Growth responses of young Douglas-fir and tanoak 11 years after various levels of hardwood removal and understory suppression in southwestern Oregon, USA

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Abstract

At two sites in southwestern Oregon, height, diameter, and crown width of young Douglas-fir (Pseudotsuga menziesii) and sprout-origin tanoak (Lithocarpus densiflorus) were measured 1–11 years after reducing the density of a 2-year-old tanoak stand to 0%, 25%, 50%, and 100% of its initial cover. Some plots also included suppression of understory vegetation. Tanoak cover developed linearly with time, with steepness of the growth trajectory increasing at a diminishing rate with increasing percentage of initial tanoak cover. Fifth-year cover of understory vegetation declined linearly with increasing percentage of initial tanoak cover (R² = 0.29). Survival of Douglas-fir (96–100%) differed little among initial abundances of tanoak, while growth trajectories for its size became increasingly exponential with decreasing percentage of initial tanoak cover. Eleventh-year heights of Douglas-fir were similar for 0%, 25%, and 50% of initial tanoak cover; however, diameter increased linearly with decreasing percentage of initial tanoak cover (R² = 0.73), and the slope of the relationship deepened with understory suppression. Our results indicate that young stands exhibiting a wide range of stand compositions and productivities can be established by early manipulations of tanoak and understory abundance. Complete removal of tanoak plus understory suppression are necessary to maximize Douglas-fir growth, while productive, mixed stands can be achieved by removing 50% or more of tanoak cover. © 1997 Elsevier Science B.V.

Keywords: Competition thresholds; Vegetation management; Pseudotsuga menziesii; Lithocarpus densiflorus

1. Introduction

Tanoak (Lithocarpus densiflorus Hook. and Arn. [Rehd.]) is a shade-tolerant, evergreen hardwood that commonly grows in the understory of conifer forests, as well as in pure stands (Tappeiner et al., 1991). It is a major component of mixed-evergreen forests of southwestern Oregon and of redwood and mixed-conifer forests of northern California (Barrett, 1995). In older conifer forests, tanoak trees can have multiple stems 2–25 m in height with basal burls from 20 cm to over 70 cm in diameter underground (Tappeiner and McDonald, 1984). When the stands are top-killed by fire or cutting, tanoaks sprout vigorously from buds on the burls. The size of the result-
ing sprout clumps and their growth rates are strongly related to dbh (stem diameter at 1.37 m above ground) of the parent tree (Tappeiner et al., 1984; Harrington et al., 1992). Thus, depending upon the size and density of tanoak prior to timber harvest or intense fire, a dense cover of tanoak sprouts may develop within 2–3 years after disturbance.

A dense cover of evergreen hardwoods and shrubs will strongly affect the development of young conifer stands. High levels of tanoak cover (50% + ) will reduce the annual basal area growth of a Douglas-fir seedling by 37% or more (Harrington et al., 1991). On dry sites, survival of conifer seedlings also can be substantially reduced (Tappeiner et al., 1992). A dense cover of hardwoods will limit survival and growth of shrub and herbaceous species (Hughes et al., 1990; Harrington et al., 1991), some of which provide browse and mast (e.g. Ceanothus, Rubus, Ribes, and Arctostaphylos spp.) for wildlife or fix nitrogen for maintenance of long-term site productivity (e.g. Ceanothus spp.). On the other hand, tanoak sprout clumps 3 years and older produce considerable mast, and provide cover for Columbian black-tailed deer (Odocoileus hemionus columbianus Richardson) and Roosevelt elk (Cercus elaphus roosevelti Merriam) and habitat for other wildlife species. Thus, forest managers need to evaluate a variety of options when establishing young Douglas-fir and tanoak stands. One part of the evaluation is the trade-off between tanoak density and conifer seedling growth, and this question is best answered by quantifying threshold relationships of competition between crop and competing species (Wagner et al., 1989). Such relationships identify the intensity of vegetation management required for cost-effective manipulation of young stand development. Early intervention with vegetation control treatments during stand establishment has been used successfully to facilitate the development of a variety of stand structures in conifer plantations (Harrington et al., 1995; Harrington and Edwards, 1996).

In 1983, a study was initiated to determine the long-term responses of Douglas-fir plantations to a range of initial abundances of tanoak, with or without suppression of understory vegetation. We measured height, stem diameter, and crown width of Douglas-fir and tanoak for 11 years after the initial stand treatments with the objective of evaluating a range of options for establishing young stands. Therefore, we compared Douglas-fir and tanoak size among levels of hardwood removal and understory suppression and developed response surface models to quantify competition thresholds. We used the threshold models to estimate the levels of vegetation control required to mitigate development of Douglas-fir and tanoak stands that fulfill various silvicultural objectives.

2. Methods

2.1. Study sites and treatments

At two sites in southwestern Oregon (Squaw near Cave Junction and Fir Point near Glendale), old-growth Douglas-fir (Pseudotsuga menziesii var. menziesii) and understory tanoak were clearcut in 1980, and woody debris was broadcast burned in spring 1981. Detailed site descriptions are given in Harrington et al. (1991). Two-year-old, bare-root seedlings of Douglas-fir were hand-planted in spring 1981 (Squaw, 3-m spacing) and 1982 (Fir Point, 2.8-m spacing). In March 1983, 24 and 15 plots of dimension 20 m x 20 m were located at Squaw and Fir Point, respectively, in areas having similar abundance and size of 2-year-old sprout clumps of tanoak. Plots at each site were grouped into three blocks according to aspect and topography. In each plot, sprout clumps were counted by 25-cm crown width classes. Multiplication of class frequencies by their respective class midpoints for crown area, summing these values, dividing by plot area, and multiplying by 100 provided an initial value of tanoak cover (%) for each plot. Plot counts of Douglas-fir seedlings also were taken.

One and two plots within each block at Fir Point and Squaw, respectively, were randomly assigned a treatment of zero (Z), low (L), medium (M), or high (H) tanoak abundance to correspond to 0%, 25%, 50%, and 100% of initial cover, respectively, remaining after removal of selected sprout clumps. For treatments Z, L, and M, tanoak clumps were removed in April 1983 with a directed spray of triclopyr (Garlon® 4, 2% in water with surfactant) 2. At

2Discussion of herbicides does not imply endorsement nor does it indicate status of product registration.
Squaw, four plots within each block (one each of treatments Z, L, M, and H) were randomly assigned for suppression of understory shrubs and herbs with a broadcast spray of glyphosate (Roundup®, 2% in water) in April 1983. At Fir Point, the remaining plot within each block was assigned treatment Z with understory suppression. In subsequent years, understory suppression was maintained by manual removal of this vegetation (March 1984) and installation (March 1985) of a 2-m × 2-m porous, polyester fabric (Terra-Mat E, Terra Enterprise, Inc., Moscow ID 83843) around individual Douglas-fir. The experimental design at each site is a randomized complete block with either a 4 × 2 factorial arrangement of treatments (Squaw) or 5 treatments (Fir Point).

2.2. Vegetation measurements and statistical analysis

During each winter 1–7 and 11 years after treatment, the following variables were measured on each of 15 Douglas-fir per plot that had been systematically located and tagged at study initiation: height (nearest 0.1 m), stem diameter (nearest 0.1 cm at 15 cm above ground), and average crown width (mean of maximum width and a width taken 90° with respect to the first measurement; each measurement taken to the nearest 0.1 m). Tanoak cover was measured each winter 1–5 years after treatment using the methods described above. In June of the first, third, fourth, and fifth years after treatment, crown coverage of understory vegetation (nearest 5%) was estimated visually by species within a square 1-m² subplot located 1 m uphill from each of five Douglas-fir per plot; third-year data were collected only on plots absent of understory suppression. Five tanoak sprout clumps, representing the range of sizes present, were located within each replication of treatments L, M, and H at each site. If the stump(s) of the parent tree had not been damaged by timber harvest and broadcast burning, the diameter (nearest 0.1 cm) of each was measured at 20 cm above ground. During each winter 1–6 and 11 years after treatment, each clump was measured for height (nearest 0.1 m) and average crown width (mean of maximum width and a width taken 90° with respect to the first measurement; each measurement taken to the nearest 0.1 m). For each clump sampled at Fir Point and those within the first block at Squaw, the tallest sprout was tagged at study initiation and its diameter (nearest 0.1 cm at 20 cm above ground) was measured at the same time as that for crown size.

All statistical analyses were conducted with a 5% significance level (Statistical Analysis Systems Institute Inc., 1989). Plot means for cover, height, diameter, and crown width were calculated for each year. Means from the fifth year (cover of tanoak and understory vegetation) and eleventh year (size of Douglas-fir and tanoak) from each site were subjected to analysis of variance (ANOVA), and when significant treatment effects were detected, mean separations were performed with Tukey’s HSD test (Petersen, 1985). If the tanoak × understory interaction (Squaw only) was significant, the data were reanalyzed via one-way ANOVA and Tukey’s HSD test to separate individual treatment means. Student’s t-statistic was used to test for significant differences between sites for number, quadratic mean diameter, and total basal area of parent stumps per tanoak clump. To illustrate their potential development, cover of tanoak and understory vegetation from 6 to 11 years after treatment was predicted with equations from Harrington et al. (1991).

For each response variable of Douglas-fir, tanoak, and understory vegetation, data from the two sites were combined and subjected to a response surface analysis (Petersen, 1985) by fitting the following full model:

\[
Y_i = \beta_0 + \beta_1 S + \beta_2 T + \beta_3 T^2 + \beta_4 U + \beta_5 T \times U + \epsilon_i
\]

where \(Y_i\) is the mean response per plot for year 5 (tanoak or understory cover) or 11 (Douglas-fir or tanoak size); \(\beta_{0-5}\) are regression parameters to be estimated; \(S = 1\) and 0 for Squaw and Fir Point, respectively; \(T\) is the percentage of initial tanoak cover (0, 25, 50, and 100 corresponding to treatments Z, L, M, and H, respectively); \(U = 1\) and 0 for presence and absence of understory suppression, respectively; \(T \times U\) is the interaction of percentage of initial tanoak cover by understory suppression; and \(\epsilon_i\) is the random error associated with each plot mean. After testing for lack of fit, final models were selected with stepwise linear regression. Intensity of competition, estimated as the slope of the response surface (Welden and Slauson, 1986), was interpreted.
as constant or changing for linear and quadratic models, respectively.

3. Results

3.1. Tanoak and understory responses

In the first year after treatment, tanoak cover varied from 0 to 27% (0–3900 clumps ha⁻¹) among the four tanoak treatments at Squaw and Fir Point (Fig. 1). From 2 to 5 years after treatment, tanoak cover grew linearly at rates that increased with increasing percentage of initial tanoak cover. Fifth-year cover of tanoak did not differ significantly between treatments M and H at either site; however, it was significantly lower for treatments Z and L vs. M (Squaw) and vs. H (Squaw and Fir Point). Eleventh-year predictions of tanoak cover varied from 74 to 99% as the percentage of initial tanoak cover increased from 25 to 100.

Fifth-year tanoak cover had a negative quadratic relationship with the percentage of initial tanoak cover ($R^2 = 0.86$) that was concave with respect to the x-axis (Fig. 2, Table 1). The shape of this response surface relationship is the cumulative result of differing cover growth trajectories that had slopes which increased with increasing percentage of initial tanoak cover, but at a diminishing rate (Fig. 1).

Although fifth-year cover of tanoak at Squaw slightly exceeded that at Fir Point, the response surface analysis failed to detect significant differences between sites.

The five most abundant species of understory vegetation (in order of decreasing abundance) were beargrass (*Xerophyllum tenax* Michx.), whipplevine (*Whipplea modesta* Torr.), autumn willow-herb (*Epilobium paniculatum* Nutt.), deerbrush (*Ceanothus integerrimus* H. & A.), and bracken fern (*Pteridium aquilinum* L. [Kuhn.]). Fifth-year predictions of understory vegetation ranged from 11 to 57% with decreasing percentage of initial tanoak cover (Fig. 1).

Eleventh-year height, diameter, and crown width of tanoak each had a negative quadratic relationship with percentage of initial tanoak cover that was slightly concave with respect to the x-axis ($R^2 = 0.73, 0.85, \text{ and } 0.37$, respectively), suggesting that intensity of tanoak competition increased with percentage of initial tanoak cover (Fig. 2, Table 1). Response surface analyses also indicated that eleventh-year height and stem diameter of tanoak at Squaw were 1.2 m and 2.6 cm larger, respectively, than those for clumps at Fir Point (Table 1, coefficients for $S$).

3.2. Douglas-fir responses

At study initiation (March 1983), Douglas-fir densities averaged 644 and 1285 seedlings ha⁻¹ at Squaw and Fir Point, respectively. At each site, eleventh-year survival of Douglas-fir (96–100%) did not differ significantly among tanoak treatments or levels of understory suppression. Growth trajectories for height, diameter, and crown width of Douglas-fir became increasingly exponential with decreasing percentage of initial tanoak cover (Figs. 3–5). Diam-
Fig. 1. Mean (years 1–5) and predicted (years 6–11, after Harrington et al., 1991) cover of tanoak and understory vegetation after removing tanoak sprout clumps to leave 0% (●), 25% (○), 50% (□), and 100% (■) of the cover of an untreated, 2-year-old stand (treatments Z, L, M, and H, respectively) with (---) or without (—) suppression of understory shrubs and herbs. Fifth-year means followed by the same letters do not differ significantly (P > 0.05).

Fig. 2. Predicted eleventh-year height, stem diameter, and crown width of Douglas-fir and tanoak and fifth-year cover of tanoak and understory vegetation after removing tanoak sprout clumps to leave 0% (●), 25% (○), 50% (□), and 100% (■) of the cover of an untreated, 2-year-old stand (treatments Z, L, M, and H, respectively). Douglas-fir responses are shown with (---) or without (—) suppression of understory shrubs and herbs.
Table 1
Regression coefficients (presented for independent variables and expressed in scientific notation, e.g. \(-6.09 \times 10^{-3} = -0.00609\)) and goodness-of-fit statistics for response-surface relationships of Douglas-fir and tanoak to percentage of initial tanoak cover and presence or absence of understory suppression. Relationships are for either the fifth-year (cover of tanoak and understory vegetation) or eleventh year after treatment (all other variables).

<table>
<thead>
<tr>
<th>Species</th>
<th>Dependent variable</th>
<th>Independent variable (^a)</th>
<th>Intercept</th>
<th>(S)</th>
<th>(T)</th>
<th>(T^2)</th>
<th>(U)</th>
<th>(T \times U)</th>
<th>Goodness-of-fit statistics (^b)</th>
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<tbody>
<tr>
<td>Tanoak</td>
<td>Cover (%)</td>
<td></td>
<td>3.00e+00</td>
<td>1.15e+00</td>
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<td>Height (m)</td>
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<td>0.37</td>
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<tr>
<td></td>
<td>Diameter (cm)</td>
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<td>4.14e+00</td>
<td>2.62e+00</td>
<td>-1.16e-04</td>
<td>0.85</td>
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<td></td>
<td>Crown width (m)</td>
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<td>7.03e-05</td>
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<td>0.37</td>
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<td>Understory</td>
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<td>0.68</td>
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<td></td>
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<td>1.59e+00</td>
<td>-2.18e-02</td>
<td>0.73</td>
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<td>15</td>
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<tr>
<td></td>
<td>Crown width (m)</td>
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<td>-2.49e-02</td>
<td>1.38e-04</td>
<td>0.75</td>
<td>0.26</td>
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</tbody>
</table>

\(^a\) \(S = 1\) and 0 for Squaw and Fir Point, respectively; \(T\) is percentage of initial tanoak cover (0, 25, 50, or 100); \(U = 1\) and 0 for presence and absence of understory suppression, respectively.

\(^b\) \(R^2\) is coefficient of determination adjusted for degrees of freedom (Draper and Smith, 1981), \(S_{x,1}\) is standard error of estimate, \(CV\) is coefficient of variation (%), and \(n\) is sample size.
Fig. 3. Mean height of Douglas-fir and tanoak saplings at Squaw and Fir Point 1–11 years after removing tanoak sprout clumps to leave 0% (●), 25% (○), 50% (□), and 100% (■) of the cover of an untreated, 2-year-old stand (treatments Z, L, M, and H, respectively) with (- - -) or without (—) suppression of understory shrubs and herbs. Eleventh-year means followed by the same letters do not differ significantly (P > 0.05).

Fig. 4. Mean diameter of Douglas-fir and tanoak saplings at Squaw and Fir Point 1–11 years after removing tanoak sprout clumps to leave 0% (●), 25% (○), 50% (□), and 100% (■) of the cover of an untreated, 2-year-old stand (treatments Z, L, M, and H, respectively) with (- - -) or without (—) suppression of understory shrubs and herbs. Eleventh-year means followed by the same letters do not differ significantly (P > 0.05). Tanoak data from Squaw are unreplicated and presented for relative comparisons only.
Mean crown width of Douglas-fir saplings and tanoak sprout clumps at Squaw and Fir Point 1–11 years after removing tanoak sprout clumps to leave 0% (●), 25% (○), 50% (□), and 100% (■) of the cover of an untreated, 2-year-old stand (treatments Z, L, M, and H, respectively) with (---) or without (—) suppression of understory shrubs and herbs. Eleventh-year means followed by the same letters do not differ significantly (P > 0.05).

Fig. 5. Mean crown width of Douglas-fir saplings and tanoak sprout clumps at Squaw and Fir Point 1–11 years after removing tanoak sprout clumps to leave 0% (●), 25% (○), 50% (□), and 100% (■) of the cover of an untreated, 2-year-old stand (treatments Z, L, M, and H, respectively) with (---) or without (—) suppression of understory shrubs and herbs. Eleventh-year means followed by the same letters do not differ significantly (P > 0.05).

At Squaw, the tanoak × understory interaction was significant for eleventh-year diameter (P = 0.05) and crown width (P < 0.01). Comparisons of treatment means for these variables indicated that Douglas-fir size was significantly less for treatment M and H vs. Z, independent of understory suppression (Figs. 4 and 5). In addition, diameter and crown width for treatment L with understory suppression did not differ significantly from that for treatment Z without understory suppression. From 7 to 11 years after treatment, Douglas-fir crown width declined slightly in most of the treatments at Fir Point (Fig. 5).

Response surface relationships of eleventh-year Douglas-fir size to percentage of initial tanoak cover were either negative linear (diameter) or negative quadratic (height and crown width), and effects of understory suppression were detected only for height and diameter (Fig. 2). Relationships of Douglas-fir height vs. percentage of initial tanoak cover were concave with respect to the x-axis ($R^2 = 0.53$), and the y-intercept was greater with vs. without understory suppression. The shape of this relationship suggests that intensity of competition from tanoak increased, while that of understory vegetation was constant, with increasing percentage of initial tanoak cover. Height averaged 0.6 m greater with vs. without understory suppression, and it was 0.5 m less at Squaw vs. Fir Point (Table 1, coefficients for U and S, respectively).

In the response surface models, the interaction of percentage of initial tanoak cover × understory suppression was significant for diameter, indicating that Douglas-fir responses to initial tanoak abundance depended on level of understory suppression. This relationship ($R^2 = 0.73$) suggests that intensity of understory competition decreased with increasing percentage of initial tanoak cover (Fig. 2)—a result of understory exclusion by tanoak. Douglas-fir diameter did not differ significantly between sites. The relationship of crown width vs. percentage of initial tanoak cover ($R^2 = 0.75$) was convex with respect to the x-axis, suggesting that intensity of tanoak com-
petition decreased with increasing percentage of initial tanoak cover. Crown width averaged 0.4 m greater at Squaw vs. Fir Point (Table 1, coefficient for S), and it did not differ significantly between levels of understory suppression.

4. Discussion

Hardwood removal and understory suppression soon after planting Douglas-fir had a pronounced effect on abundance of vegetation and size of tanoak and Douglas-fir 11 years later. Furthermore, it appears that, with adequate site preparation, Douglas-fir seedlings can be established and grown among tanoak sprout clumps with no significant reductions in seedling survival for at least 11 years. Because tanoak competition caused substantial reductions in growth of Douglas-fir seedlings at both sites, some hardwood removal probably will be required to ensure adequate growth of Douglas-fir where tanoak density is high. Maximum growth of Douglas-fir occurred in the absence of tanoak and presence of understory suppression; however, differences in tree response among intermediate levels of vegetation were not as clear. For example, at both sites eleventh-year height of Douglas-fir did not differ significantly among treatments Z, L, and M, regardless of understory suppression. Similarly, diameter and crown width at Squaw did not differ significantly between treatment Z without suppression vs. treatment L with suppression of understory vegetation.

Variation in responses of height, diameter, and crown width to competition can be explained by differences in the shape of their response surface models. Height, being less sensitive to competition than diameter or crown width because of its higher priority for allocation of photosynthate (Waring and Schlesinger, 1985), did not begin to decline appreciably until the percentage of initial tanoak cover exceeded 50. In addition, differences in site index may explain the greater eleventh-year height of Douglas-fir at Fir Point vs. Squaw (site index_100_yr = 37 and 35 m, respectively; Harrington et al., 1991). Diameter declined in direct proportion to increases in cover of either tanoak or understory vegetation, while much of the response of crown width was confined to treatments Z and L. Reductions in Douglas-fir crown width that occurred between year 7 and 11 in most of the treatments at Fir Point may be attributable to interspecific competition, because the initial density of seedlings at this site was about twice that at Squaw.

Leaving low densities of tanoak early in the establishment of young tanoak and Douglas-fir stands did not preclude its presence as a viable component later in stand development. For example, treatment L, which had 7–8% tanoak cover year after treatment, developed a fifth-year cover of 21–33%. Growth of individual tanoak, like that of Douglas-fir, increased

<table>
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<tr>
<th>Maximum development of:</th>
<th>Tanoak density (clumps ha⁻¹)</th>
<th>Tanoak cover (%)</th>
<th>Treatments from this study</th>
<th>Suppression of understory vegetation</th>
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<tr>
<td>Douglas-fir size</td>
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<td>22–27</td>
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<td>Absent</td>
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<td>Z</td>
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<th>Tanoak cover (%)</th>
<th>Treatments from this study</th>
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<td>Douglas-fir</td>
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<td>Understory vegetation</td>
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</table>

* Treatments Z, L, M, and H correspond to 0%, 25%, 50%, and 100% of the initial tanoak cover of a 2-year-old, sprout-origin stand.
with reductions in percentage of initial tanoak cover, but also with increases in parent-tree size (Harrington, 1994). For example, the response surface models predict that crown width of tanoak will average 1.9 m and 2.5 m for treatments H and L, respectively. However, at both sites some of the largest tanoak were found in treatment M because these plots contained rootstocks of large tanoak trees from the pre-disturbance stand that retained their ability to produce vigorous sprout clumps, regardless of the level of cover. Although it was not manipulated as an experimental factor in this study, it is likely that, ultimately, Douglas-fir density will set upper limits to the size and abundance of all stand components, including conifers.

Hardwood removal stimulated understory development, which subsequently limited height and diameter of Douglas-fir. At Squaw, it is apparent that intensity of understory competition varied inversely with percentage of initial tanoak cover. For example, in 50% and 100% of initial tanoak cover (treatments M and Z, respectively), Douglas-fir height and diameter did not differ in the presence vs. absence of understory suppression. However, the response surface models predict synergistic increases in Douglas-fir diameter from understory suppression when the percentage of initial tanoak cover decreases below 50. The dynamic nature by which each vegetative component responded to hardwood removal indicates that appropriate management of tanoak abundance will ensure successful establishment and growth of Douglas-fir, as well as maintain a productive understory.

Results of this research can be used to identify the initial vegetation abundances likely to result in attributes of young stands that fulfill various silvicultural objectives (Table 2). If the objective is to maximize volume growth of Douglas-fir, then complete removal of tanoak with suppression of understory vegetation is necessary, because this treatment combination is likely to cause considerable increases in diameter relative to the other treatments, and diameter is the chief determinant of individual tree volume. To promote the development of a mixed stand that emphasizes Douglas-fir, a forest manager should: (a) plant a sufficient number of Douglas-fir seedlings to ensure adequate stocking; (b) reduce tanoak cover so that 7–17% remains 3 years after site preparation (i.e. the range in first-year treatment means for L and M). As these stands develop, reductions in Douglas-fir and tanoak densities may be required to maintain tanoak mast production and a vigorous understory of shrubs and herbs. Regardless of the silvicultural objective, initial changes in vegetation abundance will have long-lasting effects on stand development; therefore, careful planning and early intervention with vegetation control are keys to successful management of Douglas-fir and tanoak.

References


