Twelfth-year response of Douglas-fir to area of weed control and herbaceous versus woody weed control treatments[1]

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Abstract: Coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) response to eight weed control treatments was measured 12 years after planting at two Oregon sites. Treatments included four areas of weed control around individual trees (0.375, 1.49, 3.35, and 5.95 m^2), no weed control (check), total vegetation control, control of herbaceous competition only, or control of woody competition only. Douglas-fir growth and woody-species invasion differed between the Coast Range site (Summit) and the Cascade Range foothills site (Marcola). Woody species reinvasion was more intense at Summit, with Douglas-fir cumulative mortality in the check treatment reaching 23% in year 12. Woody-only control improved Douglas-fir growth at Summit but had no significant effect on growth at Marcola. Total vegetation control had a profound effect on stem volume growth 12 years after planting. At Summit, total vegetation control resulted in a 355% increase in volume per hectare relative to the check. At Marcola the increase was only 63%. At Summit, growth increased with each increase in area of weed control, whereas at Marcola growth increased with increasing area of weed control up to 3.35 m^2 of control. Results suggest that much of the gain in volume growth attributable to weed control may be lost if weed-control treatments are not highly efficacious. The differential response to woody control indicates that its benefit at a given site is strongly related to the abundance of competitive hardwood species, which may be predicted from the preharvest stand structure and vegetation community.

Résumé : La réaction du douglas vert (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) typique à huit traitements de maîtrise de la végétation compétitrice a été mesurée 12 ans après la plantation dans deux stations de l'Oregon. Les traitements incluaient la maîtrise de la végétation compétitrice sur des superficies de quatre dimensions différentes autour d'arbres individuels (0,375, 1,49, 3,35 et 5,95 m^2), un témoin (pas de traitement de maîtrise de la végétation), la maîtrise de toute la végétation, la maîtrise de la végétation herbacée seulement et la maîtrise de la végétation ligneuse seulement. La croissance du douglas vert et l'invasion par les espèces ligneuses différaient entre la station de la chaîne côtière (Summit) et la station située dans les contreforts de la chaîne des Cascades (Marcola). L'invasion par les espèces ligneuses a été plus intense à Summit où la mortalité cumulative du douglas vert atteignait 23 %, 12 ans après la plantation. La maîtrise de la végétation ligneuse seulement a augmenté la croissance du douglas vert à Summit mais n'a eu aucun effet significatif sur la croissance à Marcola. La maîtrise de toute la végétation a eu un effet prononcé sur la croissance en volume des tiges 12 ans après la plantation. À Summit, ce traitement a produit une augmentation de 355 % du volume à l'hectare par rapport au témoin. À Marcola, l'augmentation n'a été que de 63 %. À Summit, la croissance a augmenté avec chaque augmentation de la superficie traitée alors qu'à Marcola, la croissance a augmenté avec l'augmentation de la superficie traitée jusqu'à 3,35 m^2. Les résultats suggèrent qu'une grande partie du gain de croissance en volume attribuable à la maîtrise de la végétation peut être perdue si les traitements ne sont pas hautement efficaces. La différence de réaction selon la station indique que les bénéfices de la maîtrise de la végétation compétitrice sur une station donnée sont fortement liés à l'abondance d'espèces feuillues compétitrices qui peut être prédite à partir de la structure et de la composition du peuplement présent avant la coupe.

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Introduction

The growth form of competing vegetation greatly influences crop seedling survival and growth in forest plantations (Miller et al. 2003). Within the range of coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), herbaceous vegetation typically dominates clearcuts immediately after harvest, giving way to domination by woody species within 5 years or so (Dyrness 1973; Schoonmaker and McKee 1988; Harrington et al. 1995; Stein 1995). The short-lived dominance of herbaceous vegetation belies its importance in influencing growth and yield in a stand. Numerous

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studies have demonstrated the importance of herbaceous vegetation as a competitor of Douglas-fir (Petersen and Newton 1983; Cole and Newton 1987; Hanson 1997; Monleon et al. 1999; Newton and Preest 1988; Rose and Ketchum 2002). Harrington et al. (1995) found that Douglas-fir basal-area response to several weed control treatments was significantly limited by herbaceous cover in years 2 and 3, shrub cover in years 3–5, and tree cover in years 3–10. To fully capture the changing dynamics in vegetation communities resulting from early treatments, studies attempting to compare the competitive effects of woody and herbaceous vegetation must be monitored long term.

Regardless of its growth form, a competitor's distance from the planted seedling influences its competitive effect (Burton 1993). Competitive effects are frequently modified in competition models using fixed-radius zones of influence that range from 1 m^2 to 20 m^2, but zone size varies depending on the model and species (Brand 1986; Daniels et al. 1986; DeLong 1991; Wagner and Radosevich 1991; Burton 1993; Richardson et al. 1996; Wagner and Radosevich 1998). Tree-centered spot herbicide treatments of varying areas can also be used to assess the zone of influence of competition. Using this approach at two southwestern Oregon sites, Jaramillo (1988) found that Douglas-fir diameter growth over the first 3 years after planting increased with increases in area of control up to 4.5 m^2 and 18.1 m^2. Similarly, Dougherty and Lowery (1991) found that diameter growth of loblolly pine (*Pinus taeda* L.) increased with increasing area of control up to 18.1 m^2 (complete broadcast control) at two southern United States sites. Richardson et al. (1996) also found that, on the more productive of two Monterey pine (*Pinus radiata* D. Don) sites, diameter growth increased with increasing spot size up to complete broadcast control (>1.5 m radius), but the optimal area of spot weed control varied depending on the productivity of the site. Mason and Kirongo (1999) also found that for Monterey pine planted on a semiarid site in New Zealand, second-year height and ground-line diameter increased with increasing spot size up to 9 m^2 (total control).

This paper presents growth results from a 12-year-old study evaluating six areas of tree-centered weed control as well as total herbaceous control for 2 years and total woody control for 3 years. The objectives of this study were (*i*) to compare Douglas-fir survival and growth across a range of weed control intensities, (*ii*) determine the area of tree-centered weed control required to maximize growth, and (*iii*) compare the relative influence of herbaceous-only and woody-only vegetation control on growth of young Douglas-fir. Third-year (Rose et al. 1999) and eighth-year (Rose and Rosner 2005) results have been presented previously. Based on regional trends in vegetation dynamics, we would expect some major changes in response to treatments to have occurred between years 8 and 12, now that competition from woody species has had enough time to become well established.

Materials and methods

Study sites

The study has been followed at two sites in western Oregon near the towns of Summit and Marcola. The Summit site is located in the central region of the Oregon Coast Range 32 km west of Corvallis (44°38′40″N, 123°33′30″W) at an approximate elevation of 234 m. Situated on hummocky ground, the site has slopes ranging from 2% to 20% with aspects varying, depending on plot location. The soil is deep and well-drained in the Apt series (Typic Haplohumults, Clayey, Mixed, Mesic), having formed in colluvium weathered from sedimentary rock. Site index is 41 m at a base age of 50 years (King 1966). Rainfall averages 1726 mm per year. This site was dominated by bigleaf maple (*Acer macrophyllum* Pursh), red alder (*Alnus rubra* Bong.), and bitter cherry (*Prunus emarginata* Dougl.) prior to harvest. After harvest in the summer of 1992, slash was removed, the ground was ripped, and the site was subsoiled with a winged blade to a depth of approximately 60 cm. Douglas-fir 1 + 1 bareroot seedlings were planted in January 1993.

Table 1. Specifications for vegetation control treatments.

Treatment (area or type)	Treatment dimension (m)
Area of control	
No herbicide (check)	0.0 × 0.0
0.38 m^2	0.6 × 0.6
1.49 m^2	1.2 × 1.2
3.35 m^2	1.8 × 1.8
5.95 m^2	2.4 × 2.4
9.63 m^2 (total vegetation control)	3.1 × 3.1
Selective control	
Woody vegetation only	3.1 × 3.1
Herbaceous vegetation only	3.1 × 3.1

The Marcola site, located in the western Cascade Mountain foothills east of Springfield (44°11′41″N, 122°46′15″W), is on a south-southeast slope (less than 10%) with elevations ranging from 244 m to 274 m. Soils are of the Nekia series (Xeric Haplohumults, Clayey, Mixed, Mesic) formed in colluvium and residuum weathered from basic rock and are well drained and moderately deep. Site index at Marcola is 37 m at a base age of 50 years (King 1966). Rainfall averages 1329 mm/year. The prior stand, which consisted of 65-year-old Douglas-fir, was logged in 1992. The site was then scarified and ripped in September of that same year and planted in February 1993 with Douglas-fir 1 + 1 seedlings. The perimeters of both sites were fenced to prevent deer browse.

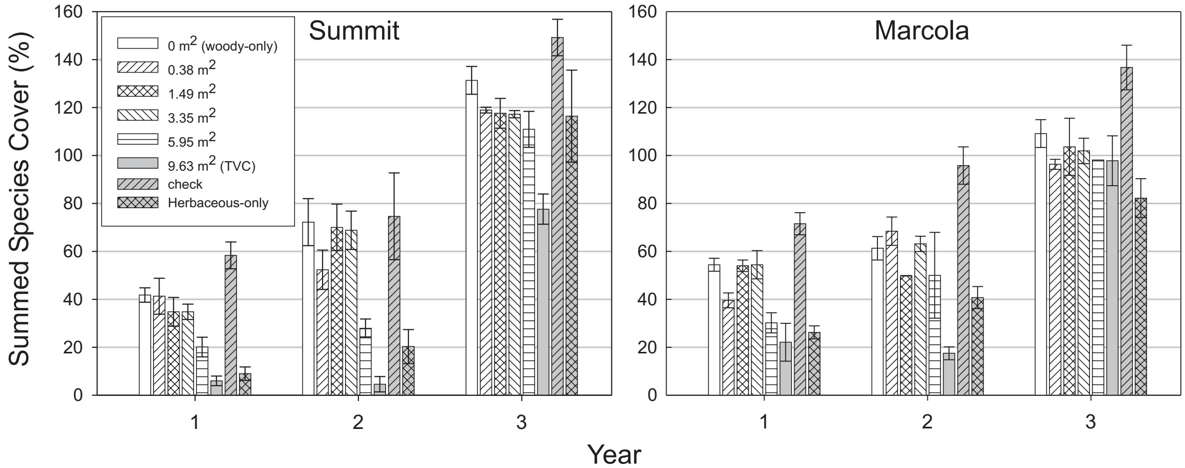
Experimental design

At both sites, a completely randomized design with eight treatments was replicated three times per site for a total of 24 plots per site. Each treatment plot measured 21.3 m × 21.3 m (0.045 ha) in which 49 seedlings were planted in a 3.05 m × 3.05 m grid surrounded by a similarly spaced buffer strip of two tree rows. The plots were laid out contiguously, where possible, before planting.

Treatments

Eight vegetation-control treatments consisted of four spot herbicide applications of different areas, an untreated check, a total vegetation control treatment (TVC) equivalent to 9.63 m^2 of control, and treatments in which either only the herbaceous plant component or only the woody plant com-

Fig. 1. Total midsummer vegetation cover (as sum of individual species cover) through the first 3 years of the study at both sites. Error bars are SEs.



ponent were controlled (Table 1). Spot herbicide applications, centered on each tree, consisted of square control areas of 0.375 m^2, 1.49 m^2, 3.35 m^2 and 5.95 m^2. For spot treatments, herbaceous weeds were controlled within the spots, and all woody competition was controlled in the entire plot, which allowed only herbaceous competitors outside the treated areas. Woody vegetation was controlled on these plots to prevent its invasion into spot treatments. This invasion was expected to be intense because of the fencing of plots to prevent deer browse.

Herbaceous treatments were applied within spot treatment areas and broadcast across entire plots in both TVC and herbaceous-only treatments; they were designed to control all herbaceous species present, requiring the use of several herbicides. Hexazinone was applied at a rate of 1.68 kg/ha (ai) in year 1, and both hexazinone (1.12 kg/ha) (ai) and sulfometuron (0.07 kg/ha) (ai) were applied in year 2. The herbicides were applied from a backpack with a gas-powered boom sprayer with nozzles adjusted for the treatment sizes given in Table 1. Applications were made before budbreak in early spring in years 1 and 2 only. Treated areas were maintained throughout the first two growing seasons by directed applications of glyphosate in a 1% aqueous solution. On all plots except the check and herbaceous-only control, woody vegetation was controlled over the entire plot by a directed basal application of 3% triclopyr in diesel applied prior to budbreak in spring. Woody control treatments were applied for the first 3 years after planting. Cover of all herbaceous and woody species through the third year of the study was reported in Rose et al. (1999). Total vegetation cover as the sum of all individual species' cover through the third year of the study is summarized in Fig. 1.

Measurements

Douglas-fir height and DBH were measured after 1, 2, 3, 5, and 8 years and were remeasured in October 2004, following the twelfth growing season since planting. Stem volume for individual trees was calculated using volume equations derived for second-growth Douglas-fir (Bruce and DeMars 1974). These equations use both DBH and height. Twelfth-year volume per hectare means were calculated on a per-plot basis by dividing the sum of all individual-tree stem volumes by the plot area.

Woody species competition was surveyed in October 2004 within six circular 10.5 m^2 subplots per plot. Woody species with height growth potential greater than 2 m were included in the survey, as the focus of this survey was on species that were likely to be continuing to assert a highly significant competitive effect on crop trees. Stems whose DBH fell within the perimeter of the subplot were counted, and DBH was measured. Total woody basal area and basal area by woody species were calculated on a per-hectare basis.

Analysis

Sites were analyzed separately. Twelfth-year DBH, height, height/diameter ratio, and individual-tree volume data were analyzed by analysis of covariance (ANCOVA) using the GLM procedure of SAS version 8.2 software (SAS Institute Inc. 2002). Initial basal diameter, which was measured shortly after planting, was used as the covariate. For each parameter, we tested for a common slope among the regression equations generated for each treatment response across the various levels of the covariate. There were no treatment × covariate interactions, so we used a common-slope model to test treatment effects and estimate treatment means. Assumptions of homogeneity of variances and normality were tested for each independent analysis. DBH and height data were normally distributed with equal variances, but variances for volume were highly heterogeneous, with greater variance occurring with greater expected values. A cube-root transformation proved to best correct heterogeneity of variances while maintaining normality.

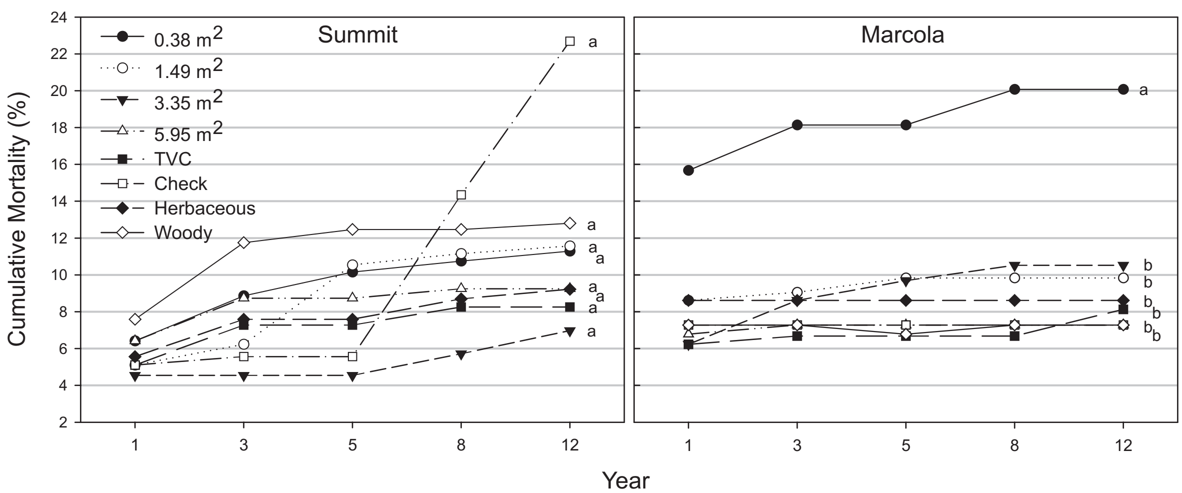
Mortality and volume on a per-hectare basis (as well as woody basal area summed across all species) were analyzed using analysis of variance (ANOVA), also with the GLM procedure of SAS version 8.2 software (SAS Institute Inc. 2002). These parameters involve plot-level responses; at the plot level, there were no significant covariate effects and, for volume and basal area, no violations of assumptions requiring a data transformation. However, mortality data required a logit transformation prior to analysis to fulfill model assumptions. All transformed means that are presented have been back-transformed. All pairwise comparisons of treat-

Table 2. Analysis of variance or covariance for 12th year data from the Summit and Marcola sites.

		Summit				Marcola			
Parameter	Effect	Numerator df	Denominator df	*F*	*p*	Numerator df	Denominator df	*F*	*p*
DBH	Treatment	7	16	12.8	<0.0001	7	16	6.7	0.0008
	Diameter[a]	1	1049	71.3	<0.0001	1	1075	56.9	<0.0001
Height	Treatment	7	16	3.9	0.0119	7	16	6.1	0.0014
	Diameter	1	1004	49.0	<0.0001	1	1074	46.1	<0.0001
Height/diameter ratio	Treatment	7	16	7.6	0.0004	7	16	1.5	0.244
	Diameter	1	1003	35.0	<0.0001	1	1074	7.3	0.0071
Individual-tree volume[b]	Treatment	7	16	9.5	0.0001	7	16	6.6	0.0009
	Diameter	1	1003	72.0	<0.0001	1	1074	58.7	<0.0001
Mortality[c]	Treatment	7	16	1.9	0.1448	7	16	3.2	0.0259
Volume per hectare	Treatment	7	16	16.3	<0.0001	7	16	8.7	0.0002
Hardwood basal area	Treatment	7	16	3.3	0.0237	7	16	4.3	0.008

[a]Basal diameter just after planting.
[b]Individual-tree volumes were cube-root transformed.
[c]Mortality values were logit transformed.

Fig. 2. Cumulative mortality (years 1, 3, 5, 8, and 12) by site for all treatments. Means with the same letter are not significantly different ($p > 0.05$).



ment means were performed using a Fisher's protected LSD test and a significance level of $\alpha = 0.05$.

Twelfth-year DBH, height, and individual-tree volume responses to increasing area of herbaceous weed control were modeled using nonlinear regression. The woody-only control treatment was used as the 0 m^2 herbaceous-control treatment in this analysis. The best model was chosen by examining residuals and R^2 values. For both sites, a three-parameter exponential equation best fit the data:

$$[1] \quad Y = Y_0 + a(1 - b^x)$$

where Y is the predicted value of DBH, height, and individual-tree volume; Y_0 equals the mean parameter value when the area of weed control is 0 m^2 (intercept); a and b are parameters to be estimated; and x is the area of weed control.

Results

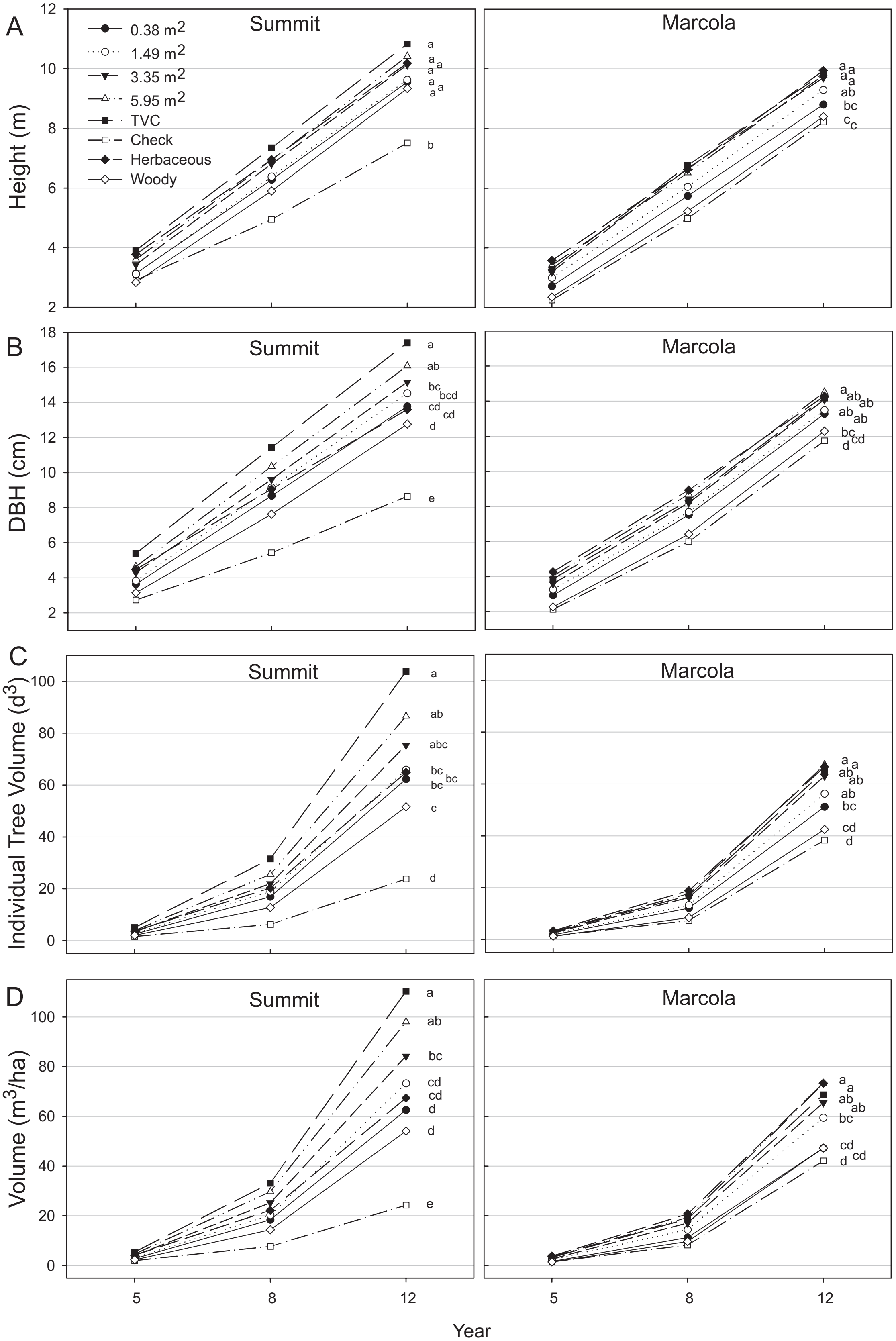
Mortality

Mortality in the check treatment at Summit increased sharply after year 5, reaching 23% in year 12. However, there were no significant differences in cumulative mortality at year 12 at Summit (Table 2, Fig. 2) because of high plot to plot variability in mortality. For example, in the three check treatment plots, mortality was 12%, 16%, and 35%. At Marcola, mortality in the 0.38 m^2 area of control treatment (20.1%) was significantly greater than mortality in all other treatments, which averaged from 7.2% to 10.5% (Table 2, Fig. 2). However, mortality in the 0.38 m^2 area of control treatment was nearly 16% the first year and subsequently rose 4%, suggesting that this response may be related to other factors in addition to area of weed control.

Growth

Height, DBH, and stem volume responded differently to weed control at the two sites (Table 2, Fig. 3). At both sites, height, DBH, and volume (individual trees and per hectare) tended to increase with increasing intensity of weed control, but treatment differences were less at Marcola than at Summit. For example, TVC at Summit resulted in a 336% increase in twelfth-year individual-tree volume and a 355%

Fig. 3. Treatment means by site for years 5, 8, and 12 for (A) height, (B) DBH, (C) individual-tree volume, and (D) volume per hectare. Means with the same letter are not significantly different ($p > 0.05$).



increase in volume per hectare relative to the check treatment. At Marcola, on the other hand, total vegetation control improved individual-tree volume and volume per hectare over the check by 64% and 63%, respectively.

The impact of herbaceous weeds can best be gauged by comparing the TVC treatment to the woody-only control treatment, since these treatments differ only in whether herbaceous vegetation was controlled, and the comparison is not confounded by the release of woody species. At both sites, TVC significantly increased growth relative to woody-only control, with TVC increasing twelfth-year individual-tree volume by 101% at Summit and 53% at Marcola. The impact of competing woody vegetation is best gauged by comparing the woody-only control treatment to the check treatment. At Summit, woody-only control improved growth in all parameters relative to the check treatment, increasing twelfth-year individual-tree volume by 117%. At Marcola, on the other hand, there were no significant differences in any parameter between the woody-only control and check treatments, with woody-only control increasing volume by a nonsignificant 11%.

Treatments have had a stronger effect on DBH growth than height growth at Summit with the TVC treatment improving DBH and height growth relative to the check treatment by 101% and 44%, respectively. At Marcola, on the other hand, total vegetation control increased DBH and height growth by 20.8% and 19.8%, respectively, relative to the check.

Another useful gauge of the effect of weed control on volume growth is to use growth curves (Fig. 3) to illustrate the extent to which more intensive weed control treatments have shortened the rotation age relative to less intensive treatments. At Summit the twelfth-year check volume (individual trees or per hectare) was achieved by the TVC treatment in year 7, which is approximately a 5 year decrease in the rotation age thus far. At Marcola, on the other hand, the twelfth-year check volume (individual trees or per hectare) was achieved by the TVC treatment in roughly year 10, which is only a 2 year decrease in its rotation age.

Regression analysis was used to look more closely at the effect of area of weed control on growth through year 12. For both sites and all three parameters, a three-parameter exponential equation fit the data best (eq. 1) (Table 3, Fig. 4). However, the individual-tree volume response to area of weed control was nearly linear at Summit (Fig. 4), with significant competitive effects of weeds at relatively large distances from the planted seedling. On the other hand, the two largest areas of weed control (5.95 m^2 and TVC) offered little advantage relative to the 3.35 m^2 treatment at Marcola. Total vegetation control improved volume relative to a 3.35 m^2 area of control by 39% at Summit and by just over 3% at Marcola.

Table 3. Regression statistics for individual-tree volume, diameter at breast height (DBH; 1.3 m), and height response to area of herbaceous weed control at Summit and Marcola sites.

Site and regression equation	R	p
Summit		
Volume = $60.14 + 64.06(1 - 0.87^{\text{area}})$	0.83	<0.0001
DBH = $13.10 + 4.70(1 - 0.82^{\text{area}})$	0.83	<0.0001
Height = $9.35 + 1.75 (1 - 0.84^{\text{area}})$	0.51	0.0049
Marcola		
Volume = $46.68 + 21.52 (1 - 0.51^{\text{area}})$	0.60	0.0011
DBH = $12.56 + 1.72(1 - 0.50^{\text{area}})$	0.52	0.004
Height = $8.44 + 1.37(1 - 0.50^{\text{area}})$	0.61	0.0009

Note: Volume was measured in cubic decimetres, DBH was measured in centimetres, height was measured in metres, and area of weed control was measured in square metres.

Height/diameter ratio

In addition to differences in Douglas-fir growth among sites, differences in growth form have also emerged over time (Table 2, Fig. 5). At both sites, height/diameter ratios have fallen since year 5, at which time the ratios were more or less inversely proportional to the growth response for individual treatments. Since year 5, however, the drop in height/diameter ratio at Summit has been such that differences in treatments have remained, with year-12 ratios ranging from 63 to 89. At Marcola, on the other hand, treatments have converged since year 5 toward a ratio of about 70 at year 12.

Woody basal area and number of stems

Herbicide treatments significantly influenced the amount of woody basal area present at both Summit (p = 0.0237) and Marcola (p = 0.0078) (Table 2). Basal area was much greater at Summit, ranging from 1.6 m^2/ha (TVC) to 23.8 m^2/ha (check), than at Marcola, ranging from 0.2 m^2/ha (5.95 m^2 treatment) to 2.0 m^2/ha (herbaceous-only) (Table 4). At Summit, all treatments that involved woody control had significantly less woody basal area than the check treatment, and herbaceous-only control reduced basal area to levels not significantly different from all other treatments except TVC. At Marcola, the two treatments without any woody control (check and herbaceous-only) had significantly more basal area than all but the smallest area of control treatment (0.38 m^2).

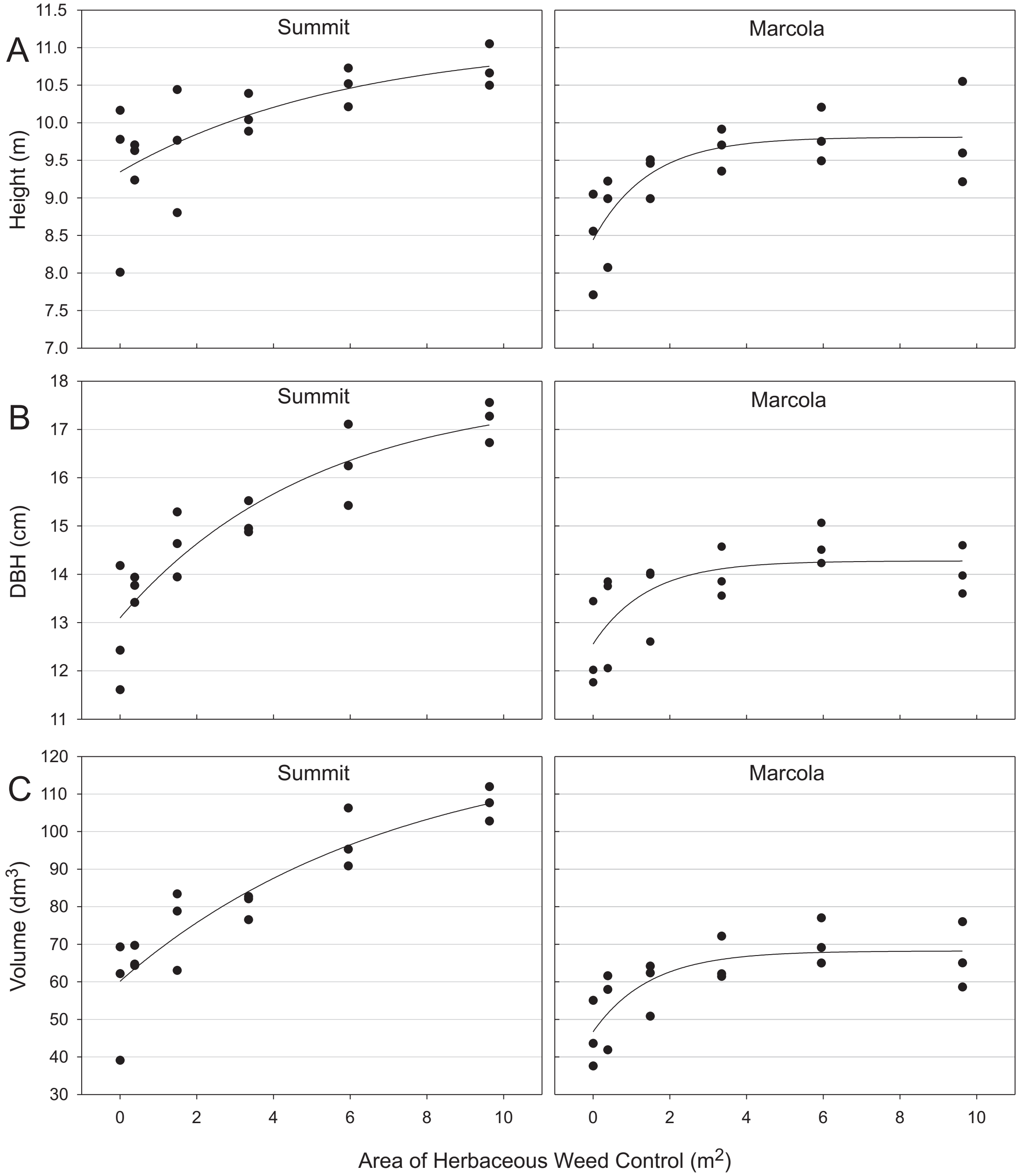
The large difference in basal area among sites is not reflected in the observed number of woody stems (Table 4). For example, although Summit had nearly 14 times more woody basal area than Marcola in the check treatment, there were roughly the same number of woody stems: 12 800 and 12 100, respectively. One reason for this discrepancy is that the dominant woody species at Marcola, beaked hazelnut (*Corylus cornuta* Marsh.), develops numerous small stems, whereas the dominant woody species at Summit, bitter cherry, develops fewer stems per individual with more secondary growth (Table 5). Although bitter cherry at Summit had less than three-fourths the number of stems as beaked hazelnut at Marcola, it developed nearly 26 times as much basal area.

Discussion

Response to herbaceous control and area of control

At both sites, controlling herbaceous weeds for 2 years after planting significantly increased growth. The difference in magnitude of response between the sites is likely due to differences in weed control efficacy (Fig. 1). Whereas grasses are the dominant growth form at Summit and were well controlled by the herbicides used in the study, bracken fern

Fig. 4. Relationships between plot mean (A) height, (B) DBH, and (C) individual-tree volume of Douglas-fir at age 12 years and area of herbaceous weed control at the Summit and Marcola sites. Lines are the curves generated by the regression models in Table 3.



(*Pteridium aquilinum* (L.) Kuhn), which formed a dense blanket of growth at Marcola, recovered from treatment and was difficult to suppress. Bracken fern has been shown to be allelopathic (Gliessman 1976) but may also compete with conifer seedlings for soil moisture, nutrients, and light. As a result, total summed cover of all species in the 5.95 m^2 treatment was 10% higher at Marcola than at Summit in year 1 and 22% higher at Marcola in year 2. Likewise, total cover in the TVC treatment was 16% higher at Marcola than at Summit in year 1 and 13% higher in year 2.

At Summit, excellent herbaceous control was achieved and volume growth increased with each increase in area of weed control. Thus, total broadcast control was necessary to maximize growth, more than doubling volume growth relative to woody-only control through year 12. The need for complete broadcast control to maximize growth is consistent with results for Douglas-fir at one of two sites in southwestern Oregon (Jaramillo 1988), loblolly pine at two southern United States sites (Dougherty and Lowery 1991), and Monterey pine at various sites in New Zealand (Richardson et al. 1996; Mason and Kirongo 1999). Variability among sites in response to area of weed control is likely related to differences in resource availability (e.g., precipitation, soil type, and soil depth) and the competitiveness of the vegeta-

Fig. 5. Height/diameter ratio means by site for all treatments years 5, 8, and 12. Means with the same letter are not significantly different ($p > 0.05$).

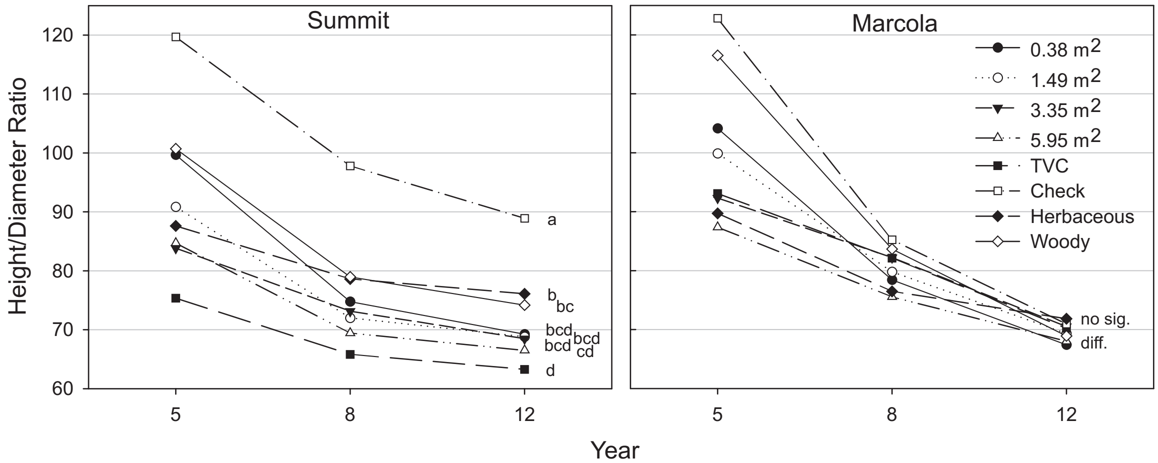


Table 4. Woody basal area and number of stems (on a per-hectare basis) by site and treatment.

Site and treatment	Basal area (m^2/ha)	Stems/ha
Summit		
0.38 m^2	7.75 ± 1.18bc	3 810 ± 1840
1.49 m^2	11.59 ± 5.90bc	4 921 ± 2222
3.35 m^2	5.30 ± 2.56bc	3 228 ± 413
5.95 m^2	7.30 ± 1.31bc	2 275 ± 370
9.96 m^2 (TVC)	1.61 ± 1.17c	1 005 ± 53
Check	23.83 ± 4.69a	12 804 ± 5300
Herbaceous	14.52 ± 1.29ab	8 730 ± 242
Woody	7.98 ± 6.61bc	3 122 ± 1005
Marcola		
0.38 m^2	1.04 ± 0.19ab	5 926 ± 106
1.49 m^2	0.67 ± 0.15b	9 418 ± 2750
3.35 m^2	0.28 ± 0.19b	3 651 ± 1514
5.95 m^2	0.18 ± 0.12b	4 603 ± 2063
9.96 m^2 (TVC)	0.43 ± 0.27b	2 275 ± 663
Check	1.71 ± 0.52a	12 116 ± 4260
Herbaceous	1.97 ± 0.60a	14 127 ± 2708
Woody	0.37 ± 0.27b	3 069 ± 610

Note: Values are means ± SE. Values with the same letter are not significantly different ($p > 0.05$). TVC, total vegetation control.

tion community; however, site factors are difficult to control, and no clear explanation for site variability has been demonstrated.

Less effective herbaceous control and bracken fern presence at Marcola explains not only the muted overall response to herbaceous weed control treatments but also the asymptotic response to area of weed control. At the Marcola site, the competitive effect of weeds outside the treated spot may have been confounded by the competitive (or allelopathic) effect of weeds within the treated spot, thus confirming the concept that even low levels of weeds close to the crop tree can seriously limit growth (Wagner 2000).

Response to woody control

Woody-only control was highly beneficial at Summit but ineffective at Marcola. The differential impact of woody competition among sites is due to differences in species composition. At Summit, bitter cherry (a species with height growth rates that can equal or exceed Douglas-fir) was abundant. At Marcola, no highly competitive tall-growing woody species was present in significant numbers. The eventual presence or lack of competitive woody species at these sites may be related to differences in the vegetation community within the previous stands. The study site at Summit had been dominated by mixed hardwoods, assuring an abundance of propagules for competitive woody species. At Marcola on the other hand, a 60-year-old Douglas-fir stand was harvested prior to the study installation, likely increasing the relative abundance of less competitive understory species.

Woody-only versus herbaceous-only control

Three years after planting, stem volume in the herbaceous-only control treatment at Summit (0.88 dm^3) had been more than 227% greater than the volume in the woody-only control treatment (0.27 dm^3) (Rose et al. 1999). Twelve years after planting, however, we found no significant growth differences between woody-only control and herbaceous-only control treatments at the Summit site. The gradual narrowing of growth differences between these two treatments illustrates the decreasing competitiveness of herbaceous vegetation and increasing competitiveness of tall-growing woody competition over time. The rate of this shift was largely mediated by the time it took woody competition to recolonize the site from residual root fragments or seed. Summed cover for woody species in the check treatment increased from 7.5% to 13.4% to 71.3% in years 1–3 of the study at Summit (Rose et al. 1999). We suspect that bitter cherry at Summit did not start to reach dominance until year 4 or 5; by year 8, bitter cherry had become so competitive in the check treatment that Douglas-fir mortality began to increase sharply.

The pattern of shifting competitiveness from the herbaceous to the woody weed community we observed at Summit is a commonly observed successional trend in the Pacific Northwest (Dyrness 1973; Schoonmaker and McKee 1988). Similar to our results at Summit, Harrington et al. (1995) found that deciduous tree cover did not begin to significantly impact Douglas-fir basal area and height growth for 3–

Table 5. Year 12 woody basal area and number of stems (on a per-hectare basis) by species across all treatments and plots (n = 24).

Site and species	Basal area (m^2/ha)	Stems/ha	Presence (no. of plots)
Summit			
Bitter cherry (*Prunus emarginata* Dougl.)	8.83±1.72	3704±996	24
Cascara buckthorn (*Rhamnus purshiana* (DC.) Cooper)	0.77±0.30	622±203	12
Beaked hazlenut (*Corylus cornuta* Marsh.)	0.11±0.07	370±212	6
Bigleaf maple (*Acer macrophyllum* Pursh)	0.19±0.18	53±46	2
Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*)	0.05±0.03	46±15	7
Elderberry (*Sambucus* spp.)	0.03	33	1
Red alder (*Alnus rubra* Bong.)	0.00	7	1
Marcola			
Beaked hazelnut	0.34±0.09	5086±1033	23
Scotch broom (*Cytisus scoparius* (L.) Link.)	0.23±0.06	1058±222	16
Cascara buckthorn	0.09±0.04	159±72	8
Chinquapin (*Chrysolepis chrysophylla* (Dougl. ex Hook.) Hjelmqvist)	0.09	112	1
Douglas-fir	0.08±0.05	66±23	7
Vine maple (*Acer circinatum* Pursh)	0.00	46	1
Serviceberry (*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roemer)	0.00	26	1
Bitter cherry	0.01	13	1
Bigleaf maple	0.00	7	1

Note: Values are means ± SE except where the species occurred on only one plot.

5 years across several Washington and Oregon Coast Range plantations already 2–3 years old at the onset of their study. After 10 years, tree cover was the most competitive component of the vegetation community. Stein (1995), studying the effects of site preparation at five Oregon Coast Range sites, observed a shift from herbaceous species' dominance in years 1–3 to increasing woody dominance beginning in year 5; the primary competitor was red alder.

Our results are similar to those of Miller et al. (2003) who found that woody-only control increased loblolly pine volume growth through 15 years on sites with high hardwood and high shrub regeneration potential but had little effect on sites with low hardwood regeneration potential. On sites with high invasion potential (>1800 hardwood rootstocks per acre), control of the dominant hardwoods, sweetgum (*Liquidambar styraciflua* L.), southern red oak (*Quercus falcata* Michx.), water oak (*Quercus nigra* L.), and blackgum (*Nyssa sylvatica* Marsh.), resulted in continually increasing volume gains through year 15 (Miller et al. 2003). Sites with low hardwood invasion potential benefited more from herbaceous-only control, similar to our Marcola site.

Height/diameter ratio

At Marcola, there were not only no significant differences in Douglas-fir growth or mortality between woody-only control and the check treatment, but by year 12, there were no differences in height/diameter ratio among all treatments. Height/diameter ratio has been associated with the recent history of competition faced by an individual tree, with ratios increasing in response to competition (Biring et al. 2003; Cole and Newton 1987; Hughes and Tappeiner 1990). Our height/diameter ratio data suggest that, by year 12, competitive effects from weeds at Marcola were nearly nonexistent, whereas competition at Summit was still considerable. In contrast to the Summit site, all competition at Marcola had become relegated to the understory, which appears to be minimizing its impact on Douglas-fir saplings.

Effect of fencing

Bitter cherry, normally preferred deer forage, was only able to become a significant component in certain plots at Summit because our plots were fenced. Had we not fenced the site, response to control of the woody component would likely have been lessened because deer would have controlled the level of cherry in untreated plots. Cover of other potentially dominant tree species was negligible. The results from this site are highly applicable to numerous vegetation communities in the region. Both bigleaf maple and red alder occur throughout the Oregon Coast Range and have high dominance potential (Cole and Newton 1987; Harrington et al. 1995; Stein 1995). Had we chosen study sites where either of these species were a significant component of the plant community, response to control of the woody vegetation component would likely have been strong with or without deer.

Summary

This study has demonstrated that herbaceous vegetation control for 2 years combined with woody control for 3 years has the potential to substantially increase volume growth through year 12, although much of this gain can be lost if weed control treatments are not highly efficacious. At a site where excellent herbaceous control was achieved, volume growth increased with each increase in area of weed control out to complete broadcast control (TVC). At a site with a highly competitive hardwood species (bitter cherry), woody-only control was equally effective as herbaceous-only control in increasing Douglas-fir growth through 12 years, but woody-only control had little effect at a site with no serious woody competition. The preharvest vegetation community appears to have had a strong influence on the presence or absence of competitive woody species within the study, thereby influencing the response to control of woody vegetation.

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