

Predicting Crown Sizes and Diameter Distributions of Tanoak, Pacific Madrone, and Giant Chinkapin Sprout Clumps

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ABSTRACT. Crown size and stem diameters were measured on a total of 908 sprout clumps of tanoak (*Lithocarpus densiflorus*), Pacific madrone (*Arbutus menziesii*), and giant chinkapin (*Castanopsis chrysophylla*). The clumps, age 1 to 16 years, were located at 23 sites in southwestern Oregon and 20 sites in northwestern California. Regression equations were developed for predicting individual-clump crown size and stem-diameter distributions of dominant sprouts from the total basal area (dm^2 at 1.37 m) in stems of the parent tree (PBA) and number of growing seasons since burning (AGE). Variables of PBA, AGE, and species in combination accounted for over 75% of the total variation in hardwood crown width and height and for 62% of the variation in sprout number. Variables describing site characteristics and competing vegetation abundance did not explain more than 2% of additional variation in hardwood crown size or sprout diameter distribution. On the basis of the Kolmogorov-Smirnoff test ($\alpha = 0.05$), the Weibull function adequately described the reverse J-shaped distribution of stem diameters for individual sprout clumps. The goodness of fit for each of the predictive models for tanoak and madrone was verified with independent data.

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Evergreen species, such as tanoak (*Lithocarpus densiflorus*), Pacific madrone

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and giant chinkapin (*Castanopsis chrysophylla*), are the dominant hardwood trees in southwestern Oregon and northwestern California. After a disturbance, such as cutting or burning, these species sprout vigorously from subterranean burls (McDonald and Tappeiner 1990, McKee 1990, Tappeiner et al. 1990). Tanoak and madrone compete vigorously with associated Douglas-fir seedlings, limiting their growth (Hughes et al. 1990, Harrington et al. 1991a) and probably their survival. On the positive side, these hardwoods provide habitat and mast or berries for a variety of wildlife (McDonald and Tappeiner 1990, McKee 1990, Tappeiner et al. 1990).

Effective management of pure hardwood or mixed hardwood/conifer stands in this region requires two types of quantitative information: (1) equations that predict size of hardwood crowns through the period of crown closure of the stand are needed to forecast expected levels of hardwood competition for associated conifer seedlings; and (2) computer simulators developed to predict growth and yield of stands in this region, such as ORGANON, require a listing of individual tree sizes for both conifer and hardwood components at an age when dominant stems can be identified (Hester et al. 1989). Thus, equations are needed to predict the number and size of dominant stems produced by individual hardwood clumps at various times since sprouting.

The objective of this study was to develop equations that predict crown size and stem-diameter distributions of individual sprout clumps of tanoak, madrone, and chinkapin. Crown development of 1- to 6-year-old sprout clumps of tanoak and madrone has been related to the size of the parent

tree from which the clump originated (Tappeiner et al. 1984). In order to predict the size of a hardwood crown and the size distribution of its dominant stems up to the time of crown closure, we supplemented the data of Tappeiner et al. (1984) to include a broader range of hardwood ages (1 to 16 years) and a wider variety of sites throughout southwestern Oregon and northwestern California.

METHODS

Site Description

Both coastal and inland sites were sampled to represent the range of climates, from cool and moist to hot and dry, in the Klamath Mountain Province of southwestern Oregon and northwestern California (Whittaker 1960). Sites had been clearcut and broadcast-burned 1 to 6 years (Oregon sites) and 2 to 16 years (California sites) before the sample. We combined data from 23 sites in southwestern Oregon [12 sites from Tappeiner et al. (1984) and 11 additional sites] and 20 sites in northwestern California (Figure 1).

At each site, the following variables were determined from field records or from on-site measurements of vegetation and topographical features: AGE (number of growing seasons since burning); Douglas-fir site index (McArdle et al. 1961), estimated from an adjacent, undisturbed stand; elevation; percent slope; and aspect (radians transformed to sine and cosine). These variables were selected because they were hypothesized to influence hardwood development.

Hardwood Measurements

Each sampled sprout clump had originated from one or more stumps of the parent tree that were intact and relatively undisturbed. Only open-grown clumps were sampled in the Tappeiner et al. (1984) data; both open- and stand-grown clumps were sampled in the supplemental data from Oregon and California.

We measured average crown width [geometric mean of maximum width and width perpendicular to maximum (Paine and Hann 1982)] and the diameter(s) of parent tree stump(s) at 0.2 m height on 2 to 15 sprout clumps of each species present on a given site. The supplemental data from Oregon and California sites also included measurements of maximum height, height of each of two dominant sprouts, and dbh (1.37 m height) of each sprout having a diameter ≥ 2.5 cm. Competing woody vegetation in a 3.6-m radius of clump center (i.e., a circular plot of 0.004 ha) was inventoried as

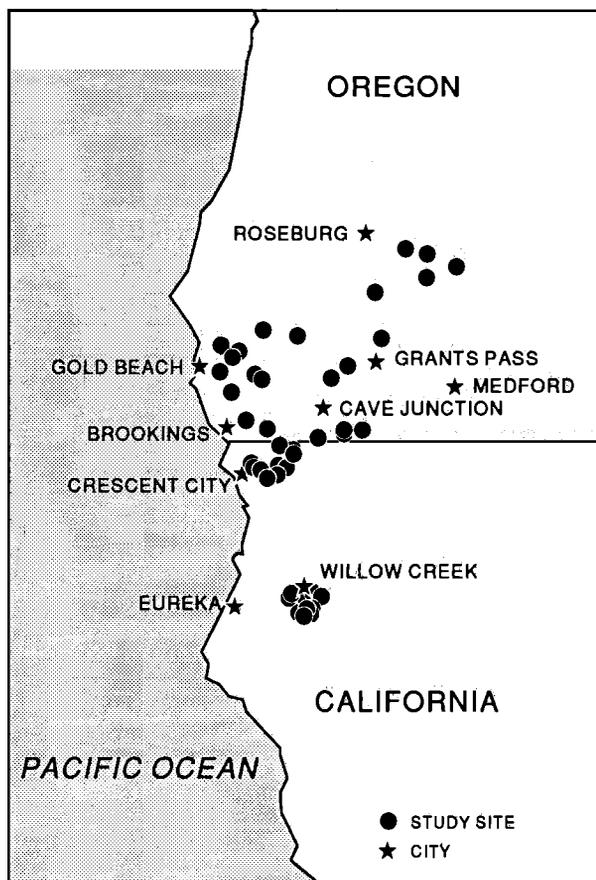


Figure 1. Study-site locations in southwestern Oregon and northwestern California.

dbh of each conifer, hardwood, and shrub stem having a diameter ≥ 2.5 cm. The ranges and sample sizes of the hardwood variables are given in Table 1.

The 1- to 6-year-old hardwoods measured by Tappeiner et al. (1984) had a shrublike growth form, and average height was estimated from three or more dominant stems. The growth form of older clumps resembled that of

a multiple-stemmed tree. To best supplement the data of Tappeiner et al. (1984), we focused our estimates of average height on older clumps that had three or more sprouts with dbh ≥ 2.5 cm. First we developed regression equation (3) to predict sprout height from dbh. Then, we calculated average height per clump as the overall mean of measured heights (i.e., the two dominant sprouts) and predicted

Table 1. Range and sample size of variables in the tanoak, madrone, and chinkapin equations for crown size and sprout-diameter distributions.

Species	Dependent variable			Independent variables (range)		
	Parameter	Range	<i>n</i>	PBA ¹ (dm ²)	AGE ² (yr)	Sprout dbh (cm)
tanoak	crown width (cm)	27-629	513	0.0-36.4	1-16	
madrone		58-684	341	0.0-33.7	2-16	
chinkapin		60-370	54	0.0-12.6	4-14	
tanoak	average ht. (cm)	20-574	225	0.0-36.4	1-16	
madrone		50-700	287	0.0-33.7	2-16	
chinkapin		285-376	5	3.1-12.6	14-14	
tanoak	maximum ht. (cm)	65-680	316	0.0-36.4	2-16	
madrone		100-910	98	0.0-33.7	2-16	
chinkapin		75-460	54	0.0-12.6	4-14	
tanoak	sprout no.	1-24	43	0.2-36.4	4-16	
madrone		1-13	54	0.2-33.7	3-16	
chinkapin		1-13	8	3.0-12.6	4-14	
tanoak	sprout ht. (cm)	65-680	351			0-10
madrone		100-910	98			0-16
chinkapin		75-460	55			0-8
tanoak	cumulative probability of dbh	0.1-1.0	112	0.2-36.4	4-16	
madrone		0.1-1.0	175	0.2-33.7	3-16	
chinkapin		0.1-1.0	23	3.0-12.6	4-14	

¹ Total basal area in stems of the parent tree.

² Number of growing seasons since burning.

heights (remaining sprouts ≥ 2.5 cm dbh).

To make our predictive equations applicable to inventory data for mature stands, we developed a regression equation to convert stump diameter(s) (0.2 m height) of each parent-tree stem to the dbh (1.37 m height) value(s) before disturbance. Data for the regression were obtained from paired diameter measurements at heights of 0.2 and 1.37 m on each of 705 stems of mature trees (342 tanoak, 283 madrone, and 80 chinkapin) growing in undisturbed stands adjacent to the study sites. Total basal area in stems of a given parent tree (PBA, dm²) was calculated as $\sum \pi$ (predicted dbh/20)².

Statistical Analysis

Because of similarities in the allometrics of the three species, we developed the predictive equations from their combined data. Linear or nonlinear functions of PBA, AGE, and indicator variables for species were selected on the basis of a Student's *t*-test ($\alpha = 0.05$) (Ratkowsky 1983) to minimize the mean-squared error and maximize the proportion of explained variation (adjusted *R*²) in dependent variables (Wilkinson 1990). In order to minimize model complexity, variables of site characteristics (site index, elevation, slope, aspect), competing vegetation abundance (BA/ha and stems/ha), and their interactions with PBA, AGE, and species were not retained in a given equation unless they explained more than 2% of additional variation in a given dependent variable.

For each model, the normality of the residuals was assessed by plotting them against predicted values of a given dependent variable. When the residuals deviated from normality, we used the weighted regression techniques of Paine and Hann (1982) to estimate model parameters.

The Weibull cumulative probability function (1) was tested for predicting sprout-diameter distributions of individual hardwood clumps:

$$P = 1 - \exp\{-[(dbh - 2.5)/B]^C\} \quad (1)$$

where

P = the cumulative probability for a given sprout dbh,

B = the Weibull *B*, or scale, parameter

C = the Weibull *C*, or shape, parameter

In order to estimate model (1), we calculated the cumulative probability for each 1-cm sprout dbh class within a sprout clump and combined data for all clumps. We used least-squares regression to estimate model parameters, because predictions from maxi-

num-likelihood parameter estimates fit poorly. We tested the goodness-of-fit of model (1) with the Kolmogorov-Smirnov (K-S) test ($\alpha = 0.05$) (Ostle and Mensing 1975).

Model Verification

To verify the predictive equations, we used remeasured growth data of individual sprout clumps of tanoak (Harrington 1989) and madrone (Hughes et al. 1990) from untreated plots at three Oregon sites. Chinkapin growth data were not available for model verification.

Using techniques similar to those of this study, we measured crown width, average height (after Tappeiner et al. 1984), maximum height, sprout number, and sprout dbh each year from 1982 to 1988 for 33 tanoak (2 to 8 years old) and 15 madrone (5 to 10 years old). A verification data set was constructed by randomly selecting a single annual measurement for each sprout clump. The K-S test was used to verify the predicted diameter distributions of 18 hardwood clumps that had stem diameters ≥ 2.5 cm.

RESULTS

Predictive Equations

The following linear equation was developed for converting stump diameter (0.2 m height) of the parent tree to dbh (1.37 m height) before disturbance:

$$\begin{aligned} dbh &= -0.5544 + 0.8469 \\ &\quad (\text{diameter at 0.2 m}) \\ n &= 705, \text{ adjusted } r^2 = 0.992, \\ s_{y,x} &= 1.580 \end{aligned}$$

Regression parameters for species differences were not retained in this model, because they explained less than 0.1% additional variation in dbh.

Model form (2) was developed for predicting hardwood crown width, height (maximum and average), and number of sprouts of dbh ≥ 2.5 cm:

$$Y = b_0(PBA^{b_1})(AGE^{b_2}) \quad (2)$$

where $PBA(dm^2)$ is total basal area in stems of a given parent tree, AGE is number of growing seasons since burning, and b_0 , b_1 , and b_2 = regression coefficients.

A linear model (3) provided the best description of the relationship between height and dbh of dominant sprouts:

$$\begin{aligned} \text{sprout height} &= b_0 + b_1 \\ &\quad (\text{sprout dbh}) \end{aligned} \quad (3)$$

where b_0 and b_1 = regression coefficients.

Model form (4), an expansion of model (1), adequately described the

Table 2. Equations for predicting (a) crown width (cm), (b) average height (cm), and (c) maximum height (cm) for sprout clumps of tanoak, madrone, and chinkapin from PBA (total basal area in stems of the parent tree, dm^2) and AGE (number of growing seasons since burning).¹

Species	Regression coefficients			adj. R^2	$s_{y,x}$	n
	b_0	b_1	b_2			
(a) crown width = $b_0(PBA^{b_1})(AGE^{b_2})$						
tanoak	0.9126 E + 2 ²	0.1877	0.4780	0.753	47.5	908
madrone	0.9591 E + 2	0.1585	0.4780			
chinkapin	0.9126 E + 2	0.1585	0.4780			
(b) average height = $b_0(PBA^{b_1})(AGE^{b_2})$						
tanoak	0.6002 E + 2	0.1319	0.6852	0.764	53.3	517
madrone	0.8397 E + 2	0.7053 E - 1	0.6852			
chinkapin	0.6002 E + 2	0.7053 E - 1	0.6852			
(c) maximum height = $b_0(PBA^{b_1})(AGE^{b_2})$						
tanoak	0.7800 E + 2	0.1462	0.5804	0.758	65.7	468
madrone	0.1075 E + 3	0.1082	0.5804			
chinkapin	0.7800 E + 2	0.1082	0.5804			

¹ Each model was developed from data pooled across the three species. $s_{y,x}$ is the standard error of the estimate; adj. R^2 is the coefficient of determination adjusted for degrees of freedom.

² Symbolology for scientific notation, 0.9126×10^2 .

sprout diameter distributions of individual hardwood clumps:

$$P = 1 - \exp\left(-\left\{\frac{dbh - 2.5}{[b_0(PBA^{b_1})(AGE^{b_2})]^C}\right\}\right) \quad (4)$$

where PBA and AGE are as defined for model form (2), b_0 , b_1 , and b_2 = regression coefficients, and $b_0(PBA^{b_1})(AGE^{b_2})$ was substituted for the Weibull B parameter, and C is the Weibull C parameter.

Some of the parameters for the regression models that predict hardwood crown size (Table 2) and sprout-diameter distributions (Table 3) varied by species. Variables describing site characteristics and competing vegetation abundance were not retained as predictors in any of the models because they did not explain more than 2% of additional variation in the dependent variables.

Variables of PBA, AGE, and species accounted for more than 75% of the variation in crown width, average height, and maximum height of hardwoods (Table 2), and 62% of the variation in sprout number (Table 3). Sprout dbh and species explained 93% of the variation in sprout height, and the regression slope parameter for

tanoak was significantly greater than that for madrone or chinkapin ($P < 0.001$) (Table 3).

Although some of the regression parameters for the crown width model varied by species, a plot of predicted crown width versus AGE revealed only minor species differences, especially when PBA equaled 3 dm^2 (Figure 2a). For each species, crown width at 16 years was approximately 400 and 550 cm for clumps with PBA of 3 and 15 dm^2 , respectively. In contrast, predicted average height versus AGE differed distinctly by species, with growth rates ranking madrone > tanoak > chinkapin (Figure 2b). At 16 years, height of madrone clumps originating from small parent trees (PBA = 3 dm^2) exceeded that for tanoak clumps from large parent trees (PBA = 15 dm^2). Predicted average height versus AGE for chinkapin, however, varied little with increasing PBA.

For PBA values of 3 or 15 dm^2 , tanoak clumps had more sprouts (dbh ≥ 2.5 cm) than madrone or chinkapin at 16 years (Figure 2c). For example, the regression models predict 22 sprouts for 16-year-old tanoak clumps with a PBA of 15 dm^2 , but only 10

Table 3. Equations for predicting (a) sprout number, (b) sprout height (cm), and (c) cumulative probability of sprout dbh for sprout clumps of tanoak, madrone, and chinkapin from PBA (total basal area in stems of the parent tree, dm^2) and AGE (number of growing seasons since burning).¹

Species	b_0	b_1	b_2	C	adj. R^2	$s_{y,x}$	n
(a) sprout number = $b_0(PBA^{b_1})(AGE^{b_2})$							
tanoak	0.3989	0.5956	0.8708		0.619	3.07	105
madrone	0.2017 E + 1 ²	0.3241	0.2509				
chinkapin	0.3989	0.3241	0.8708				
(b) sprout height = $b_0 + b_1$ (sprout dbh)							
tanoak	0.1237 E + 3	0.6339 E + 2			0.929	34.8	504
madrone	0.1380 E + 3	0.4865 E + 2					
chinkapin	0.1237 E + 3	0.4865 E + 2					
(c) cumulative probability of sprout dbh = $1 - \exp\left(-\left\{\frac{dbh - 2.5}{[b_0(PBA^{b_1})(AGE^{b_2})]^C}\right\}\right)$							
tanoak	0.1444 E - 1	0.3196	0.1591 E + 1	0.7400	0.532	0.188	310
madrone	0.2673 E - 1	0.3196	0.1591 E + 1	0.7400			
chinkapin	0.1444 E - 1	0.3196	0.1591 E + 1	0.7400			

¹ Each model was developed from data pooled across the three species. $s_{y,x}$ is the standard error of the estimate; adj. R^2 is the coefficient of determination adjusted for degrees of freedom.

² Symbolology for scientific notation, 0.2017×10^1 .

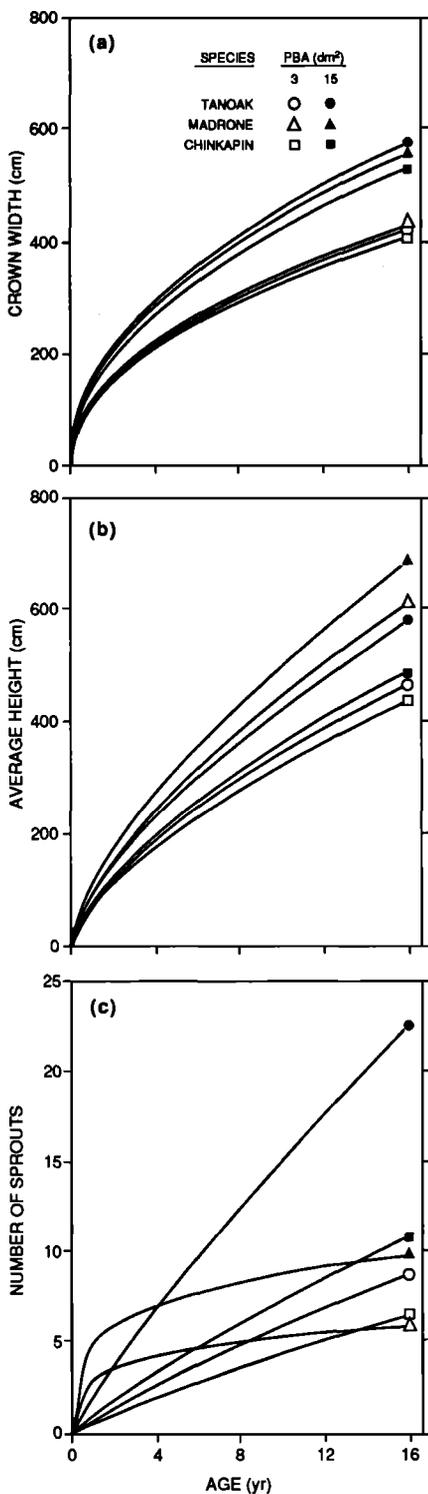


Figure 2. Predicted 16-year development of (a) crown width, (b) average height, and (c) sprout number of sprout clumps of tanoak, madrone, and chinkapin for parent-tree basal areas (PBA) of 3 and 15 dm².

sprouts for clumps of madrone and chinkapin of the same age. For PBA values of 3 or 15 dm², the predicted number of sprouts was similar in madrone and chinkapin; however, the initial increase in sprout number with AGE was much greater for madrone.

Frequency of stem diameters of sprouts plotted against dbh (1-cm classes) followed a reverse J-shaped

curve for each of the three species (Figure 3). For constant values of AGE, the height of the predicted diameter distributions increased as PBA varied from 3 to 15 dm², indicating increases in sprout number for all dbh classes. For constant values of PBA, the predicted distributions for tanoak and chinkapin lifted as AGE varied from 5 to 15 years, also indicating increases in sprout number for all dbh classes (Figure 3). In contrast, the frequency of madrone sprouts in the 3-cm dbh class decreased as AGE increased, indicating no replacement of sprouts in the smallest diameter class as frequencies were redistributed to larger classes.

Model Verification

To provide a visual assessment of the fit of the predictive equations to the verification data, we plotted predicted values for crown size (width, average height, and maximum height), sprout height, and sprout number against observed values for these variables (Figure 4). In general, we feel that the models fit the verification data adequately. If these verification data are assumed to be an adequate test of model bias, the models slightly underpredict crown size, sprout height, and sprout number, especially for large sprout clumps.

According to the K-S test, predicted distributions for sprout diameters deviated significantly ($\alpha = 0.05$) from the observed diameter distributions in only 11 of the 105 sprout clumps of the model-building data set. For the verification data set ($n = 18$), none of the predicted diameter distributions deviated significantly from the observed distributions.

DISCUSSION

The predictive equations provide a technique for assessing the development of individual sprout clumps of tanoak, madrone, or chinkapin through 16 years after cutting and burning the parent trees. Predictions of hardwood crown size can be used to forecast potential competition for associated conifer seedlings (Harrington et al. 1991b) and to efficiently allocate space in mixed stands to conifers and hardwoods. Since growth of Douglas-fir seedlings is inversely related to hardwood cover (Hughes et al. 1990, Harrington et al. 1991a), preharvest stands with the greatest potential recovery rates following disturbance (i.e., those with high levels of hardwood basal area and stem density) could be prioritized for vegetation management. Growth reductions and mortality of conifers could be limited by modifying their planting arrangement to accommodate hardwoods with large PBA. Hardwoods with large PBA are probably capable of produc-

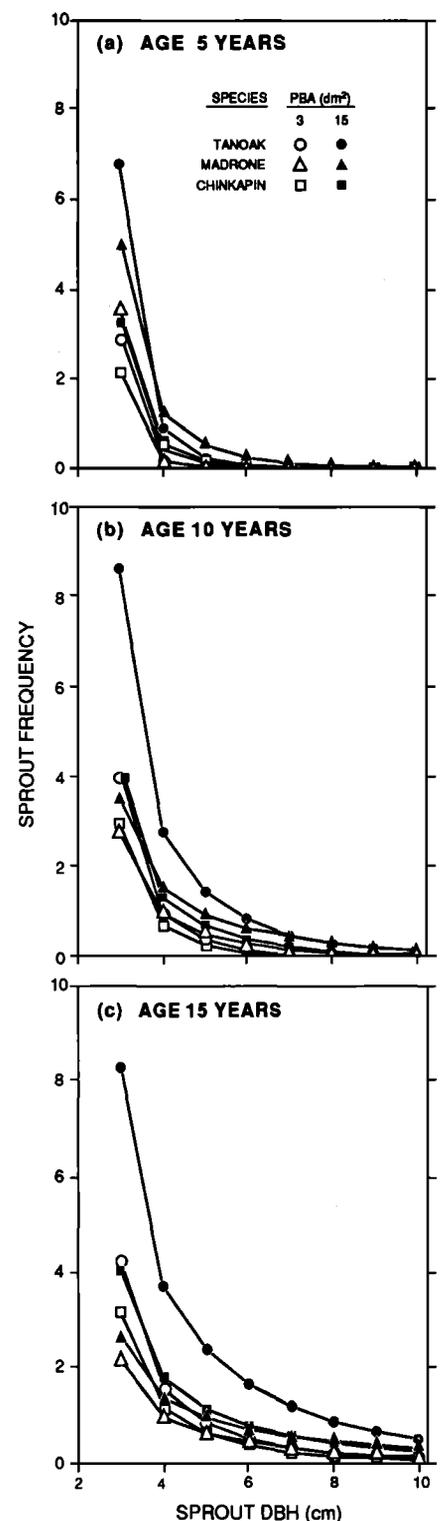


Figure 3. Predicted sprout frequency per 1-cm dbh class for sprout clumps of tanoak, madrone and chinkapin for AGE values of (a) 5, (b) 10, and (c) 15 years and for parent-tree basal areas (PBA) of 3 and 15 dm².

ing wildlife habitat and food early in stand development; thus, they could be identified and managed as potential crop trees.

We recommend the following procedure for developing a list of stem sizes (i.e., height and dbh) for an individual sprout clump as input for computer

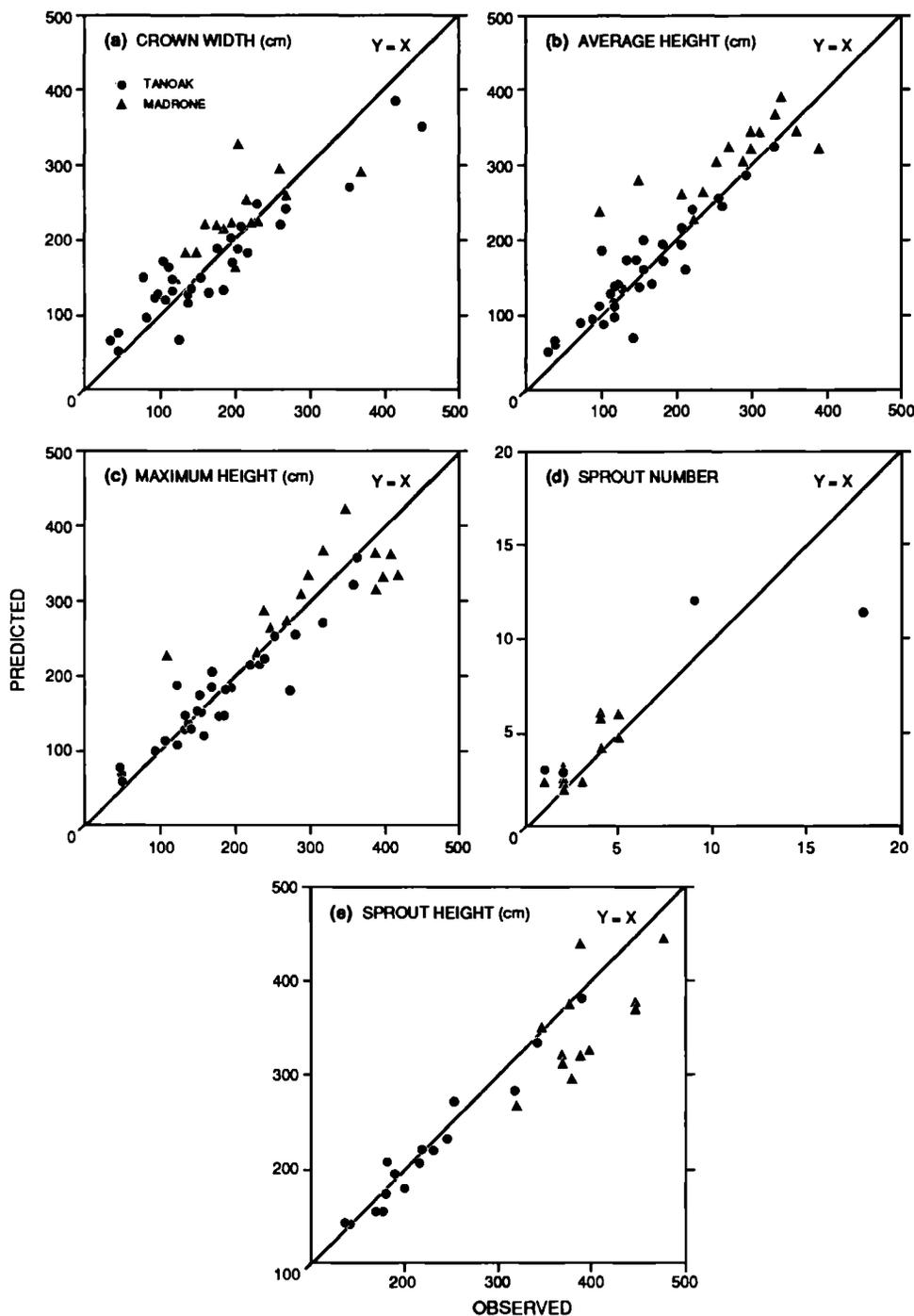


Figure 4. Predicted values of hardwood (a) crown width, (b) average height, (c) maximum height, (d) sprout number, and (e) sprout height plotted against observed values from the verification data set. Variables (a)–(d) were predicted from parent-tree basal area (PBA) and AGE; variable (e) was predicted from sprout dbh.

simulators of stand growth (see Table 3).

- 1 Use PBA and AGE to predict sprout number for a given clump.
- 2 Predict a dbh value for each sprout with Equation (5), a solution of the Weibull cumulative probability function (1) for dbh:

$$dbh = \frac{\exp\{\ln_e[-\ln_e(1 - P)]\}}{C + \ln_e(B)} + 2.5 \quad (5)$$

where P = random number between 0 and 1, and C , B = Weibull parameters as defined in Equation (4).

3. Use the regression equation in Table 3 to predict sprout height for each dbh.

To ensure maximum validity of the equations, we recommend confining predictions of clump development to the ranges of independent variables in Table 1. It is important to note the limited data on which the predictive equations for chinkapin were based. In this study, site characteristics and competitor abundance had little or no effect on the development of hardwood clumps. Thus, our predictive equations are applicable to clearcut

and burned areas of various site qualities and stand characteristics. □

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Cone Production by Rooted Cuttings, Grafts, and Seedlings of Western Larch

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ABSTRACT. Cone production in 1991 was compared among rooted cuttings from juvenile trees, grafts from mature scions, and seedlings planted in a common garden in Plains, MT, in 1981 and 1983. The differences among tree types were statistically significant for the mean number of cones per tree, but were not significant for the percent of trees producing cones. A projection of cone production per 1,000 trees showed that the grafts would produce nearly twice the number of cones as the seedlings and more than five times the number of cones as the rooted cuttings under the same conditions.

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Despite its relatively limited natural distribution, western larch (*Larix occidentalis* Nutt.) is one of the most desirable forest tree species in the Inland Northwest. This fast-growing conifer produces high quality, high value wood that is used interchangeably with Douglas-fir for construction lumber, plywood, and other industrial uses (Schmidt et al. 1976). Western larch is the only coniferous species that contains arabinogalactan, a water-soluble natural gum that is used in offset lithography, food preparation, pharmaceutical products, paints, and inks. Genetic studies of growth and phenological characteristics of western larch seedlings have shown similarities among sources across much of its range, suggesting that relatively long-

distance seed transfer is feasible if modified by moderate restrictions on elevational transfer (Rehfeldt 1982). In addition, relatively high genetic gains have been predicted for juvenile height growth in this species (Fins and Rust 1989).

All of these factors have contributed to increased interest in artificial regeneration of western larch in the Inland Northwest, but in the last decade, planting efforts have been hampered by a shortage of seed due to repeated cone crop failures. Although cone crops have been irregular over many years (Schmidt et al. 1976), only recently have spring frosts been implicated in the frequent failures. In studies conducted over a widespread area from 1985 through 1990, nearly all sample trees produced male and female strobili each year. However, spring frosts subsequently killed most of the strobili in all but the lowest elevation sites, and insects often killed or damaged the few cones that remained (Shearer 1990).

Assuming that spring frosts will continue to decimate western larch cone crops, the development of practices that would increase the reliability of cone production would be highly valuable. One alternative is to establish seed orchards in areas not subject to frequent spring frosts and which can be protected from other damaging agents.

In many seed orchards, grafts are

used to replicate the selected genotypes several to many times, which, with random mating among clones, can be expected to provide consistently high genetic gains from orchard seed. An additional feature of grafted trees is that they tend to retain the physiological stages of sexual maturity of their donors (Olesen 1978, Zobel and Talbert 1984). Thus, for late-maturing species, such as western larch, which does not produce abundant cone crops until 40-50 years of age (Schmidt and Shearer 1990), grafts made with scions from mature donors should produce seed considerably sooner than sexually immature seedlings (Zobel and Talbert 1984).

As with many other forest tree species, western larch trees can be vegetatively propagated by grafting (Staubach and Fins 1988) or by rooting cuttings (Edson et al. 1991). While both types of propagules have been recommended for use in seed orchards, little is known about the onset and relative rates of cone production compared to seedlings in the same environments. The purpose of this study was to compare cone production among rooted cuttings, grafts, and seedlings of western larch trees growing in the same environment.

MATERIALS AND METHODS

In fall 1981, rooted cuttings, grafts, and seedlings of western larch were planted in 10-tree row plots at 6 × 6 ft spacing at the Champion Timberlands Nursery at Plains, MT. Cutting donors (34 two-year-old seedlings) and scion donors (20 fifty-year-old trees) were from the same stand at Pryne's Reservoir in western Montana. Rooting and grafting took place during the spring of 1981 (Staubach 1983). The rootstock used for the grafts were 2-0 bareroot seedlings. Comparison seedlings were operational planting stock grown by three private nurseries in Montana. Thirty-eight percent of the seedlings were containerized stock that had been germinated in the spring of 1981,