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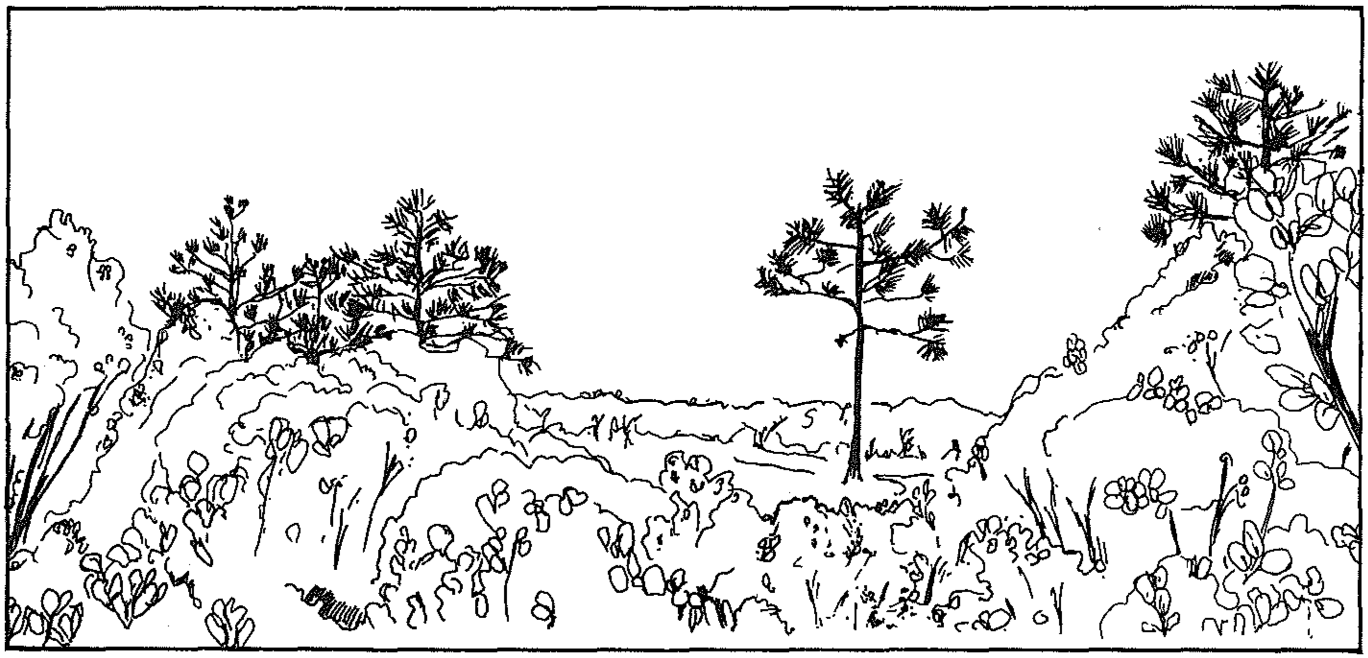
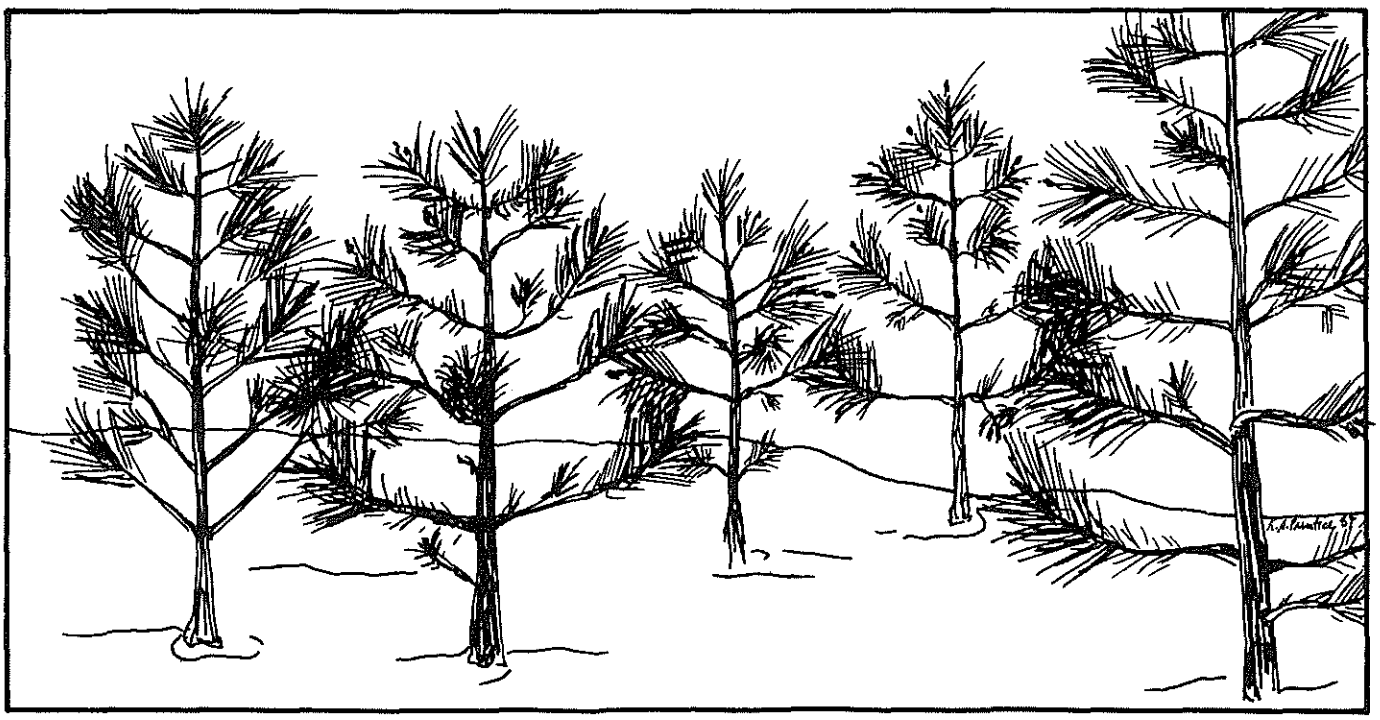
Brush Reduces Growth of Thinned Ponderosa Pine in Northern California

William W. Oliver





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IN BRIEF...

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The role of stocking control in increasing the growth and vigor of potential crop trees in young plantations of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) is well recognized. Most stocking level recommendations, however, are for stands that contain little or no understory woody vegetation (brush). And yet brush is known to be a common and aggressive competitor that robs ponderosa pines of soil moisture and nutrients. Lack of information on the interrelationships of levels of tree stocking and competing brush quantities impairs the efficiency and even the effectiveness of plantation management.

The effects of tree spacing and brush competition were evaluated on a site of low productivity in California's North Coast Range. Moisture and possibly nutrients were limited by a shallow, skeletal soil. Site index was estimated to be 17 m (55 ft) at 50 years.

Eleven-year-old saplings were thinned to square spacings of 2.1, 2.4, 3.0, and 4.3 m (7, 8, 10, and 14 ft) in each of three blocks. After 5 years, the plots were subdivided into thirds. All, half, and none of the understory brush (principally hoary manzanita [*Arctostaphylos canescens* var. *candidissima* Eastw. Munz]) was manually removed in a split-plot design.

An analysis of variance showed that brush crown cover was significantly ($p < 0.05$) related to periodic annual increment (PAI) in diameter-at-breast-height (d.b.h.), height, and stem volume of the pines. Differences in d.b.h. and height growth were significant among all three brush treatments when all spacings were combined. Stem volume production rose significantly when all brush was removed but not when half the brush was removed. Without brush control, the plantation growth rate declined in all characteristics from the first to the second 5-year period after tree thinning.

Spacing significantly influenced diameter growth only when all brush was removed. Height growth and stem volume production were not significantly influenced by spacing, probably because of the short period of growth monitored after brush treatment and differences in initial tree size among plots.

No relationship between 5-year change in brush crown cover and trees per hectare was found. The ponderosa pines, even when closely spaced at 2.1 by 2.1 m (7 by 7 ft), did not suppress growth of brush. Instead, increasing brush density restricted tree growth, suggesting that brush exploited the site's resources more vigorously than did the pines.

A threshold value of brush crown cover below which brush did not suppress tree growth was not found in this study. A multivariate, nonlinear equation relating brush crown cover and trees per hectare to PAI d.b.h. (R^2 = 0.90) suggests that any amount of brush will restrict d.b.h. growth. Only when brush cover is light will spacing exert an influence. At coverages greater than about 30 percent, brush competition overwhelms intertree competition and all trees regardless of spacing grow at the same rate.

Tree death was negligible but insect damage was abundant during the period of observation. The gouty pitch midge (*Cecidomyia piniinopis* Osten Sacken) caused the most noticeable damage associated with brush treatment but not with tree spacing. Larval feeding of this and other unidentified insect species deformed tops and caused loss of foliage. Insect damage tended to exacerbate the growth loss caused by brush competition.

As currently practiced, brush control methods do not eliminate all brush. Unless these methods can be expected to reduce brush coverage substantially over a major portion of early stand life, benefits to tree growth and health will be fleeting, at best. Even small amounts of brush can restrict tree growth markedly, and the major tree growth losses found in this study should prevail in similar plantations on sites of low productivity. Consequently, the cost of brush control should be included as an integral part of the regeneration cost. If, however, brush control is not planned, yields and rotations should be adjusted accordingly.

Stocking control is a cultural treatment commonly applied in young plantations of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*). Its role in increasing the growth and vigor of potential crop trees is well recognized. Recommended stocking levels for a range of management objectives, sites, and tree sizes are available and are being refined as research continues (Barrett 1979; U.S. Dep. Agric., Forest Serv. 1973).

These stocking level recommendations are for stands that contain little or no understory of woody vegetation (brush). And yet we know brush to be a common and aggressive competitor, robbing ponderosa pines of soil moisture and nutrients. Forest managers estimate that growth loss from competing brush is substantial in nearly one-third of all ponderosa pine plantations in California.[1] Currently, brush is being treated on about 4000 ha (10,000 acres) of these plantations annually.

Lack of information on the interrelationships of levels of tree stocking and competing brush quantities impairs the efficiency and even the effectiveness of plantation management. Competing brush can lengthen the time to first comercial thinning regardless of tree spacings or site productivity. Barrett (1973) estimated that brush control would have saved a decade of time to first commercial entry in a stand of pine poles spaced 5.7 by 5.7 m (18.7 by 18.7 ft) on a medium site in central Oregon. On a highly productive site in California, the equivalent of 3 years' growth in diameter-at-breast-height (d.b.h.) was lost to brush competition after 12 years when trees were planted at about the same spacing (Oliver 1979).

On sites of low productivity, brush competition can exert even stronger effects. After 19 years, planted pines competing with dense manzanita and ceanothus brush were only 27 percent as large in diameter and 35 percent as tall as pines free of brush (McDonald 1982). Part of this size difference resulted from greater damage from frequent insect attacks that destroyed buds and needles. Yields projected from these growth rates fall far short of nominal management objectives (Fiske 1982).

This paper reports the effects of tree spacing and brush growing in a ponderosa pine plantation on a site of low productivity in the North Coast Range of California. Implications for managing pine stands and controlling brush are suggested.

[1]Data on file at the Pacific Southwest Forest and Range Experiment Station, Redding, Calif.

STUDY AREA

The effects of tree spacing and brush competition on planted ponderosa pine are being evaluated on the Trough Springs Ridge 14 km (9 mi) southwest of Stonyford, Colusa County, at 1280-m (4200-ft) elevation on the eastern slope of the North Coast Range (lat. 39° 17′ N., long. 122° 40′ W.). Plots are within a 15-ha (36-acre) area. Almost all slope aspects and gradients up to 20 percent are represented.

Average annual precipitation is 1041 mm (41 inches), about 10 percent of which falls within the April through August growing season. Summers are hot with maximum daily temperatures in July usually about 32° C (90° F).

The soil has been classified as Maymen Series, a Dystric Lithic Xerochrept derived from Pre-Cretaceous metasedimentary rocks. Depth to lithic contact varies from 20 to 33 cm (8 to 13 inches), but some roots can penetrate to an unknown depth along the extensive vertical fractures. Maymen Series, which usually supports chaparral, is found extensively on steep slopes between 300 and 1200 m (1000 and 4000 ft) on the west slope of the Sierra Nevada and on the Coast Range.

The average site index, as measured by naturally established surrounding trees, is estimated to be 17 m (55 ft) at 50 years for trees less than 100 years of age (Powers and Oliver 1978). For older trees, a lower site index, about 14 m (45 ft), is a common phenomenon on shallow soils (Zinke 1959).

The original cover of Pacific Ponderosa Pine-Douglas-fir (Society of American Foresters Type 244) (Eyre 1980) was burned in August 1959. The following April, material remaining after salvage logging was windrowed and the cleared area cultivated with a rangeland disk. Ponderosa pine, stock class 2-0 and 2-1 from the appropriate seed zone, was hand planted at spacings that varied between 1.2 by 1.2 and 1.8 by 2.4 m (4 by 4 and 6 by 8 ft).

Survival was excellent, but tree growth was slowed by a shallow soil with little moisture-holding capacity apparently aggravated by severe brush competition. Eleven years after planting, trees averaged 2.8 cm (1.1 inches) in d.b.h. and 1.8 m (6 ft) tall. Stand density varied from 1422 to 3407 trees per ha (576 to 1380/acre). Manzanita (*Arctostaphylos canescens* var. *candidissima* Eastw. Munz, primarily, and scattered *A. roofii* [Gankin 1966]) formed a uniform understory. Brush crowns averaged 0.7 m (2.3 ft) and covered 30 percent of the area.

METHODS

Tree growth was evaluated at four tree spacings, established by thinning—2.1 by 2.1, 2.4 by 2.4, 3.0 by 3.0, and 4.3 by 4.3 m (7 by 7, 8 by 8, 10 by 10, and 14 by 14 ft). In fall 1970, each spacing was assigned to three 0.10-ha (0.25-acre) plots in a randomized block design. Plots were grouped into three blocks on the basis of small differences in site quality. Three additional plots, one each per block, were lightly thinned, leaving more than 1480 trees per ha (600/acre) as reserve to cover possible plot losses in the future. All plots were surrounded by a buffer strip 6 m (20 ft) wide.

Thinning was from below, leaving as potential crop trees the most vigorous, well-formed specimens as far as this was compatible with reasonably uniform spacing. Slash was left to decay on the site.

Before growth began the next spring, all trees were tagged, described by crown class, measured for d.b.h. to the nearest 0.25 cm (0.1 inch), and noted for insect damage and disease. Also, 20 percent of the trees, randomly chosen in each plot, were measured to the nearest 0.3 m (1 ft) for total height, crown width, and crown length. Upper stem diameters were measured directly on 20 trees per plot to obtain total stem volumes. Selection probability for this sample was proportional to estimated height.

The existing brush understory was measured to explain possible variation in tree growth not attributable to spacing. Three 0.002-ha (0.005-acre) circular brush sampling plots were permanently established at random locations in each tree plot. In each brush sampling plot, the species and mean maximum crown diameter and height of each woody plant were tallied to the nearest 0.03 m (0.1 ft).

Five years later, in fall 1975, when all tree and brush measurements were repeated, growth and vigor of the trees had deteriorated, probably because soil moisture and nutrients were limited by severe brush competition. A brush density treatment, therefore, was superimposed on each stand density plot. Each 0.10-ha (0.25-acre) stand density plot was divided into three equal subplots. All brush tops were manually removed from one-third, left untouched in one-third, and every other brush top, systematically chosen, was manually removed from the final third. Severing the above-ground parts killed most *A. canescens* var. *candidissima* outright because this species does not sprout. But the sprouting *A. roofii* required follow-up cutting. Tree measurements were unaffected except for assigning each tree its appropriate brush subplot. New brush sample plots had to be established, however.

Three brush sampling plots—0.001 ha (0.0025 acre) (half the area of the previous brush sampling plots)—were established at randomly chosen locations in the subplot with full brush. Three more brush sampling plots were established in subplots with half the brush removed. Measurements within the brush sampling plots were the same as in the previous brush sampling scheme. Two growing seasons after the brush was treated, we sampled d.b.h. on 217 trees selected at random within all tree spacings and brush treatments.

Ten years after tree thinning, all measurements were repeated (*table 1*). In addition, annual height growth for the last 5-year period was estimated by measuring internodal distances on a random sample of three trees in each brush-free subplot.

Tree and stand characteristics at the three measurement times were calculated as follows:

• Mean diameter-at-breast-height—d.b.h. of the tree of mean basal area.

• Total height—from a regression of height on d.b.h. calculated from the height sample trees separately on each subplot.

• Crown width and live crown ratio—arithmetic means.

Table 1—*Tree, stand and brush characteristics 5 years after brush treatment in a plantation of sapling ponderosa pines thinned to different spacings*

Tree spacing (m)	Brush Removal	Brush Coverage	D.b.h.	Height	Live crown ratio	Basal area	Total volume
		pct	*cm*	*m*	*pct*	*m²/ha*	*m³/ha*
4.3 by 4.3	None	42	7.6	3.4	65	2.6	4.2
	Half	19	7.0	3.4	64	2.2	3.8
	Full	0	8.4	3.8	77	3.1	5.5
3.0 by 3.0	None	66	6.8	3.2	57	4.2	7.6
	Half	34	7.0	3.3	69	4.1	7.4
	Full	0	7.6	3.5	68	4.3	7.3
2.4 by 2.4	None	39	4.9	2.5	58	3.0	5.7
	Half	19	6.4	3.0	63	4.8	10.0
	Full	0	7.7	3.6	69	6.9	11.9
2.1 by 2.1	None	51	6.4	3.0	59	6.7	10.8
	Half	17	6.6	3.1	62	7.4	12.0
	Full	0	7.3	3.4	65	8.6	16.6

• Stem volumes inside bark in cubic meters from a 0.3-m (1-ft) stump to tip—calculated by Grosenbaugh's (1974) STX computer program.

• Plot volumes immediately after thinning and subsequently were obtained by the following equation:

$$V = \frac{K}{n_j} \bullet \sum_{i=1}^{n_j} \left(\frac{V_{ij}}{est_i} \right)$$

in which

V = plot volume in cubic meters.

K = estimated sum of all tree heights in plot immediately after thinning.

n_j = number of trees measured for upper stem diameters living at time j.

V_{ij} = measured volume of tree i at time j.

est_i = estimated height of tree i.

Periodic annual increments (PAI) during the 5-year period after treating the brush were analyzed statistically (*table 2*). Overall treatment effects on PAI in d.b.h., height, and stem volume were evaluated by a split-plot analysis of variance (*table 3*). Stand and tree responses found statistically significant ($p \leqslant 0.05$) were evaluated further by multiple range tests or by regressions that included the three additional plots lightly thinned to more than 1480 trees per ha (600/acre).

RESULTS AND DISCUSSION

Without brush control, the plantation growth rate declined in all characteristics from the first to the second 5-year period after tree thinning. Mean PAI of all spacings in the subplots with no brush removal were:

Stand attribute:	*1 to 5 years*	*6 to 10 years*
D.b.h. (cm)	0.38	0.25
Height (m)	0.113	0.073
Basal area (m²/ha)	0.349	0.308
Volume (m³/ha)	0.5290	0.5185
Live crown ratio (percent)	−2.2	−2.6

Growth in both diameter and height was only two-thirds of what it had been during the first 5-year period. And basal area and volume growth per hectare, normally expected to increase rapidly at this age, actually declined slightly.

Length of living crown remained almost unchanged during the two 5-year periods. As a result, live crown ratio diminished 2.2 percent annually during the first 5 years, and worsened to 2.6 percent during the second 5-year period. Unless crowns lengthen, in 7 more years the average tree will have only 40 percent of its length in live crown. Ponderosa pine with crown ratios less than 40 percent may experience more growth losses because they apparently lack sufficient foliage to support rapid growth (Hallin 1956).

Brush-Spacing Effects

Analysis of variance showed that 5 years after brush treatment, both tree spacing and brush density, expressed as percent cover of brush crowns, significantly affected PAI of the planted pines (*table 3*).

Diameter Growth

Trees released from brush responded immediately with increased diameter growth. Results of the random sample of trees measured for d.b.h. after two growing seasons indicated a PAI equal to that found after five growing seasons. Average d.b.h. growth regardless of tree spacing was 0.25 cm (0.10 inch) for trees in subplots with full brush, 0.31 cm (0.12 inch) for trees in subplots with half brush, and 0.48 cm (0.19 inch) for trees in subplots with no brush.

Table 2—*Periodic annual increments for 5 years after brush removal in a plantation of sapling ponderosa pines thinned to different spacings*

Tree spacing (m)	Brush Removal	Brush Coverage	D.b.h.	Height	Live crown ratio	Basal area	Total volume
		pct	*cm*	*m*	*pct*	*m²/ha*	*m³/ha*
4.3 by 4.3	None	11	0.25	0.07	−2.7	0.15	0.25
	Half	8	.30	.12	−2.1	.16	.29
	Full	0	.61	.19	−1.0	.36	.63
3.0 by 3.0	None	22	.28	.08	−3.1	.30	.60
	Half	12	.32	.11	−1.6	.32	.64
	Full	0	.47	.17	−0.9	.46	.81
2.4 by 2.4	None	10	.22	.07	−2.2	.24	36
	Half	5	.32	.11	−1.4	.42	.80
	Full	0	.43	.16	−0.9	.65	1.06
2.1 by 2.1	None	13	.28	.09	−2.7	.50	.75
	Half	5	.30	.12	−2.1	.59	.94
	Full	0	.41	.14	−1.4	.79	1.50

Table 3 — *Values of "F" for annual increments during the 5-year period after brush removal in a plantation of sapling ponderosa pines thinned to different spacings*

Source	Df	"F" value when attribute was...		
		D.b.h.	Height	Volume
Block	2	2.18	24.97**	3.33
Trees per ha (T)	3	9.86**	0.92	2.84
Error	6	—	—	—
Brush (B)	2	89.70**	42.16**	7.68**
T × B	6	4.39*	1.08	0.62
Error	12	—	—	—

*Statistically significant at P = 0.05 level.
**Statistically significant at P = 0.01 level.

Periodic annual diameter growth was strongly influenced by both tree spacing and brush cover. Tree spacing had no discernible effect on diameter growth unless all brush was removed (*fig. 1*). When trees were free of brush, differences in annual diameter growth among the spacings were significant between the 0.61 cm (0.24 inch) grown by trees spaced 4.3 m (14 ft) apart and all narrower spacings. The power of the test may have been insufficient to detect further trends.

Diameter growth differences were significant among all three brush treatments when all spacings were combined. Even the overall mean PAI increase of 0.05 cm (0.02 inch) attributable to removing half the brush plants was significant. Removal of all plants increased diameter growth by an additional 0.18 cm (0.07 inch) annually across all spacings.

A significant interaction between tree spacing and brush treatment was detected for PAI d.b.h. (*table 3*). I presume that this statistical interaction is indicative of intertree competition and brush competition working together to suppress diameter growth. Removing brush from around widely-spaced trees allowed trees to grow rapidly because they were free of competition for the site's resources. But removing brush from around closely-spaced trees had less effect on growth because intertree competition still restricted tree growth. In this study, trees spaced 4.3 by 4.3 m (14 by 14 ft) grew 0.36 cm (0.14 inch) more in diameter annually when all brush was removed (*table 2*) — a statistically significant gain. The difference attributable to brush removal narrowed as spacings narrowed until the difference became a nonsignificant 0.13 cm (0.05 inch) annually at the 2.1-m (7-ft) spacing.

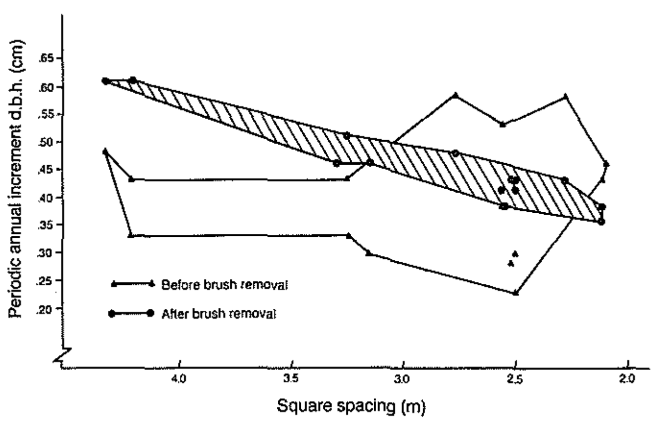

Figure 1 — Diameter growth in a sapling ponderosa pine plantation varied widely and was not closely correlated to tree spacing when brush was present.

Another interaction of importance concerns the competitive ability of trees, especially at close spacings, to suppress growth of brush. This question could not be answered by the main analysis of variance. Therefore, 5-year change in both brush crown cover in percent and brush crown volume in the brush subplots were plotted over trees per hectare. No trend of decreasing brush growth with increasing stand density was detected. The reverse was true, however. Increasing brush density restricted tree growth. Apparently, the trees are not exploiting the site's resources to the extent that the site is exploited by the brush.

Because tree spacing, and especially brush treatment, significantly influenced diameter growth, the relationships could be investigated further by regression analysis. Of particular interest was the presence of a threshold value of brush quantity below which brush might not suppress tree growth. But first I had to determine which aboveground attribute of brush was most closely related to tree growth. This question is of significance both to researchers investigating brush effects on tree growth and to forest managers evaluating brush control needs. Bentley and others (1971) expressed brush quantities as crown volume in cubic feet per acre. Dahms (1950) and Barrett (1973) expressed brush quantities as a percent of ground area covered by the vertical projection of their crowns. In this study, both measures were evaluated by comparing their coefficients of linear correlation with PAI d.b.h. of the pines. Crown cover percent yielded a higher correlation (r = 0.71) than did crown volume (r = 0.62). Similar results were found when analyzing the data in a companion study on a highly productive site.[1] Brush crown cover in percent and trees per hectare were the independent variables chosen to predict PAI d.b.h. The equation which fit best and gave biologically defensible solutions was obtained by nonlinear methods:

$$\text{PAI DBH} = \alpha_1 \, \text{EXP} \left\{ \frac{\alpha_2 \, \text{COV} + \alpha_3}{\text{TPH} + \alpha_4} \right\} + \frac{\alpha_5}{\text{TPH} + \alpha_6}$$

in which

PAI DBH = periodic annual increment in d.b.h. in cm
COV = coverage of brush crowns in percent
TPH = trees per hectare
α_1 = 0.028855
α_2 = −232.920887
α_3 = 7146.815769
α_4 = 2304.065885
α_5 = 3494.315102
α_6 = 13,486.463260

This equation explained 90 percent of the variation for mean diameter growth with a standard error of the estimate of 0.038 cm (0.015 inch).

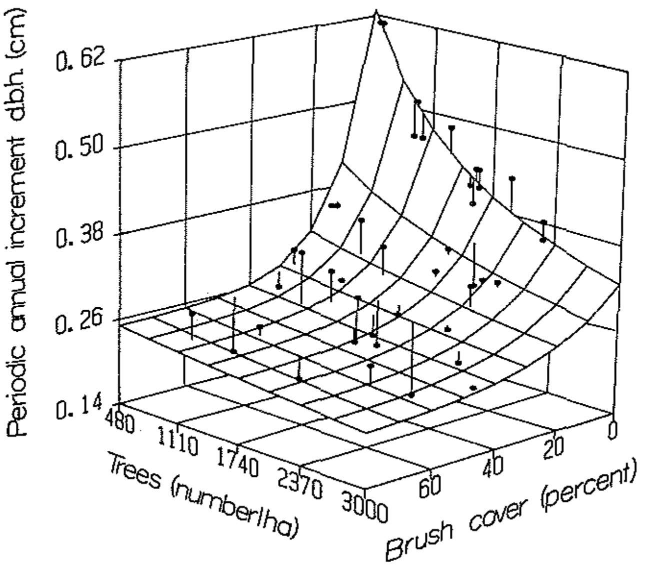

Figure 2—At brush coverages greater than about 30 percent, periodic annual diameter increment of ponderosa pine planted at a poor site was similar regardless of spacing.

A threshold value similar to that reported by Bentley and others (1971) is not apparent from *figure 2*. The equation suggests that, for this plantation at least, any amount of brush will restrict diameter growth, and only when brush cover is light will spacing exert an influence. At coverages greater than about 30 percent, brush competition overwhelms intertree competition and the response surface becomes almost horizontal. Trees at all spacings grow about 0.23 cm (0.09 inch) annually. Thirty percent crown cover was recommended by Kirchner and others (1978) as the density at which brush control efforts should begin. They based their recommendation on comparative heights of pine seedlings in plantations in the southern Sierra Nevada on sites more productive than Trough Springs Ridge.

Height and Volume Growth

In contrast to diameter growth, height growth response was delayed for 2 years after brush removal. Regardless of spacing, trees in brush-free subplots grew 0.11 m (0.36 ft) annually for the first 2 years. Then height growth jumped to 0.19 m (0.63 ft) annually for the next 3 years.

Growth in mean height and stem volume per hectare were not significantly influenced by spacing (*table 3*). The hypothesis that random variation caused the apparent tendency of brush-free trees to grow faster at wider spacings could not be rejected (*table 2*). The strong trend of increasing stem volume growth per hectare with closer spacings usually found in sapling stands was not statistically significant in this study probably because of differences in initial tree size among plots thinned to different spacings.

Brush treatment, however, exerted a statistically significant influence on growth in mean height and stem volume per hectare. Height growth was particularly sensitive to brush removal. Even removing half the brush significantly improved height growth, although the overall difference was only 0.04 m (0.12 ft) per year. Stem volume production per hectare per year rose 0.51 m^3 (7.3 ft^3/acre) overall when all brush was removed, a 29 percent increase in production over untreated brush plots ($p < 0.05$). Removing half the brush, however, did not result in a significant rise in annual production.

Mortality and Damage

Only seven trees died during the two periods reported—too few to relate to tree spacing or brush density. Insect damage was abundant and widespread, however. The larval feeding of many insect species on tree branches, buds, and the main stem deformed tops and resulted in loss of foliage. The two insects causing the most noticeable damage were the Sequoia pitch moth (*Vespamima sequoiae* Hy. Edwards) and the gouty pitch midge (*Cecidomyia piniinopis* Osten Sacken). Many others were not identified.

The larvae of the Sequoia pitch moth bore in the cambial region causing masses of pitch to form (Furniss and Carolin 1977). Indeed, resin flow from injured pines may promote pitch moth attacks (Powers and Sundahl 1973). And, presumably, because more vigorous trees produce more resin, tree thinning and brush removal, by increasing tree vigor, may be expected to promote more pitch moth attacks.

No relationship was found between tree spacing, brush density, or tree vigor (as measured by d.b.h. growth) and Sequoia pitch moth attack. Diameter growth of trees with pitch masses was similar to that of the average tree in each plot. About 74 trees per ha (30/acre) regardless of tree spacing or brush density seem to have been attacked within the past 3 years (as gauged by freshness of pitch masses). This level of attack appears to have been maintained in the plantation for many years.

Larval mining by the gouty pitch midge is the other prominent insect-caused damage. This mining scarred and twisted branches, caused resin exudations, and killed tops.

Deformed tops were counted in an attempt to quantify the amount of damage from attacks of the gouty pitch midge and other insects. The tops were chosen because they are easily measured and are a significant cause of growth loss. Tree spacing was found to be unrelated to incidence of top deformities but brush crown cover was related. The proportion of trees with deformed tops was correlated positively and significantly ($p < 0.01$) with brush crown cover. About 10 percent of the trees in brush-free subplots suffered deformed tops. The incidence doubled to 23 percent in plots with 60 percent brush crown cover.

The results of insect-caused top deformities taken from small plots probably are representative of results expected in practice from large plots. Greater amounts of insect damage with greater amounts of brush were noted in another ponderosa pine plantation (McDonald 1982). At first, I speculated that larger differences may have been masked because insects moved freely into and through adjacent subplots with widely differing brush and tree spacing treatments. Probably, however, these insects successfully attacked trees regardless of vigor, and vigorous trees are better able to withstand larval mining with only minor damage.

MANAGEMENT IMPLICATIONS

The history of the plantation on Trough Springs Ridge is a common one in northern California. A wildfire burned a stand of the Pacific Ponderosa Pine-Douglas-fir forest type on an exposed site with a shallow, skeletal soil. The area was planted with ponderosa pine that survived well, but manzanita brush invaded the plantation almost immediately. Eleven years after planting, brush competition was suppressing tree growth severely.

What options are available to the manager of such a plantation? If nothing is done, brush competition and insect attacks seem likely to continue and, possibly, intensify. Trees in the plantation on Trough Springs Ridge, which should have been growing 0.66 cm (0.26 inch) in diameter and 0.27 m (0.9 ft) in height annually (Oliver and Powers 1978), were growing only 0.38 cm (0.15 inch) in diameter and 0.07 m (0.24 ft) in height. And these rates were decelerating at an age when they should have been accelerating. How long this 10-year trend will continue can be speculated only. But yields certainly will be reduced and rotations lengthened. In projecting McDonald's (1982) data and those of others, Fiske (1982) estimated that trees competing with brush densities rated medium or heavier would take 10 years longer to reach diameters targeted for 55-year-old trees. Basal area targets could be delayed 3 to 5 decades because of higher tree mortality rates in dense brush. In his projection, Fiske assumed that on a medium site, brush would suppress pine growth for 30 years. Older trees were expected to grow at the same rate as trees free of brush. Greater losses are anticipated if current trends are projected. Nineteen-year trends of volume growth of ponderosa pine competing with mountain misery (*Chamaebatia foliolosa* Benth.) were projected to age 50 by Tappeiner and Radosevich (1982). They estimated a 75 percent reduction in net wood production from understory competition.

Investments in cultural treatments such as thinning and fertilizing may be wasted if brush is not controlled. Trees spaced 1.8 by 1.8 m to 4.6 by 4.6 m (6 by 6 ft to 15 by 15 ft) all grew at about the same rate in diameter when brush coverage was greater than 30 percent. Conversely, close spacing of trees did not restrict brush growth effectively. Results suggest instead that brush is better able to exploit the site's resources than is the pine. Nitrogen fertilization, for example, failed to stimulate ponderosa pine growth unless manzanita brush was eliminated (Powers and Jackson 1978).

If the manager elects to control brush, growth may increase dramatically. Depending on spacing, brush-free trees on Trough Springs Ridge grew 45 to 140 percent faster in diameter and 62 to 170 percent faster in height than trees in dense brush. Elsewhere, smaller but consistent growth rate differentials have been maintained for 12 years (Barrett 1973).

Practicable brush control methods do not eliminate all brush. And, unless these methods can be expected to reduce brush coverage substantially over a major portion of the early stand life, benefits to tree growth and health may be fleeting at best. I conclude at Trough Springs Ridge that even small amounts of brush can restrict tree growth markedly. Brush coverage had to be less than 20 to 30 percent before tree growth response was noticeable.

The major growth losses from brush competition experienced at Trough Springs Ridge should prevail in similar plantations on sites of low productivity. If true, the cost of brush control should be included as an integral part of the regeneration cost. If, however, brush control is not planned, yields and rotations should be adjusted accordingly.

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The effects of tree spacing and brush competition were evaluated on a ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) site of low productivity in California's North Coast Range. Eleven-year-old saplings were thinned to square spacings of 2.1, 2.4, 3.0, and 4.3 m (7, 8, 10, and 14 ft), and all, half, and none of the understory brush (principally manzanita [*Arctostaphylos* sp.]) manually removed in a split-plot design. Analysis of variance showed that brush crown cover was significantly related to periodic annual increment in diameter-at-breast-height, height, and volume of the pines. Spacing significantly influenced diameter growth only when all brush was removed. A nonlinear equation relating brush cover and trees per hectare to periodic annual increment in diameter explained 90 percent of the variation. The results suggest that, for the plantation studied, any amount of brush will restrict diameter growth. When cover exceeds 20 to 30 percent, brush competition overwhelms intertree competition, and trees grow at about the same rate regardless of spacing.

Retrieval Terms: Pinus ponderosa, Arctostaphylos sp., plantation management, vegetation management, tree growth, North Coast Range, California