Understory Response Following Varying Levels of Overstory Removal in Mixed Conifer Stands

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ABSTRACT: Diameter growth rates of understory trees were measured for periods both before and after overstory removal on six study areas in northern California. All the species responded with increased diameter growth after adjusting to their new environments. Linear regression equations that predict posttreatment diameter growth increment of the residual trees are presented for the six study areas.

Additional key words: diameter increment equation; northern California

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Today, in states like California, social, legislative, and economic considerations are compelling public and private forest managers to look for alternatives to clearcutting that will not dramatically change forest appearance. This evolution in management philosophy makes silviculture practices like overstory removal attractive harvest alternatives to clearcutting and regeneration (Laacke and Fiddler 1986; Guldin 1995). Practices like overstory removal can create stands with structural diversity that are well stocked with well distributed crop trees (Helms and Standiford 1985; Laacke and Fiddler 1986; Guldin 1995; Oliver 1995).

Consequently, forest managers are interested in understanding the advantages and disadvantages as well as stand adequacy for overstory removal. If properly implemented, the residual forest resulting from overstory removal serves as immediate growing stock and the time needed to grow merchantable-sized trees may be reduced. In addition, from an aesthetic perspective, the residual forest has an appearance of a continuous forest canopy. Also, the residual forest provides soil protection and cover for wildlife.

The objective of this research is to determine diameter growth rate response of residual trees (2.54 cm dbh or greater) following varying levels of overstory removal and to document the growth of these trees over a long period of time in the true fir (TF), east-side pine (EP), and Sierra Nevada mixed-conifer (MC) timber type on the Plumas, Klamath, Lassen, Modoc, and Shasta-Trinity National Forests and the Swain Mountain Experimental Forest of the Pacific Southwest Research Station, all in northern California. Furthermore, it provides 14-, 15- or 16-year posttreatment diameter growth response equations for the residual trees. The first growth periods, 8 years or 10 years, were the length of time from overstory removal to the time the plots were installed. The periods 14-, 15- or 16-year posttreatment were the length of time from overstory removal to the time the plots were remeasured in 1994.

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METHODS

Between 1978 and 1982, 14 timber sales on the Plumas, Klamath, Lassen, Modoc, and Shasta-Trinity National Forests and the Swain Mountain Experimental forest of the Pacific Southwest Research Station, all in northern California were designed and implemented as overstory removals. Sales were in the true fir (TF), east-side pine (EP), or Sierra Nevada mixed-conifer (MC) timber type. Before cutting, the Region-5 Silvicultural Development Unit established two to seven homogeneous units within each sale area for sampling before and after harvest conditions. Overstory volume removed from the timber sale units ranged from 72 to 707 m^3/ha. These units ranged from 0.73 to 3.0 hectares in size, depending on stand size and condition. From the fourteen overstory removal sale areas, six sale areas that were representative of the entire fourteen areas were selected which provided the data base for this study. Two are in the Lassen National Forest, two in the Plumas National Forest, one in the Shasta-Trinity National Forest, and one in the Swain Mountain Experimental Forest of the Pacific Southwest Research Station (PSW). These six areas are composed of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), California white fir (*Abies concolor* [Gord. & Glend.] Lindl.), California red fir (*Abies magnifica* A. Murr.), incense-cedar (*Libocedrus decurrens* Torr.), sugar pine (*Pinus lambertiana* Dougl.), ponderosa pine (*Pinus ponderosa* Laws.) and Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.). Between 1988 and 1989 residual trees 2.54 centimeters (cm) diameter at breast height (dbh) or larger were measured and trees 7.62 cm dbh and larger were cored. The increment core samples were used to age sampled trees. The trees were remeasured again in 1994. Increment cores were used to determine past outside-bark dbh for each sample tree. To show the effect of varying levels of overstory removal on residual trees, a 2-dimensional bar chart was used to display a combined data of 8-year and 10-year pretreatment periodic annual diameter increment (cm), 8-year and 10-year posttreatment periodic annual diameter increment (cm), and 9- to 16-year posttreatment periodic annual diameter increment (cm) by species for the six areas.

For detailed description of study areas, study design, plot location, and installation, refer to the study design manual on file at the Pacific Southwest Research Station, Redding, California.

ANALYSES

Past outside bark diameter at breast height, for each sample tree at the time of overstory removal and 8-years or 10-years before overstory removal were calculated using bark growth adjustment factors developed for each species (Dolph 1984). To eliminate the measurement bias that occurs when increment cores are used instead of repeated measurements of dbh to determine outside-bark diameter growth, the diameter growth measurements were adjusted by using the equation presented in Zumrawi (1990).

To show the effects of overstory removals on residual trees, a 2-dimensional bar chart was used to depict a combined dataset of 8-year and 10-year pretreatment periodic annual diameter growth (cm), 8-year and 10-year posttreatment periodic annual diameter growth (cm), and 9 to 16 year posttreatment periodic annual diameter growth (cm) by species from the six timber sale areas. Linear regression equations were used to select the model that provided the best fit for posttreatment diameter growth increment (cm) of the residual trees. In this analysis, 14-, 15-, or 16-year posttreatment diameter growth increment was selected as the dependent variable for the species within each of the six timber sale areas. The standard linear regression model used was:

$$\hat{Y} = \beta_1 + \beta_2 \cdot X_1 + \beta_3 \cdot X_2 + \beta_4 \cdot X_3 + e$$

where, $\hat{Y}$ is the expected value of 14-, 15-, or 16-year posttreatment diameter increment (cm), X_1 is Initial dbh (cm), X_2 is Pretreatment 8-year or 10-year dbh growth (cm), X_3 is the sum of the residual trees basal area in trees with $dbh's_1$ larger than the subject tree's dbh_1 (m^2), e is a random error component with an expected value of zero and variance of σ^2, and β_1, β_2, β_3, and β_4 are regression coefficients to be estimated. For developing the regression equations, as a result of analyses of covariance, ponderosa pine and Jeffrey pine data were combined. Each of the study areas was composed of more than two species with the exception of Nuisance area, which had only red and white fir. White fir was the predominant species at each of the study areas with the exception of the Nuisance units which were composed of about 75% red fir and 25% white fir.

RESULTS

Regardless of species, the residual trees from the six overstory removal study areas responded by increasing diameter growth—the 9- to 16-year period—after adjusting to their new environment (figure 1). There were no significant visual difference between the 8-year or 10-year pretreatment periodic annual diameter growth increment and their 8-year or 10-year posttreatment counterpart (figure 1).

Although all the independent variables strengthened the regression model, initial diameter and 8- or 10-year pretreatment diameter growth increment were on the average the best predictors of posttreatment dbh growth.

1. Johnson's Ravine units - Plumas National Forest

Table 1—Equation, parameter estimates, and summary statistics for data used in equation parameter estimates for white fir and Douglas-fir for Johnson's Ravine units on the Plumas National Forest.

The following model form was used for all species: $\hat{Y} = \beta_1 + \beta_2 \cdot X_1 + \beta_3 \cdot X_2 + \beta_4 \cdot X_3$ where, $\hat{Y}$ is the expected value of 15-year posttreatment diameter increment (cm), X_1 is Initial dbh (cm), X_2 is pretreatment 8-year dbh diameter increment (cm), and X_3 is the sum of the residual trees basal area in trees with $dbh's_1$ larger than the subject tree's dbh_1 (m^2).

White fir

$R^2 = 0.476$; Adjusted $R^2 = 0.472$; Standard error of estimate = 0.698528; N = 401

$\beta_1 = 0.585086$; $\beta_2 = 0.022963$; $\beta_3 = 1.761658$; $\beta_4 = -1.910840$

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	401	0.5842	7.1628	1.6746	0.9610
X_1 (cm)	401	1.4732	26.7716	4.0646	3.3973
X_2 (cm)	401	0.2794	3.4290	0.6563	0.3241
X_3 (m^2)	401	0.0000	0.2471	0.0823	0.0680

Douglas-fir

$R^2 = 0.289$; Adjusted R^2 0.276; Standard error of estimate = 0.973746; N = 174

$\beta_1 = 1.492709$; $\beta_2 = 0.05953$; $\beta_3 = 0.535954$; $\beta_4 = -2.226717$

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	174	0.5334	6.9342	2.0603	1.1444
X_1 (cm)	174	0.1016	38.9382	7.1528	7.1633
X_2 (cm)	174	0.2794	6.3246	0.7531	0.5659
X_3 (m^2)	174	0.0000	0.2425	0.0912	0.0729

2. Nuisance units - Swain Mountain Experimental Forest

Table 2—Equation, parameter estimates, and summary statistics for data used in equation parameter estimates for white and red fir for Nuisance units on the Swain Mountain Experimental Forest.

The following model form was used for all species: $\hat{Y} = \beta_1 + \beta_2 \cdot X_1 + \beta_3 \cdot X_2 + \beta_4 \cdot X_3$ where, $\hat{Y}$ is the expected value of 14-year posttreatment diameter increment (cm), X_1 is Initial dbh (cm), X_2 is pretreatment 8-year dbh diameter increment (cm), and X_3 is the sum of the residual trees basal area in trees with $dbh's_1$ larger than the subject tree's dbh_1 (m^2).

White fir

$R^2 = 0.678$; Adjusted $R^2 = 0.671$; Standard error of estimate = 1.488461; N=135

$\beta_1 = 1.308372$; $\beta_2 = 0.050595$; $\beta_3 = 1.546470$; $\beta_4 = -1.168990$

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	135	0.5334	11.2268	3.4330	2.5952
X_1 (cm)	135	0.3302	56.5658	16.2372	13.0348
X_2 (cm)	135	0.2749	8.2550	1.0470	1.1297
X_3 (m^2)	135	0.0000	1.0739	0.2268	0.2430

Red fir

$R^2 = 0.721$; Adjusted $R^2 = 0.718$; Standard error of estimate = 1.143038; N=339

$\beta_1 = 0.393796$; $\beta_2 = 0.047980$; $\beta_3 = 1.462290$; $\beta_4 = -0.240425$

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	339	0.5334	11.3538	2.4942	2.1536
X_1 (cm)	339	1.4732	65.1002	10.0266	9.9147
X_2 (cm)	339	0.2794	5.9944	1.0201	0.8860
X_3 (m^2)	339	0.0000	1.0526	0.2951	0.1869

3. Ashpan units - Lassen National Forest

Table 3—Equation, parameter estimates, and summary statistics for data used in equation parameter estimates for white fir, incense-cedar, and ponderosa pine for Ashpan units on the Lassen National Forest.

The following model form was used for all species: $\hat{Y} = \beta_1 + \beta_2 \cdot X_1 + \beta_3 \cdot X_2 + \beta_4 \cdot X_3$ where, $\hat{Y}$ is the expected value of 15-year posttreatment diameter increment (cm), X_1 is Initial dbh (cm), X_2 is pretreatment 8-year dbh diameter increment (cm), and X_3 is the sum of the residual trees basal area in trees with $dbh's_1$ larger than the subject tree's $dbh_1 (m^2)$.

White fir

$R^2 = 0.793$; Adjusted $R^2 = 0.792$; Standard error of estimate = 1.019009; N = 410;
$\beta_1 = 0.452650$; $\beta_2 = 0.042159$; $\beta_3 = 1.556146$; $\beta_4 = -0.345494$

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	410	0.3810	14.5796	2.778	2.233
X_1 (cm)	410	1.0414	71.0692	13.735	12.512
X_2 (cm)	410	0.2286	6.8326	1.178	1.049
X_3 (m^2)	410	0.0000	1.0191	0.250	0.230

Incense-cedar

$R^2 = 0.678$; Adjusted $R^2 = 0.632$; Standard error of estimate = 0.728699; N = 25
$\beta_1 = 0.448340$; $\beta_2 = 0.063968$; $\beta_3 = 1.311775$; $\beta_4 = -0.559722$

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	25	0.8128	6.0960	2.0787	1.2017
X_1 (cm)	25	1.8542	11.6078	5.4610	3.2572
X_2 (cm)	25	0.5588	2.1336	1.0231	0.6218
X_3 (m^2)	25	0.0316	0.2406	0.1090	0.0601

Ponderosa pine

$R^2 = 0.712$; Adjusted $R^2 = 0.682$; Standard error of estimate = 0.813210; N = 33
$\beta_1 = 0.526531$; $\beta_2 = 0.055560$; $\beta_3 = 1.194360$; $\beta_4 = -2.047985$

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	33	0.6604	5.8166	2.1251	1.4425
X_1 (cm)	33	1.4986	42.7990	12.4514	11.9029
X_2 (cm)	33	0.2794	2.5400	1.0599	0.6490
X_3 (m^2)	33	0.0000	0.7794	0.1753	0.1788

4. Baker units - Lassen National Forest

Table 4—Equation, parameter estimates, and summary statistics for data used in equation parameter estimates for white fir, incense-cedar, and ponderosa pine for Baker units on the Lassen National Forest.

The following model form was used for all species: $\hat{Y} = \beta_1 + \beta_2 \cdot X_1 + \beta_3 \cdot X_2 + \beta_4 \cdot X_3$
where, $\hat{Y}$ is the expected value of 15-year posttreatment diameter increment (cm), X_1 is Initial dbh (cm), X_2 is Pretreatment 8-year dbh diameter increment (cm), and X_3 is the sum of the residual trees basal area in trees with $dbh's_1$ larger than the subject tree's $dbh_1 (m^2)$.

White fir
$R^2 = 0.703$; Adjusted $R^2 = 0.698$; Standard error of estimate = 1.258685; N=155
$\beta_1 = 0.936319$; $\beta_2 = 0.017542$; $\beta_3 = 2.014347$; $\beta_4 = -2.244906$

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	155	0.7874	13.8176	3.2405	2.2886
X_1 (cm)	155	1.4732	33.2740	11.3215	7.7417
X_2 (cm)	155	0.2794	4.2672	1.2721	0.8272
X_3 (m^2)	155	0.0000	0.4441	0.2035	0.1413

Incense-cedar
$R^2 = 618$; Adjusted $R^2 = 0.609$; Standard error of estimate = 0.922139; N=119
$\beta_1 = 0.783234$; $\beta_2 = 0.060019$; $\beta_3 = 1.531049$; $\beta_4 = -2.748025$

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	119	0.6604	8.0518	2.4211	1.4738
X_1 (cm)	119	1.4224	27.8892	7.4439	6.3217
X_2 (cm)	119	0.5334	2.4384	0.9949	0.4957
X_3 (m^2)	119	0.0000	0.2471	0.1208	0.0745

Ponderosa pine
$R^2 = 0.774$; Adjusted $R^2 = 0.769$; Standard error of estimate = 0.893487; N=169
$\beta_1 = 0.762186$; $\beta_2 = 0.039165$; $\beta_3 = 1.301063$; $\beta_4 = -1.114868$

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	169	0.3556	9.5250	2.5770	1.8606
X_1 (cm)	169	1.4986	57.5310	8.3205	7.0319
X_2 (cm)	169	0.2794	5.6642	1.2733	1.0660
X_3 (m^2)	169	0.0000	0.4468	0.1504	0.1306

5. Clear Creek units - Plumas National Forest

Table 5—Equation, parameter estimates, and summary statistics for data used in equation parameter estimates for white fir, incense-cedar, and Douglas-fir for Clear Creek units on the Plumas National Forest.

The following model form was used for all species: $\hat{Y} = \beta_1 + \beta_2 \cdot X_1 + \beta_3 \cdot X_2 + \beta_4 \cdot X_3$ where, $\hat{Y}$ is the expected value of the natural log of 16-year posttreatment diameter increment (cm), X_1 is Initial dbh (cm), X_2 is the natural log 10-year pretreatment diameter increment (cm), and X_3 is the sum of the residual trees basal area in trees with $dbh's_1$ larger than the subject tree's $dbh_1 (m^2)$.

White fir
$R^2 = 0.631$; Adjusted R^2 0.628; Standard error of estimate = 0.398525; N = 327
$\beta_1 = 0.438603$; $\beta_2 = 0.257867$; $\beta_3 = 0.572599$; $\beta_4 = -0.496208$

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	327	-0.2073	3.5274	0.7597	0.6533
X_1 (cm)	327	0.3874	4.2086	1.9057	0.7986
X_2 (cm)	327	-1.2751	1.9653	-0.1671	0.5882
X_3 (m^2)	327	0.0000	0.8203	0.1930	0.1816

Incense-cedar
$R^2 = 0.571$; Adjusted $R^2 = 0.542$; Standard error of estimate = 0.354433; N = 49
$\beta_1 = 0.087994$; $\beta_2 = 0.316401$; $\beta_3 = 0.323544$; $\beta_4 = -0.637387$

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	49	-0.2073	1.9934	0.6204	0.5178
X_1 (cm)	49	0.7337	4.1673	2.0282	0.7886
X_2 (cm)	49	-1.1881	1.3704	-0.2649	0.5209
X_3 (m^2)	49	0.0000	0.5202	0.1527	0.1308

Douglas-fir
$R^2 = 0.670$; Adjusted R^2 0.667; Standard error of estimate = 0.402687; N = 84
$\beta_1 = 0.264725$; $\beta_2 = 0.391084$; $\beta_3 = 0.444312$; $\beta_4 = -0.618182$

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	84	-0.2390	2.5789	1.0169	0.6982
X_1 (cm)	84	0.5317	3.6455	2.2165	0.7549
X_2 (cm)	84	-2.9799	1.2396	-0.1272	0.6704
X_3 (m^2)	84	0.0000	0.8119	0.1495	0.1392

6. Algoma units - Shasta-Trinity National Forest

Table 6—Equation, parameter estimates, and summary statistics for data used in equation parameter estimates for white fir, incense-cedar, ponderosa pine, and Douglas-fir for Algoma units on the Shasta-Trinity National Forest.

The following model form was used for all species: $\hat{Y} = \beta_1 + \beta_2 \cdot X_1 + \beta_3 \cdot X_2 + \beta_4 \cdot X_3$ where, $\hat{Y}$ is the expected value of 16-year posttreatment diameter increment (cm), X_1 is Initial dbh (cm), X_2 is the 10-year pretreatment diameter increment (cm), and X_3 is the sum of the residual trees basal area in trees with $dbh's_1$ larger than the subject tree's $dbh_1\,(m^2)$.

White fir

R^2 = 747; Adjusted R^2 = 0.744; Standard error of estimate = 1.425071; N=248

β_1 = 0.762275; β_2 = 0.031623; β_3 = 1.905888; β_4 = -1.660163

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	248	0.5334	18.0848	3.1939	2.8172
X_1 (cm)	248	1.0160	43.7388	9.5116	8.0149
X_2 (cm)	248	0.2794	5.9944	1.2829	1.0911
X_3 (m^2)	248	0.0000	0.8714	0.3193	0.2449

Incense-cedar

R^2 = 0.754; Adjusted R^2 0.751; Standard error of estimate = 0.835371; N = 213

β_1 = 0.322331; β_2 = 0.019097; β_3 = 1.476258; β_4 = -0.356837

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	213	0.5588	8.9154	2.2042	1.6731
X_1 (cm)	213	1.4224	72.8472	8.3567	8.5520
X_2 (cm)	213	0.3048	5.4610	1.0840	0.8057
X_3 (m^2)	213	0.0000	0.8705	0.3093	0.2397

Douglas-fir

R^2 = 0.860; Adjusted R^2 = 0.849; Standard error of estimate = 1.450578; N = 42

β_1 = 1.824187; β_2 = 0.091052; β_3 = 1.501438; β_4 = -2.732571

Variables	Number of cases	Minimum	Maximum	Mean	Standard Dev
$\hat{Y}$ (cm)	42	0.7874	13.3858	4.5587	3.7286
X_1 (cm)	42	1.9304	38.5572	10.8954	10.2368
X_2 (cm)	42	0.2794	6.9088	1.5760	1.6678
X_3 (m^2)	42	0.0000	0.6958	0.2283	0.1857

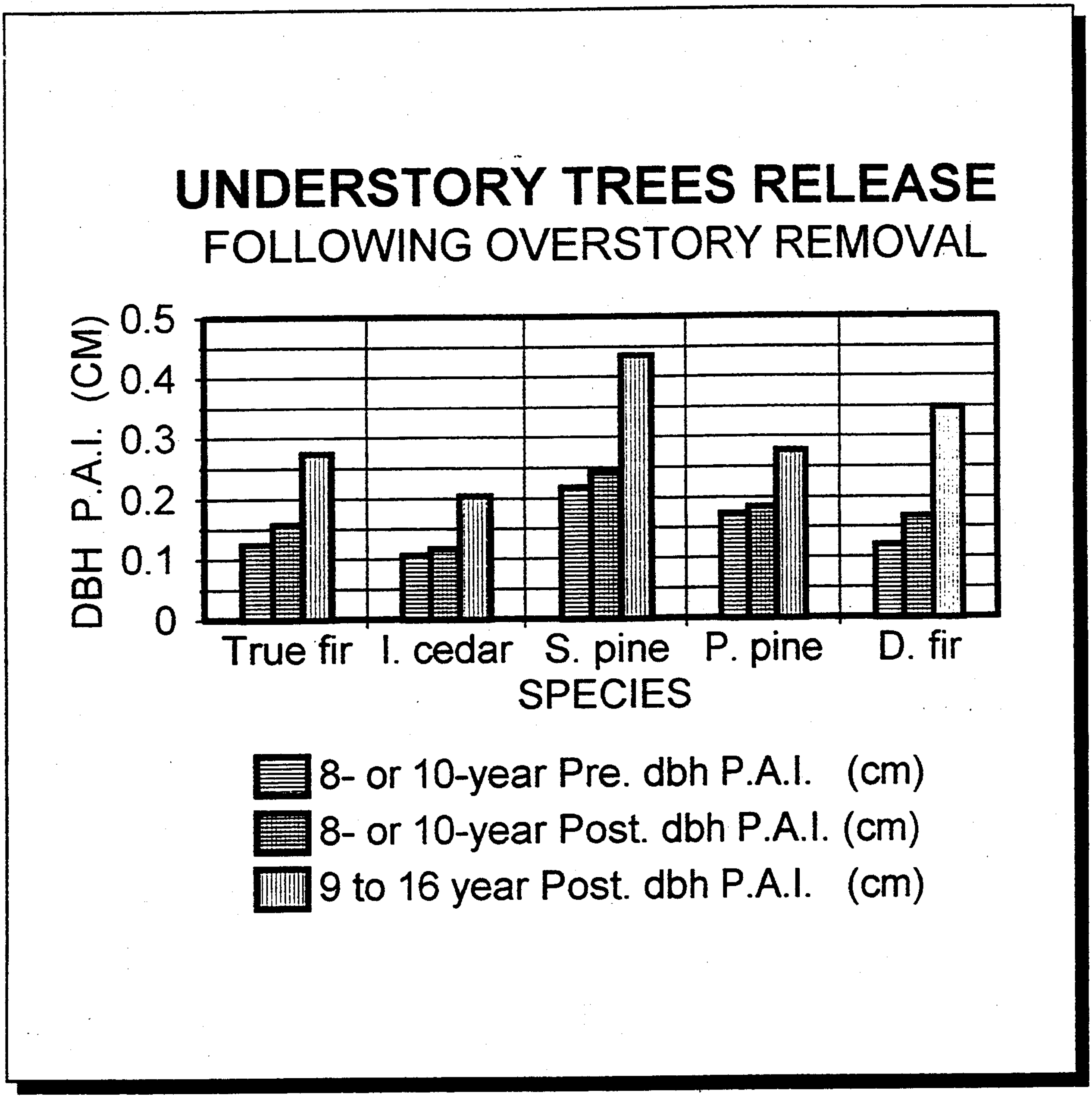

Figure 1.—Periodic annual diameter increment of residual trees by species following varying levels of overstory removal in mixed conifer stands (diameter classes combined) 8-year or 10-year pretreatment, 0- to 8-year or 10-year posttreatment, and 9- to 16-year posttreatment for Ashpan units on the Lassen National Forest, Baker units on the Lassen National Forest, Johnson's Ravine units on the Plumas National Forest, Clear Creek units on the Plumas National Forest, Algoma Units on the Shasta-Trinity National Forest, and Nuisance units on the Swain Mountain Experimental Forest of Pacific Southwest Research Station all in northern California (with a combined dataset from the six areas).

DISCUSSION

Regardless of species, residual trees responded to overstory removal by increasing their diameter growth after adjusting to their new environment—the 9- to 16-year period (Figure 1). This compares well with the findings of Gordon (1973) for northern California. We can not tell how many years it took the residual trees to adjust to their new environment because measurements were not done on an annual basis. Based on observations, we can say that it took the residual trees between three and seven years to adjust to their new environment depending on the best combinations of amount of overstory removed, stand condition, and tree potential (Oliver and Larson 1996 p. 95). This compares well with the findings of McCaughey and Schmidt (1982). With time and on average, sugar pine diameter growth response was the greatest followed by Douglas-fir and white fir. Incense-cedar and ponderosa pine showed the least response. This compares well with the findings of Oliver and Dolph (1992) for northern California.

On average, 8-year or 10-year posttreatment periodic annual diameter growth increment were not different from their 8-year or 10-year pretreatment period (figure 1). However, after the residual trees had adjusted to their new environment, 9- to 16-year posttreatment periodic annual diameter growth increment showed a substantial increase in growth response compared to their 8-year or 10-year posttreatment counterparts. Although how long this acceleration in growth will continue is uncertain, studies have shown that it can continue beyond 21 to 30 years after treatment (Roe and DeJarnette 1965; Harring and McMinn 1980).

Linear regression equations were developed to predict 14-, 15- or 16-year posttreatment diameter growth increment. The equations were developed for each species within each timber sale area (tables 1 - 6). For developing the regression equations, ponderosa pine and Jeffrey pine data were combined within each timber sale area as a result of analyses of covariance. The independent variables were initial diameter (X_1), 8-year or 10-year pretreatment diameter growth increment (X_2), and the total basal area per plot of residual trees larger in diameter than that of the subject tree (X_3) . Although all the independent variables strengthened the regression model, initial diameter and 8- or 10-year pretreatment diameter growth increment were on the average the best predictors of posttreatment dbh growth.

After overstory removal, the residual trees compete for the growing space previously occupied by the removed overstory trees, which in turn is influenced by species composition and crown position (Oliver and Larson 1996 p. 95). To estimate the competitive position that a residual tree holds within a plot after overstory removal, X_3 was included in the equations. This variable (X_3) has been used as a tree-position variable in equations for predicting basal area growth because it defines a tree's position in relation to all trees measured in a plot or stand (see Ritchie and Hann 1985; Wykoff 1986; Dolph 1988). Since X_3 is the sum of basal area of the residual trees in trees with diameter larger than the subject tree's diameter, the largest-diameter tree in the plot would have X_3 value of zero, while the smallest-diameter tree in the plot would have an X_3 value near but somewhat less than the plots's total basal area.

Additionally, the increment attained by an individual tree is also dependent on its competitive status relative to neighboring trees—a tree's relative size. As a result, relative size is tied to stand density. Therefore, in sparsely stocked plots or stands, dominance would be less of a factor, because the more open-grown the tree, the less it is influenced by competitors (Wykoff 1990). The effect of competitive stress due to neighboring trees is represented by X_3, because for a given tree, diameter increment should decrease as X_3 increases and vise versa. Consequently, the coefficient of X_3 is negative, indicating a competition modifier that would reduce diameter growth rates relative to a tree's competitive status.

CONCLUSIONS

Silvicultural practices like overstory removal can be attractive harvest alternatives to clearcutting and regeneration, because it serves as immediate growing stock and the time needed to grow merchantable-sized trees may be reduced. Also, it can help create needed structural diversity. From an aesthetic perspective, the residual forest resulting from overstory removal has an appearance of a continuous forest canopy. Furthermore, the residual forest provides soil protection and cover for wildlife.

Nevertheless, overstory removal has three major disadvantages: (1) it may wrongly be used on sites where more intensive management practices should otherwise be used; (2) it can result in logging damage that may predispose advance regeneration to long-term disease problems; and (3) for optimum results, skilled loggers familiar with improved harvesting techniques (which cost more) are used because of the need to protect damage to advanced regeneration. The above disadvantages notwithstanding, alternatives like overstory removal if implemented successfully, can result in uneven-aged mixed-species stands that are well stocked with well-distributed crop trees.

Meanwhile, for a stand to be adequate for overstory removal, it has to exhibit the following characteristics: (a) the stand has to be made up of at least two age classes, with the older class merchantable and removable and (b) the residual stand should be adequately stocked with well-distributed crop trees, whose value would equal or exceed that attainable should the stand otherwise be regenerated.

Finally, examination of the linear regression equations developed to predict 14-, 15- or 16-year posttreatment diameter growth increment show that the equations are consistent with our current biological and silvicultural knowledge.

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