the sites, 18 7 m^2 and 42 m^2 treatment plots had greater stem volume than the 4.6 m^2 treatment plots, but the larger treatments did not differ, which suggests that the maximum control area for response falls somewhere between 4.6 m^2 and 18.7 m^2. Growth response in our study fell within this range. However, we suspect that growth gains with vegetation control areas much greater than 9.3 m^2 will be small at best and likely site dependent. That is, only on the best sites will continued increases be seen with areas of control greater than 9.3 m^2. This should be especially true with young trees that can exploit only a limited area of soil, particularly in the Douglas-fir region in the Pacific Northwest, which receives limited and sporadic summer rainfall. In this region, most operational planting is at 3.7 m spacing or less, and applications of herbicide on excess of 9.3 m^2 are virtually broadcast treatments that negate many advantages of spot applications.

From our findings and those of other similar studies, it appears that, for a wide range of conifer species across a wide range of environments, growth response reaches a maximum with nearly complete vegetation control (Balneaves 1987, Dougherty and Lowery 1991, Oester et al. 1995, and Richardson et al. 1995). In New Zealand, second-year stem diameter and height of radiata pine (*Pinus radiata* D. Don) increased incrementally with control area up to the point of complete vegetation control (Balneaves 1987). Richardson et al. (1995) found that on the better of two New Zealand sites, first-year root-collar diameter of radiata pine increased with increased spot-control up to 3 m (the largest diameter tested). However, on a poorer site, root-collar diameter did not respond past 1 m control diameter. Third-year results of a similar study (Dougherty and Lowery 1991) evaluating vegetation-control treatments of 0 m^2, 0.28 m^2, 1.21 m^2, 2.6 m^2, and 4.65 m^2 on Georgia and Oklahoma sites showed that site quality mitigated the response of loblolly pine. Seedlings grew best on the best site, and maximum response occurred with the largest treatment area (4.65 m^2) on both sites. Oester et al. (1995) found no differences in stem volume of fifth-year ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) with spot treatments of 0.4 m^2 and 2.3 m^2; however, volumes were greater than on the untreated plots and smaller than on plots with broadcast, complete vegetation control. In all of these studies, maximum growth occurred with the greatest area of control. Generally, seedling growth of a wide range of conifers increases with increased area of control across a wide range of environments.

Woody-Only Versus Herbaceous-Only Control

Our findings support the growing body of evidence that early competition with herbaceous vegetation can be far more limiting to Douglas-fir survival and growth than early competition with woody vegetation, especially on sites prone to quick herb establishment. In the past, forest regeneration managers in the Pacific Northwest have largely ignored the influence of herbaceous vegetation. Woody vegetation has long been thought of as the principle competitor because it limits light and reduces soil-water and nutrient availability (Howard and Newton 1984, Chan and Walstad 1987, Peterson et al. 1988, Harrington and Tappeiner 1991, Wagner and Radosevich 1991). Land managers have thus concentrated their efforts on controlling woody vegetation through site preparation, and, if needed, subsequent release treatments. Herbaceous competition has often been thought to be of minor concern because it seldom overtops young conifers and is relatively shallow rooted. Our results suggest this common notion to be in error and support the conclusion of other authors (Cole and Newton 1987, Newton and Preest 1988) that herbaceous vegetation increases water stress and decreases growth of Douglas-fir over the first 3 yr after planting.

On hotter, drier sites in southern Oregon, herbaceous vegetation has been shown to depress conifer volume more than high densities of manzanita (*Arctostaphylos patula* Greene) in the first 5 yr after stand establishment (White and Newton 1989). Our results support these findings. In the southeastern United States, early herbaceous control of loblolly, slash (*Pinus eliottii* Engelm.), and longleaf (*Pinus palustris* Mill.) pine has also resulted in increased survival and growth (Creighton et al. 1987, Glover et al. 1989) Studies evaluating herbaceous-only and woody-only control in the southeastern United States suggest that early herbaceous control yields greater conifer growth than early woody control (Cain 1991, Miller et al. 1991).

In the Pacific Northwest, growth gains achievable with early herbaceous control may eliminate the need for brush release treatments later on some sites. In coastal forests of this region, herbaceous vegetation dominates most regenerating clearcuts for the first 2 to 3 yr after harvest (Dyrness 1973, Schoonmaker and McKee 1988). It is typically not until late in year 2 or 3 that woody competition begins to limit seedling growth. The intensive site preparation treatments used at all three sites may have delayed the eventual establishment of woody competitors even longer, resulting in less competitive effect than would have occurred in the absence of site preparation. Two years of herbaceous vegetation control on top of the site preparation treatments at the Summit and Marcola sites resulted in mean third-year heights of 203 cm and 183 cm, respectively. Those seedlings are in no danger of being overtopped by woody vegetation and are beginning to dominate the site. In contrast at Pedee, herbaceous control did not promote growth as effectively, partially because exclusion of herbaceous species resulted in increased blackberry cover, which competed effectively with the planted Douglas-fir. Thus, the herbaceous treatment simply shifted competition from herbaceous to woody competitors. However, herbaceous and woody cover on this site did not significantly explain the variation observed in seedling growth which suggest other site and microsite related factors are dictating growth on this site more so than vegetation control.

The relative influence of herbaceous and woody competitors differed by site and the influence of each of these competitor types was mitigated by the effectiveness of the treatments on the plant communities at each site. Many herbicides used to control herbaceous vegetation, such as hexazinone, sulfometuron, metsulfuron, and atrazine, have some level of control on woody species either by affecting mature plants or preventing establishment of germinants Early herbaceous treatments can delay establishment of woody competitors depending on the herbicide used and makeup of the soil seed bank, which in turn increases the potential for planted Douglas-fir to dominate the site, especially where sites have been prepared by removing residual shrub rootstocks. This apparently occurred at the Marcola site with the herbaceous treatment limiting the expansion of bracken fern cover. At Summit, woody cover was slow to dominate the site and was not strongly influenced by either the herbaceous or woody treatments until year three. Thus, at Summit, growth was more influenced by the herbaceous cover on the site than woody and at Marcola both the herbaceous and woody components influence growth. This is shown nicely when cumulative cover is regressed against stem volume at both sites. In both cases the model explained over 80% of the variability in stem volume measured but at Summit, herbaceous cover accounted for the majority of this variability (68%), and at Marcola both cumulative herbaceous and woody cover accounted for more equal proportions of the total variability (41% and 47% respectively).

Height–Diameter Ratio

Lower height–diameter ratios accompanied increases in area of control as seedlings had more available resources to allocate to diameter growth, a common response to crowding or overtopping (Cole and Newton 1987, Hughes and Tappeiner 1990). The greater the level of crowding or competitive stress, the greater the ratio. Cole and Newton (1987) found that ratios above 100 were associated with poor height growth, ratios above 70 were associated with decreased height growth, and ratios below 70 were associated with maximum height growth.

In this study, only trees in untreated plots had ratios approaching 70; ratios for trees in the all other plots were below 55. In general, we found that as the control area increased, the height–diameter ratio decreased, which supports the findings of Cole and Newton (1987) and Hughes and Tappeiner (1990). However, our findings suggest those trees with height–diameter ratios in the low to mid 60s are not achieving maximum potential. Trees with ratios in that range had reduced diameter, height, and subsequent stem-volume growth as a result of competition. Trees with ratios in the mid 50s faced less severe competition and performed well by those measures. Trees with ratios in the high 40s and low 50s are nearing maximum potential on a site. More research is needed at varying competition levels to learn how tree age and overall size influence the ratio.

Management Implications

Spot spraying offers several advantages. It is helpful where aerial spray applications are unsuitable because of terrain, residual overstory, and neighbors. It applies less active ingredient over the landscape and in some cases lowers costs. It can be applied to vegetation adjacent to crop trees but, where there are rare plant species or where species diversity is an issue, can leave the remainder of the vegetation untouched. For example, on a site with 1,000 trees ha^{-1}, a 1 m^2 treatment around each tree will use 90% less active ingredient than an aerial broadcast treatment and will affect only 10% of the ground area.

However, ground-based applications may cost more than aerial applications, depending on the terrain. If a ground-based system is chosen because aerial application is not feasible, a broadcast treatment may be preferable to spot application for maximizing growth, for the following reasons: First, maximum seedling growth will not be achieved with spot applications. Managers should be aware that by opting for a spot treatment they trade some growth for other objectives. Second, the duration of weed-free conditions may vary with area. In this study, areas were kept clear of encroaching vegetation by additional, directed applications of glyphosate. Operationally, this is not feasible, and vegetation can be expected to reinvade, the rate of invasion varying with the residual soil activity of the herbicide and with area. Small spots with greater edge-to-area ratios have a greater potential to be reinvaded than large spots. Site quality may also influence treatment longevity. High-quality sites with greater soil moisture and fertility increase plant vigor and resistance to herbicide damage, and promote more vigorous weed growth. Soil-active herbicides are less persistent on the moist soils with high organic matter that are associated with high site quality. Finally, the technology to apply large spots is not yet perfected. Applications with a full-cone nozzle driven by a Meterjet dispenser or by a flat-fan nozzle work well for spots of 1 m radius and less, but larger spots require a different apparatus. The large spots in our study were applied by a boom sprayer with several nozzles, which was adequate for experimental purposes but large, heavy, and cumbersome for operational purposes.

Conclusions

Douglas-fir seedling growth in this study increased with increased area of spot treatment up to near the point of full vegetation control. The influence of area of vegetation control on conifer seedling growth was similar across a range of environmental conditions. However, as shown by the lack of significant growth response to areas of control greater than 3 m^2 on one site, factors such as slope, aspect, stock quality, fertility, and soil compaction can affect seedling growth more so than excellent weed control.

Early control of herbaceous vegetation has a greater potential to shorten Douglas-fir rotation age than early control of woody vegetation. By vigorously controlling such vegetation before or soon after planting, managers can exploit an opportunity to induce large growth gains that may, in the future, compound into large differences in stem volume and, therefore, allow shorter rotation ages.

Literature Cited

BALNEAVES, J.M. 1987. Growth response of radiata pine to area of herbaceous weed control. Proc. N.Z. Weed Pest Control Conf. 40:49–51.

CAIN, M.D. 1991. The influence of woody and herbaceous competition on early growth of naturally regenerated loblolly and shortleaf pines. South. J. Appl. For. 15:179–185.

CHAN, S.S., AND J.D. WALSTAD. 1987. Correlations between overtopping vegetation and development of Douglas-fir saplings in the Oregon Coast Range. West. J. Appl. For. 2:117–119.

COLE, E.C., AND M. NEWTON. 1987. Fifth-year responses of Douglas-fir to crowding and nonconiferous competition. Can. J. For. Res. 17:1371–1378.

CREIGHTON, J.L., B.R. ZUTTER, G.R. GLOVER, AND D.H. GJERSTAD. 1987. Planted pine growth and survival responses to herbaceous vegetation control, treatment duration, and herbicide application technique. South. J. Appl. For. 11:223–227.

DOUGHERTY, P.M., AND R.F. LOWERY. 1991. Spot-size of herbaceous control impacts loblolly pine seedling survival and growth. South. J. Appl. For. 15:193–199.

DYRNESS, C.T. 1973. Early stages of plant succession following logging and burning in the western Cascades of Oregon. Ecology 54:57–69.

GLOVER, R.G., J.L. CREIGHTON, AND D.H. GJERSTAD. 1989. Herbaceous weed control increases loblolly pine growth. J. For. 87(2):47–50.

HARRINGTON, T.B., AND J.C. TAPPEINER II. 1991. Competition affects shoot morphology, growth duration, and relative growth rates of Douglas-fir saplings. Can. J. For. Res. 21:474–481.

HOWARD, K.M., AND M. NEWTON. 1984. Overtopping by successional Coast-Range vegetation slows Douglas-fir seedlings. J. For. 82:178–180.

HUGHES, T.F., AND J.C. TAPPEINER II. 1990. Relationship of Pacific madrone sprout growth to productivity of Douglas-fir seedlings and understory vegetation. West. J. Appl. For. 5:20–24.

ISAAC, L.A. 1940. Vegetation succession following logging in the Douglas-fir region with special reference to fire. J. For. 38:716–721.

JARAMILLO, A.E. 1988. Growth of Douglas-fir in southwestern Oregon after removal of competing vegetation. USDA For. Serv. Res. Note PNW-RN-470. 10 p.

MALAVASI, U.C. 1978. Early plant biomass trends following forest site preparation on the Oregon Coast Range. M.S. thesis, Oregon State Univ., Corvallis, OR. 77 p.

MILLER, J.H., ET AL. 1991. A regional study on the influence of woody and herbaceous competition on early loblolly pine growth. South. J. Appl. For. 15:169–179.

NEWTON, M., AND D.S. PREEST. 1988. Growth and water relations of Douglas-fir *(Pseudotsuga menziesii)* seedlings under different weed control regimes. Weed Sci. 36:653–662.

OESTER, P.T., W. EMMINGHAM, P. LARSON, AND S. CLEMENTS. 1995. Performance of ponderosa pine seedlings under four herbicide regimes in northeast Oregon. New For. 10:123–131.

PETERSEN, T.D., AND M. NEWTON. 1983. Growth of Douglas-fir following release from snowbrush and forbs in the Oregon Cascades. Proc. West Soc. Weed Sci. 36:58–59.

PETERSEN, T.D., M. NEWTON., AND S.M. ZEDAKER. 1988. Influence of *Ceanothus velutinus* and associated forbs on the water stress and stemwood production of Douglas-fir. For. Sci. 34:333–343.

PREEST, D.S. 1977. Long-term growth responses of Douglas-fir to weed control. N.Z. J. For. Sci. 7:329–332.

RICHARDSON, B., ET AL. 1995. The ultimate spot: Optimising spot weed control N.Z. J. For. Sci. 26(1/2):265-275.

SCHOONMAKER, P., AND A. MCKEE. 1988. Species composition and diversity during secondary succession of coniferous forests in the western Cascade Mountains of Oregon. For. Sci. 34:968–979.

STEWART, R.E., L.L. GROSS, AND B.H. HONKALA. 1984. Effects of competing vegetation on forest trees: A bibliography with abstracts. USDA For Serv. Gen. Tech. Rep. WO-43. 414 p.

WAGNER, R.G., T.D. PETERSEN, D.W. ROSS, AND S.R. RADOSEVICH. 1989 Competition thresholds for the survival and growth of ponderosa pine seedlings associated with woody and herbaceous vegetation. New For 3:151-170.

WAGNER, R.G., AND S.R. RADOSEVICH. 1991. Interspecific competition and other factors influencing the performance of Douglas-fir saplings in the Oregon Coast Range. Can. J. For. Res. 21:829–835.

WHITE, D.E., AND M. NEWTON. 1989. Competition interactions of whiteleaf manzanita, herbs, Douglas-fir, and ponderosa pine in southwest Oregon Can. J. For. Res. 19:232–238.