23 Year Response of Ponderosa Pine and Douglas-fir Plantations to Shrub Density in Treated Stands of Madrone and Whiteleaf Manzanita

By Mike Newton and Liz Cole
Oregon State University College of Forestry

Abstract

Ponderosa pine (*Pinus ponderosa*) grown in mixture with whiteleaf manzanita (*Arctostaphyllos viscida*) and Douglas-fir (*Pseudotsuga menziesii*) grown in mixture with Pacific madrone (*Arbutus menziesii*) had roughly one fourth the volume at plantation age 22-23 when grown with uncontrolled competition than where woody competition was completely controlled at age 2. Both experiments were conducted on federal lands withdrawn from production due to difficulty of regeneration and poor growth potential. When competition was removed, height/age relationships at plantation age 22 and 23 put both species and sites in the range of medium quality rather than poor, indicating that these are commercially operable sites. These studies support the concept that competition management reveals the innate productivity of some sites for ponderosa pine or Douglas-fir that presently appear too poor to manage economically. They also underscore the potential for shortening the time interval between planting and harvest of sawlog timber on below-average sites.

Introduction

In 1980, the Forestry Intensified Research (FIR) program was initiated by the College of Forestry to evaluate reforestation options relevant to ponderosa pine and Douglas-fir sites in southwest Oregon where previous attempts had resulted in a high rate of failure. At that time, an 110,000 ha-area of "withdrawn" lands was perceived as having future productive potential if suitable regeneration could be obtained and maintained (Walstad, 1992). Vegetation and its competing effects were identified as a key constraint, and various FIR workers launched intensive studies to investigate creative ways of establishing conifer stands to replace brushfields. Tesch et al (1992) described the general problem of need for control of non-coniferous vegetation in the difficult southwestern Oregon climate and terrain in order to obtain survival of conifers. They also outlined some of the unique adaptations of the sclerophyll shrubs and hardwoods toward their own survival, all of which tend to increase their importance as competitors. At the termination of the FIR program, there were many installations indicating that successful regeneration was possible at affordable prices, and with a variety of technical strategies. Unfortunately, at that time, funding was terminated for all programs, and no follow-up has been possible on most of them.

We have managed to maintain two installations that evaluate the performance of ponderosa pine and Douglas-fir under a variety of intensities of competition from shrubs and hardwoods. Dr. Tim Harrington, of the USDA Forest Service, PNW Research Station, Olympia, has maintained measurements on two installations of similar design that evaluate the impact of tanoak on Douglas-fir growth. This report provides 22-23 years of data from experiments that evaluate effects of density of whiteleaf manzanita mixed with ponderosa pine of the same age, and also variable-density Pacific madrone in Douglas-fir, with a brief look at Harrington's Douglas-fir/tanoak installations for comparison.

The Study Sites

Ponderosa pine/whiteleaf manzanita. Study of whiteleaf manzanita in ponderosa pine was conducted on what was perceived to be a very poor site (600 mm precipitation) near Ruch, Oregon in the hot, dry valley of the Applegate River. White and Newton (1989) and Hanson (1997) have reported intermediate data from these installations. The ponderosa pine study was located on xeric low-elevation sites with west- southwest-facing slopes. Soil is a clay loam 60 to 90 cm deep underlain by metasedimentary rock. In late 1980, the sites were cleared and then brush piled in windrows and burned. In spring 1981, the soil was ripped with a crawler tractor to a depth of 45 cm along planting rows. In those rows, Douglas-fir and ponderosa pine bare-root stock were planted in a 50:50 mixture at a spacing of about 3 x 3-m or slightly closer. These plantations occurred in three units previously dominated by 40 to 50-year-old whiteleaf manzanita, and not previously occupied by conifers except near roadsides and isolated clumps upslope. One of these units (China Gulch) was broadcast sprayed with hexazinone (entire site, including herb plot) to provide survival by decreasing herbaceous competition; the other two units (Big and Little Humbug) were mulched with fiber or asphalt plus fiber-impregnated mats 90 x 90 cm square to ensure early survival.

After the first year, it became obvious that manzanita seedlings had germinated at densities capable of forming exceedingly dense stands. We used these sites to establish a shrub density study by thinning the manzanita and removing all other shrub and herb cover. To achieve the thinning, 1.2-liter soft-drink cups were placed over each conifer seedling, and over each manzanita seedling to be retained after marking locations at 60 x 60, 85 x 85, 120 x 120, 165 x 165 and 240 x 240-cm spacings or with all shrubs removed (Trees Only). These spacings are equivalent to 27000, 13500, 6720, 3360, 1700, and 0 shrubs per hectare (sph). The 85-cm spacing was installed in two plots in each of the three replications. In one of these, no further weeding was done after an initial application of hexazinone to ensure survival, offering an opportunity to measure the role of herbs added to shrubs. The other one was treated like the other densities, i.e. with conifers and spaced shrubs remaining and herbs removed. All plots initially sprayed for control of herbs were also weeded for three additional years so as to eliminate confounding of effects from herbaceous vegetation and other shrub species. The Trees Only plots were sprayed in the first four years to prevent invasion of competitors.

Each spacing of manzanita was organized in a square configuration across 20 x 20-m (66 x 66-foot) square plots in which initial populations of conifers ranged downward from 50 trees/plot. Gaps in the manzanita pattern were filled in by transplanting wild local stock. Each conifer seedling received a permanent number, and 25 manzanitas on each plot were tagged for measurement. Trees were thinned to 20 trees per plot at age 6, with the intention of having as close to an even mixture of pine and Douglas-fir as possible following heavier mortality in Douglas-fir. In the seventh and eighth years of the study, exceedingly hot dry summers occurred, and mortality removed nearly all Douglas-fir, leaving mostly pine as the nucleus of the study. Nearly all the plots now have less than 20 conifers, mostly pines. There has been some shrub mortality, primarily in the denser spacings, as the result of competitive interaction.

In 2002, one of the units (China Gulch) was subjected inadvertently to a mechanical fire hazard reduction treatment to eliminate continuity of fuel. This operation removed all the manzanita in all plots, and removed some of the remaining conifers. This practice was shut down before it reached the other units, but in the China Gulch unit, the population of measurement trees was reduced without silvicultural guidance. There is therefore an unknown influence of the fire hazard reduction treatment on mean tree size although all remaining individual trees were identified and measured. Because only one growing season had passed between fire-treatment and the time of re-measurement, effect on increment per tree since the previous measurement is thought to be very small.

Douglas-fir/madrone. The study of madrone with Douglas-fir was on land currently classified as Douglas-fir site V (King, 1966) within a slash-and-burn administrative study toward the rehabilitation of madrone-dominated steep ground without herbicides. This was a site at about 600-m elevation with very shallow soil but with 1270 mm precipitation near Canyonville, OR. The Douglas-fir site was on a unit designated as "Shoestring", and represented the outcome when a unit is slashed and burned hot after being occupied almost exclusively by madrone and poisonoak (*Rhus diversiloba*) for the previous forty-plus years. Following the burn, the site was planted in 1980 with two-year-old bare-root Douglas-fir on a 240 x 240-cm or closer spacing. Very little herbaceous cover appeared in the first year, and cover was sparse the second year. The second year after planting, when madrone sprouts were the dominant vegetation and about 2 m tall, we designed the study to evaluate the long-term influence of density of sprout clumps on planted Douglas-fir. In this study, we superimposed a pattern of controlled densities of the sprouting madrone clumps, among which were interspersed other shrubs, herbs and a few volunteer conifers. This study has been reported previously by Hughes et al. (1987), Pabst et al., (1990) and Hanson (1997).

The experimental design required fixed spacings of madrone sprout clumps on 0.04-ha square plots. Clump spacing was achieved by identification of sprout clumps to be left untreated followed by chemical removal of excess sprout clumps with 2,4-D directed sprays to leave clumps at spacings of 7 x 7 m (204 clumps per hectare (cph)) and 3.6 x 3.6-m (772 cph). The densest sprout clump treatment relied on natural spacing in which clump spacing varied around 180 x 180 cm (3086 cph) with no removals. A fourth treatment, in which all madrone clumps were targeted for killing, was also provided, making four levels of madrone competition ranging from none to unrestricted. In the years following treatment, the density of madrone increased due to volunteers and recovering sprout clumps, and remains somewhat different from that planned. For each level of madrone, there was a factorially combined treatment applied in year 3 in which herbs and other shrubs were treated (or not) with a directed spray of glyphosate. The herb treatment did not control evergreen shrubs such as canyon liveoak (*Quercus chrysolepis*) effectively (they remain), but did give temporary control of herbs and longer-term control of poisonoak, deerbrush ceanothus (*Ceanothus integerrimus*) and a few other deciduous species. Each combination was applied in three replications within that burned unit in forming a 2 x 4 randomized complete block factorial design

Initially, fifteen Douglas-fir seedlings were selected at random in each plot for repeated measurements. At age 13, we observed that this population represented a variable fraction of the total number of conifers present in each plot. We therefore thinned the population at that time to a planned level of 20 trees per plot (494 trees per hectare (tph), 200 trees per acre (tpa)) in all but unthinned-madrone plots, and tagged all trees. We opted to postpone thinning in the densest madrone plots to ensure that we would have a measurable population of conifers in the longer term; there was no obvious indication at that time of imminent intraspecific competition among the conifers in this understory situation. The sample of Douglas-fir in thinned plots was chosen from healthy, previously tagged trees, and was brought to a total of 20 by adding the healthiest looking among the untagged trees. In this process, a few trees were overlooked, hence some plots retained more than 20 trees, of which 20 were tagged. Data are therefore presented on a per-tree basis rather than total stand. In general, these data can be expanded to 494 tph (200 tpa) to create a common expansion factor because crowns had not closed at the time of thinning.

Companion studies. The Harrington studies were of similarly designed evaluations of sprout clump density effects on growth of Douglas-fir on previously logged and burned site class IV and V sites with a history of dense tanoak understories. They were also a part of the original program established in 1980-81 by Newton and Tappeiner, and have been followed up by Harrington and Tappeiner (1997); a report on this was submitted by Harrington at the 2004 Forest Vegetation Management Conference. Selections of data from those studies will be displayed in this report for comparative purposes.

All sites. All studies are on federal land. In 1983, herbicide use was suspended on all federal lands, interrupting the plan to spray for five consecutive years after planting to avoid confounding from herbs and miscellaneous shrubs. Fiber mats were installed on seedlings where herbs and shrubs were to be controlled. In one installation, one replication of ponderosa pine plots was weeded by hoeing a 1.5-m (five-foot) diameter circle around five conifers per plot for one additional year so we could evaluate the effect of continued weeding through year 5. No further weeding was done beyond that.

Measurements.

All trees of record were measured for height, and diameter at 15 and 137 cm (where present) during the first five years, and at years 7, 8, 13, and 14 (Douglas-fir). For year 23, diameters were measured on all record trees and heights were measured on a 35-40% subsample (8 trees/plot). At that time, height increments (nodes) were noted as far back as possible. Ponderosa pine are one year younger than the Douglas-fir, but were measured during the same calendar years, plus the fifth year (i.e. the sixth for Douglas-fir). Height was measured for all ponderosa pine for year 22. At the last measurement, crown length, and two-dimensional crown widths were recorded for both species. Hanson (1997) reported on the first 13 years in pine and 14 years in Douglas-fir.

The earlier measurements of shrubs in the ponderosa pine study were reported by White and Newton (1989), Hughes et al (1987), and Hanson, (1997). At each tree-measurement entry, manzanitas were measured for basal diameter, height, and two dimensions of crown width. These measurements included comparable measures of the same labeled manzanita shrubs as measured previously. The most recent measures of manzanita included height and crown width only. In the current measurements for the Douglas-fir study, we increased the measurements of madrone, and measured dbh of every madrone in five systematically located 2.5-m-radius subplots in each plot, and height of the madrone stem nearest each subplot center. No madrone measurements made between those reported by Hughes et al (1990) and Pabst et al (1990) and by us in year 23 have been previously summarized.

Soil moisture measurements were made in both studies with a neutron probe water meter in the first five years after planting, and water stresses were recorded in both shrub foliage and conifers. Also on these plots, data are available pertaining to the capacity of bedrock to retain water available for use by both shrubs and conifers (Wang et al, 1995; Zwieniecki and Newton, 1994, 1995, 1996a and 1996b). Water depletion was reported for the ponderosa pine study by White and Newton (1989) and for the Douglas-fir study by Pabst et al (1990) for the early years of the study, and no further water measurements have been made. These observations confirmed that these sites are extremely droughty every summer, and that the sclerophyll vegetation can reduce the soil water to extremes of tension. While we do not refer further to these data in this report, those records are valuable descriptions of the early water economy of plantations with varying densities of evergreen competition on shallow soils with southerly exposures.

Analyses

Analyses of the ponderosa pine data are based on a randomized complete block design evaluating seven vegetation treatments in which one replication was confounded by fuel treatment that removed all shrubs and a fraction of measurable trees at age 21. For year 22, two analyses were run which used 1) all three replications and 2) only the two intact replications. Results from the analyses were similar between the runs, so results are presented for all replications. Analyses were run for year 22 height, dbh, and volume (calculated from equations in Walters et al. 1985). Due to heterogeneity of variance, all measurements were log-transformed prior to analyses. Scheffe, Bonferroni, and Tukey's adjusted means tests were used to compare ANOVA means.

In addition to ANOVA, linear regression was used to evaluate the relation between manzanita density and ponderosa pine height, dbh, and volume at age 22. For these analyses, the two intact replications (Humbug units) were analyzed together, and separate equations were developed for the China Gulch unit. Because the manzanita data were calculated at the plot level, regressions were based on plot means rather than individual trees.

For the Douglas-fir/madrone study, the study design was a randomized block 2 x 4 factorial with four densities of madrone nominally, with and without herb treatment. Recovery of treated clumps and establishment of madrone seedlings changed the desired numbers of clumps within the density treatments. Examination of the actual numbers of surviving madrone clumps indicated that there were two types of confounding with a standard ANOVA analysis. First, on one block for two of the densities, there was over a two-fold difference in numbers of clumps between with and without herb treatments. Second, on one of the blocks, the numbers of clumps in the low and medium densities were similar. It was decided that cph should be used as a continuous variable, and analysis of covariance be used to compare models in a series of regressions (Littell et al. 1996) to test for separation of the herb treatments. Analyses were run for year 23 height, dbh, and volume (calculated from Walter et al. 1985). Log transformations were necessary to stabilize variance and because the relationships between dbh and cph and volume and cph were not linear. Heights for record trees that were not part of the height subsample were estimated from equations developed from the height subsample trees.

Results

Ponderosa pine. Height (Figure 1), dbh (Figure 2), and volume (Figure 3) of ponderosa pine were substantially affected by manzanita despite the pine being dominant over manzanita for most of their lives. ANOVA means of heights and diameters for the treatments where manzanita remained at any spacing were no longer significantly different from each other despite their having been different in earlier years (Hanson, 1997). Where the shrubs had been completely removed, diameters, and volumes are significantly greater than where manzanita densities with or without herbs were at densities of 13500 sph or more (Table 1). Pine height also displayed poor growth at ages 21 and 22 reflecting the severely prolonged summer drought in 2001 and 2002, but this was not obviously related to treatment (Figure 1).

Table 1. *p* values and least-squared means from ANOVAs for pine height, dbh, and volume at age 22. Means have been back-transformed from log values. Manzanita densities are given as of the time of establishment, 1981.

	Height		**DBH**		**Volume**
ANOVA *p* values for plot	.0072		.0042		.0034
	Means				
Manzanita Density (sph)	cm		mm		m^3
27000	627 ab[1]		144 b		.044 b
13500	589 b		140 b		.038 b
13500+herbs	562 b		130 b		.031 b
6720	684 ab		154 ab		.050 ab
3360	790 ab		174 ab		.071 ab
1700	735 ab		172 ab		.066 ab
Trees Only	964 a		220 a		.132 a

[1] Means within column followed by the same letter are not significantly different at *p*=0.05 using Bonferroni's adjusted means comparisons.

Pine showed a variable tendency for growth in early years to decrease with each increment of manzanita, both in height and diameter. The poorest growth in early years was shown in the manzanita treatment (13500 sph) in which herbs were not treated after the first year, and where the effects of herbs persisted for some years. This effect is no longer significant.

Based on regression analyses, mean pine height, diameter, and volume (Figure 4) were all significantly, negatively correlated with manzanita density. However, if the Trees Only plots were not included in the regression, the relationship was not significant (*p*>.05) for the intact (Humbug) units.

Manzanita had reached the point of crown overlap at all densities. Individual manzanita demonstrated a negative response to manzanita density (Figure 5). Current crown diameters of manzanitas were significantly ($p<.05$) and negatively correlated with manzanita density.

Douglas-fir. Height, dbh, and volume of Douglas-fir were still showing signs of herbaceous weed control ($p<.026$), although the differences between the two herb treatments were not great (Figures 6 to 8). Analyses indicated that slopes of the lines were not different between the two herb treatments, indicating that trees were exhibiting the same relationship with madrone density, with or without the presence of herbaceous plants. All parameters exhibited strong trends of decreasing size with increasing madrone density ($p<0.05$). Because of the confounding of madrone density on blocks, and madrone density and herbaceous treatments, it is difficult to examine changing size in time. To illustrate the effects of madrone density in time, plot means are graphed against time and madrone density (cph in year 23) (Figure 9). Diameters continue to diverge rapidly in Douglas-fir growing in various densities of madrone. Differences appear to be increasing with time, but we do not have diameter measurements in 2000, 2001, and 2002 to inform about the effect of recent climate.

Tanoak studies. A superficial comparison of our two studies with the two tanoak studies (Harrington and Tappeiner, 1999 recently measured by Harrington) show considerable consistency in effects of woody competitors on planted conifers in response to evergreen woody competitors (Figure 10). Harrington's measurements of Douglas-fir growing among regulated densities of tanoak are from two closely related studies in the same area utilizing a similar design. Volumes represented in Harrington's data include a period of three years of development after the landowners inadvertently removed the tanoaks and other competitors manually from the study plots, hence only limited conclusions can be drawn about whether conifers are on their originally charted trajectories.

Discussion

The data presented here show that herbs that decreased the subsequent size of ponderosa pine after planting no longer have significant negative effects at age 22. Examination of trends within blocks indicated that there were some differences among the blocks. Trees at Big Humbug showed no long-term differences attributable to herbs, while trees at Little Humbug showed a persisting effect of herbs. Trees at China Gulch exhibited what appeared to be a merging of height and diameter trends with and without herbs between ages 13-22, but the removal of some of the crop trees may be affecting these trends. We have no explanation for this interaction apart from the implication that there is something about these sites that placed slightly different limitations on growth that is somehow associated with presence of herbs. Both White (1988) and Ortiz-Funez (1989) reported that the presence of herbs was associated with a much-reduced biomass of manzanita in the herb-containing plots. Even after the shrubs had suppressed out the herbs, the smaller crowns of the shrubs may have resulted in later development of water stress for ponderosa pine than in the plots with no herbs, although this cannot be verified now.

Newton and Preest (1988, Douglas-fir) and recent long-term studies by Miller et al (2003, loblolly pine (*P. taeda*)) in the southeast make clear that herbs can influence long-term conifer growth. Miller et al (2003) also showed that effects of herbs and woody species differ in degree of influence with stand age and woody plant development, and we see this effect in both these experiments under very different site conditions. In the Douglas-fir experiment, differences related to herbaceous vegetation persist, although the size differences are small. Herbaceous vegetation was sparse in the first year, and control did not occur until year 3 for any of the treatments. In the pine experiment, hexazinone or fiber mats were applied to all plots in year 1 to ensure survival, and herbaceous vegetation was thereafter only allowed to develop on a higher manzanita density treatment. Therefore, for both of these experiments, the "herbaceous" effect is confounded with timing of control. In addition, these studies are old enough so that the dominant woody species have clearly had an effect on understory shrubs and herbs. In the pine study, herbs have now been suppressed almost out of existence at all densities of manzanita, and the herb effect has been supplanted by that of shrubs. By age 22, manzanita had nearly closed canopies at all spacings. This may have led to reduced competitiveness of other understory species.

The prolonged summer drought in 2001 and 2002 affected the two species similarly. Whereas the ponderosa pine study sites had roughly half the total precipitation of the Douglas-fir sites, both appeared to have exhausted their available moisture supplies before the end of terminal elongation early in the summer drought period. The result of this for both species was an abrupt decrease in height growth in the last two years of measurement; the reduction was similar for the two species despite their differences in sites and elongation habits.

Our data and Harrington's report provide consistent evidence that conifers established at the same time as managed densities of sprouting or germinating woody evergreen cover show reduced growth with increasing levels of competition. In each study, decreases in height and diameter were observed as the result of uncontrolled competition following complete clearing. Douglas-fir volume in the tanoak and madrone studies increased by a factor of four as the result of complete control of sprouts at age 2 when compared to the highest density of clumps. Volume of ponderosa pine demonstrated a similar increase when manzanita density was reduced to zero a year after planting pine on a thoroughly prepared site. These studies were established on sites where planting in established brush was expected to result in failure. We therefore suggest that the differences between levels of competition we report here would be greater if seedlings were planted in established, dense brushfields.

We also note that while previous reports showed decreasing pine growth with increasing manzanita density, this pattern has changed to one in which the plots with manzanita are now apparently fully occupied with a mixture of shrubs and pine, and the pines are all growing similarly, but substantially less, with any level of manzanita than where there is none. Only at China Gulch is there a marked difference in pine growth among shrub densities.

In the manzanita study, although pine in the lower densities of manzanita did not differ significantly from pine in the Trees Only treatment (p>.05), only the Trees Only treatment had very large trees in it (Figure 11). The lack of a significant relationship between manzanita density and pine size when the Trees Only plots were not included in the regression indicates that major increases in growth would not be expected on these sites until manzanita density decreased below 1700 sph (the lowest density we studied) for manzanita establishing at the same time as the pine. If on these sites, manzanita did not get established until after the plantation, as is typical with vegetation management treatments, then pine may be able to tolerate higher levels of manzanita than when the shrubs establish at the same time as the pine. In the madrone study, Douglas-fir in the lowest density of madrone (originally 200 sprout cph) and in the Trees Only plots were not significantly different in size. There was a greater overlap of diameters between these treatments than with the pine, although the largest trees were still found in the Trees Only plots. The amount of shrub or clump removal necessary to increase growth will vary for each site and by when the shrubs/clumps become established relative to the plantation.

Our data extend over a long enough period to offer a chance at evaluating impact of planting and vegetation management on projected conifer growth as estimated by various growth models. The Shoestring site adjacent to the study plots supported a few Douglas-fir 40+ years old of natural origin growing in gaps between similar-aged madrone clumps. Site index (King, 1966) was calculated from these trees to be 55 feet at 50 years breast height age in madrone populations also responding to fire. This observation helps provide perspective on relative competitive differences and potential successional tracks between planted and naturally seeded Douglas-fir when established at the same time as sprout clumps following fire. Planted conifers from our experiments are much taller for their ages on this site than are the naturally-regenerated trees. These experiments provide evidence that planting alone will provide trees that are considerably taller and larger for their ages than naturally regenerated stands under heavy competition on the same poor site.

We projected measures of site index (McArdle et al. 1961; King, 1966) with and without removal of madrone (Table 3) suggesting that these sites managed without shrub control will follow a different site curve from that of stands with access to most of the soil resources, as suggested by Newton and Hanson (1998). To simplify this comparison, we averaged over the herb treatments and because one of the blocks (block C) had higher densities of madrone in the high and medium density treatments than the other two blocks, we separated the blocks into two groups—blocks A and B and block C. To generate the numbers listed in Table 3 we used total age 25 years and interpolated the numbers from McArdle, et al.'s (1961) Table 1. Because King (1966) uses breast height age in his tables, we used a different approach for comparison to King. Our trees took 8.5 to 10 years to reach breast height (based on total age), depending upon replication and madrone density. On the average, the Trees Only plots reached breast height about 0.5 year earlier than the high density madrone plots and the trees on blocks A and B 1 year earlier than block C. For comparative purposes, we used breast height age 16 for blocks A and B and 15 for block C. In addition, our estimates are based on the overall average for each treatment, rather than the top 99/ha (40/ac) that King used for site index estimates. Our site index values would be higher if based on only the largest 99 tph.

Table 3. Estimated site index for treatments on Douglas-fir/madrone competition study site.

			McArdle et al. 1961		**King 1966**
	Density Treatment	**2002 Height(ft)**	SI_{100}	SI_{50}	SI_{50}
Blocks A and B	None	39.1	109	76	98
	Low	37.9	105	74	95
	Medium	35.3	98	69	88
	High	31.8	88	61	79
Block C	None	34.3	95	66	92
	Low	36.0	100	70	96
	Medium	31.5	87	61	84
	High	27.0	74	53	71

When we compare the periodic height growth with data listed by King (1966), there is evidence that height curves are of a different shape. These data show that there is logic in measuring site index in stands grown with low levels of competition, and that departure from conventional model growth curves can be expected as the result of vegetation management. However, the possibility always exists that once weeded trees fully occupy the site, their total stand growth will then decrease or plateau similar to unweeded trees, with timing dependent on initial spacing or thinning. In that instance, the prolonged presence of hardwood or shrub cover with which the conifers must share the site will likely lead to delay in arrival at that plateau, and to lower growth as long as the site is shared. The projected "increase" in relative site index resulting from early increased height growth would not be sustained, and the weeded and unweeded trajectories would eventually merge at the same plateau.

Conclusions

Despite being different species, and on sites with different terrain, soils and rainfall, these experiments show conceptually similar responses of planted conifers to controlled densities of competitors in two studies and locations, and striking similarity to Harrington's studies. Patterns of growth differed substantially from one replication to another and one site to another, but removal of nearly all large woody competitors increased growth substantially compared to relatively dense competitors. The gains in growth from removal of competitors shortened the period between planting to onset of merchantable volumes by many years. Estimates of site productivity may be lower where sites trees have grown in mixture with competing hardwoods or evergreen shrubs.

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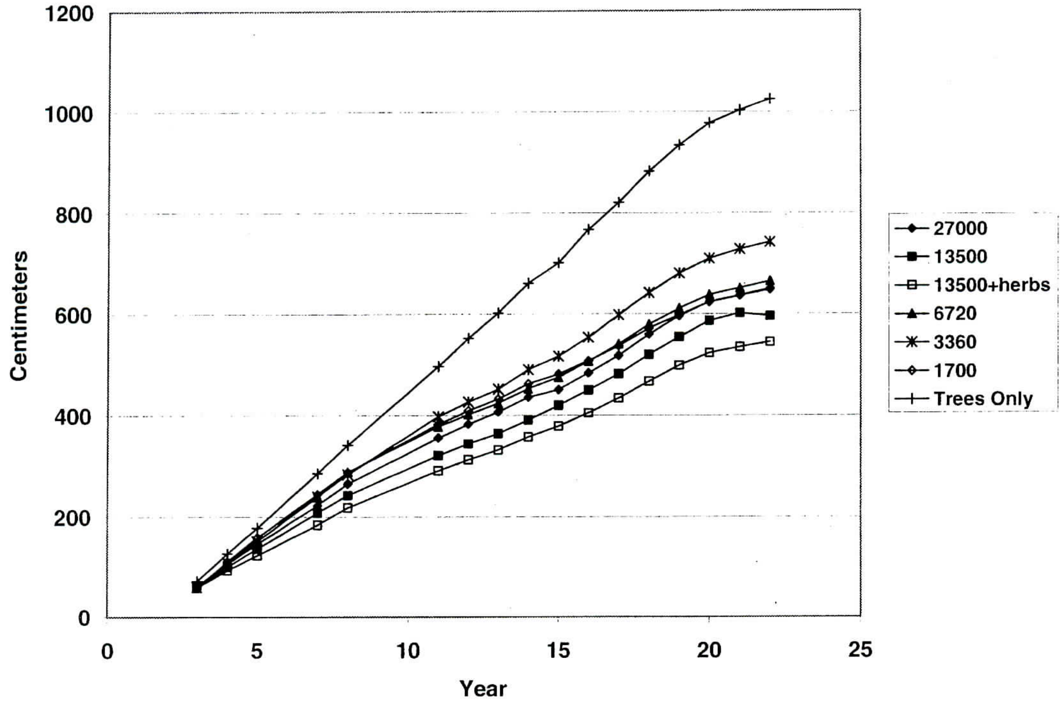

Figure 1. Treatment means for total height for ponderosa pine in the manzanita study. Treatment numbers in the legend are initial manzanita sph.

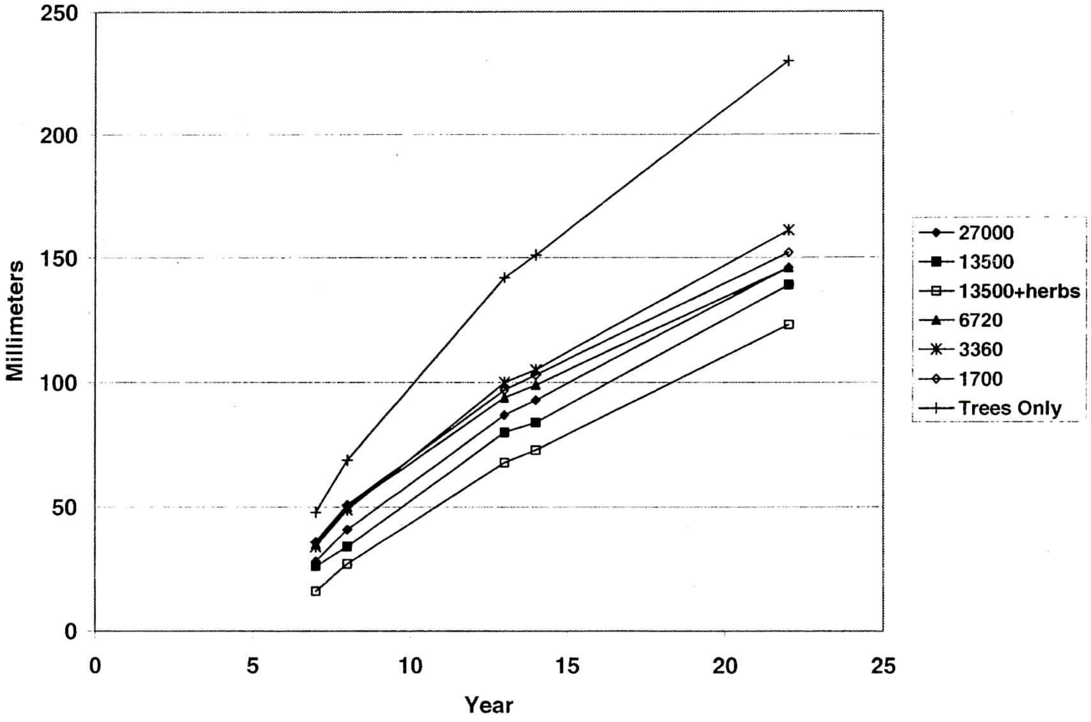

Figure 2. Treatment means for diameter at breast height for ponderosa pine in the manzanita study. Treatment numbers in the legend are initial manzanita sph.

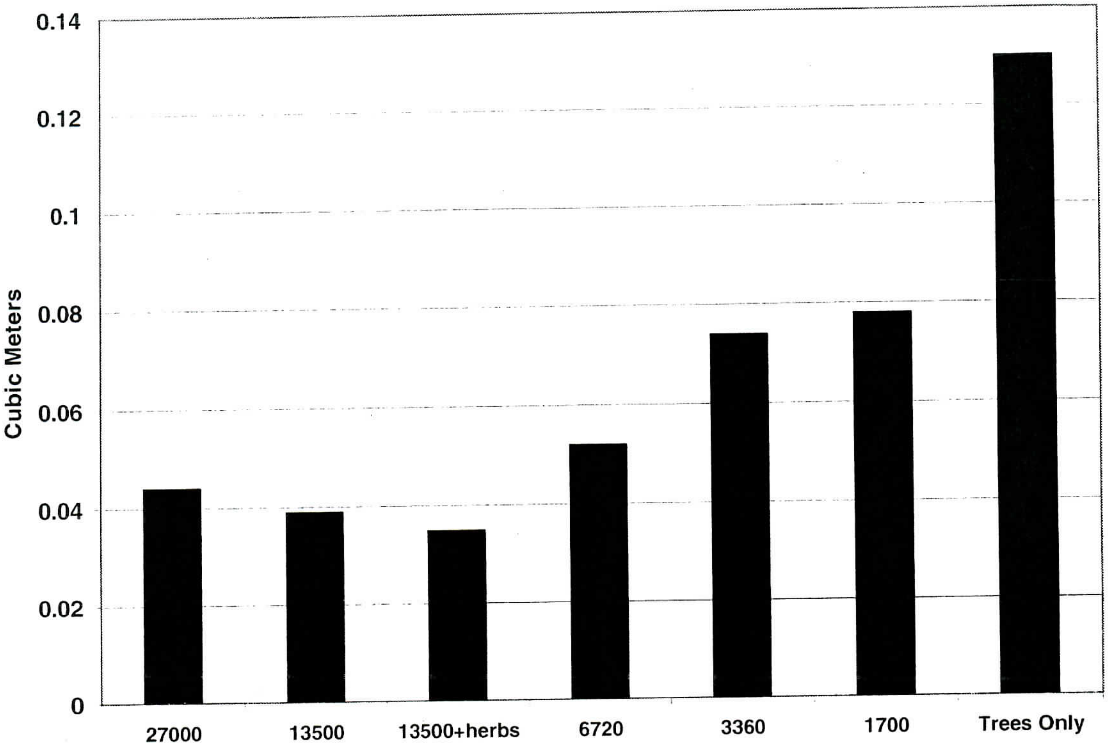

Figure 3. Treatment means for volume/tree at age 22 for ponderosa pine in the manzanita study. Treatment numbers for the x axis are initial manzanita sph.

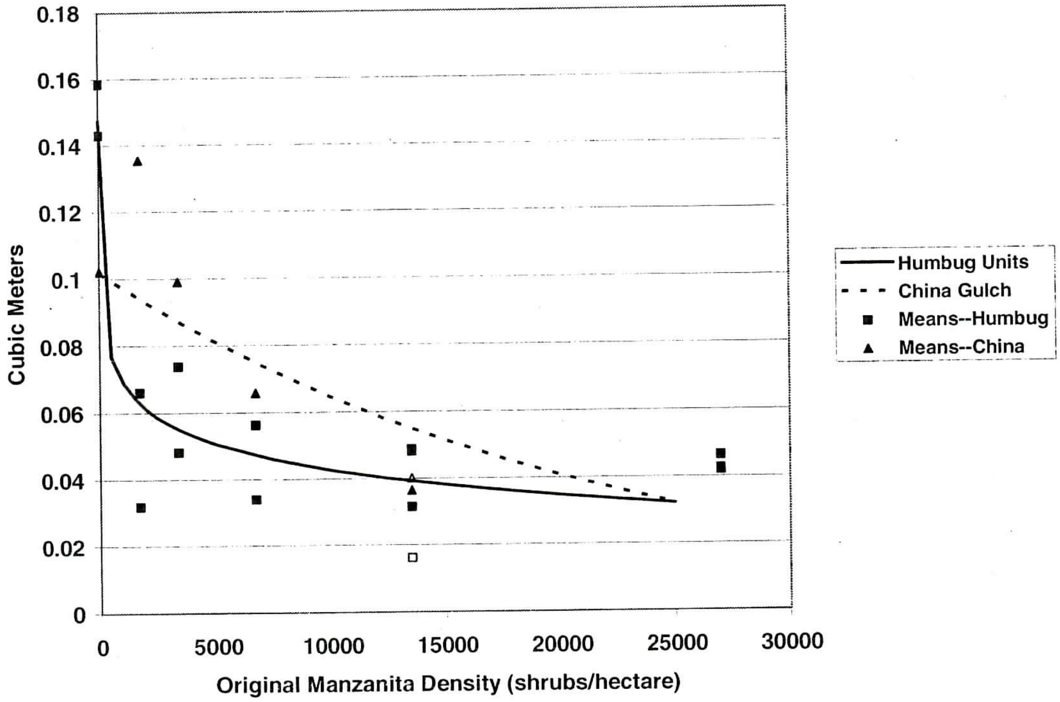

Figure 4. The relationship between plot means of manzanita density and volume/tree at age 22 for ponderosa pine in the manzanita study.

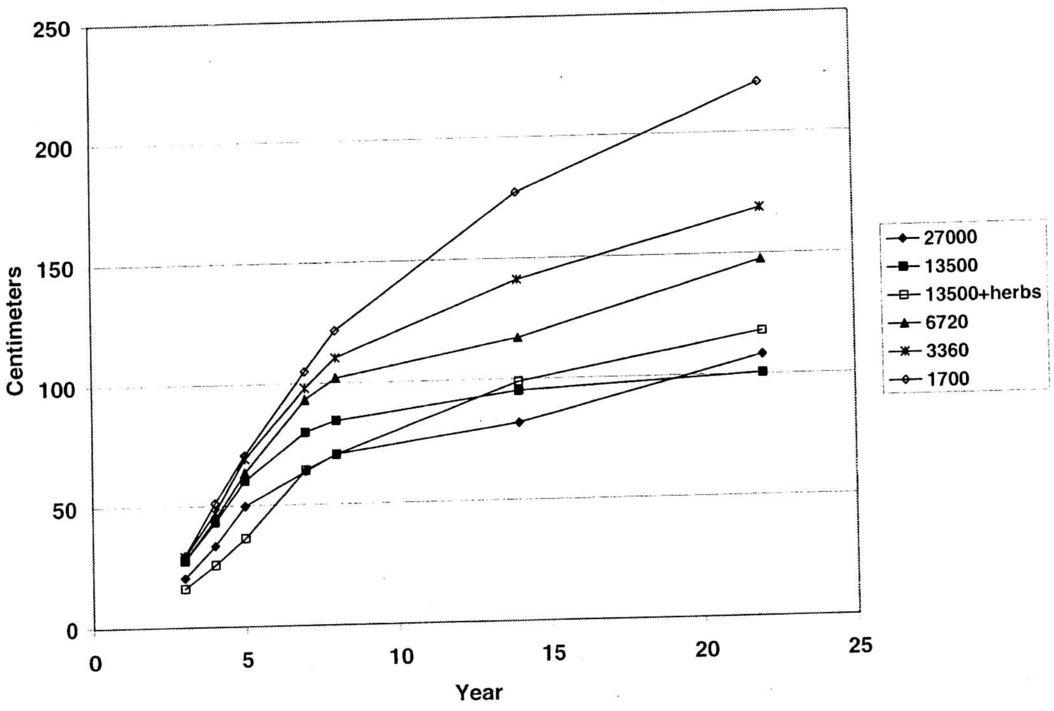

Figure 5. Treatment means for manzanita crown width. Treatment numbers in the legend are initial manzanita sph.

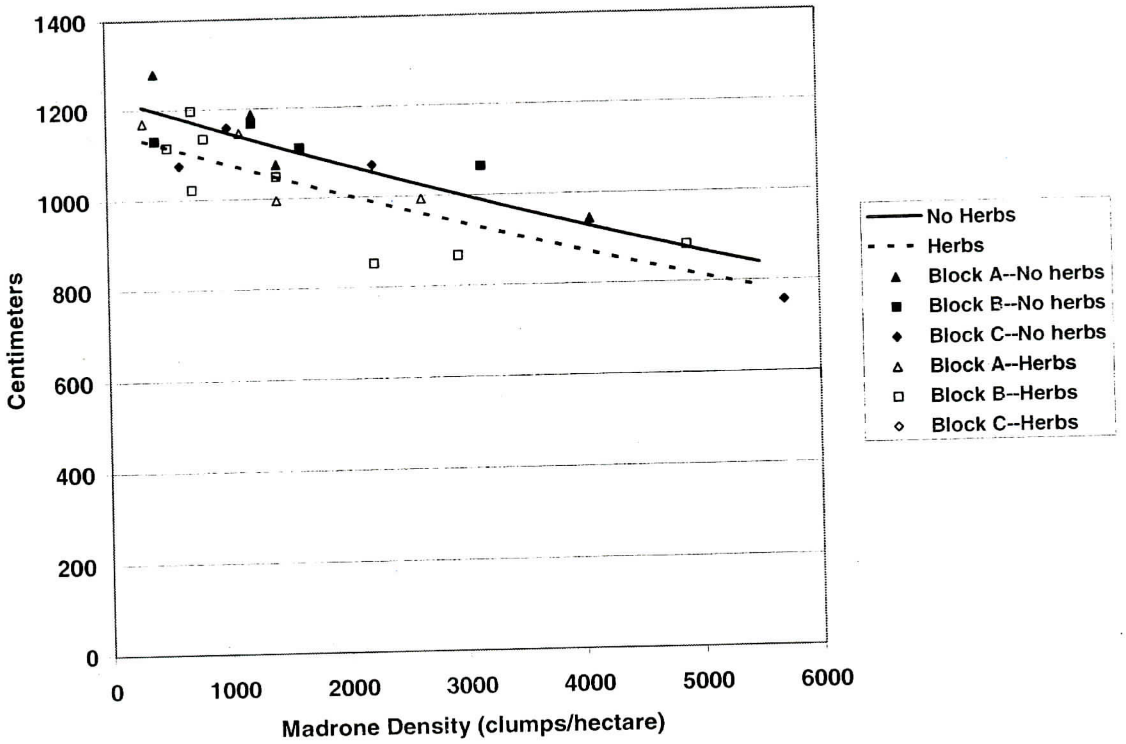

Figure 6. Total height at age 23 by madrone density (year 23) for Douglas-fir in the madrone study.

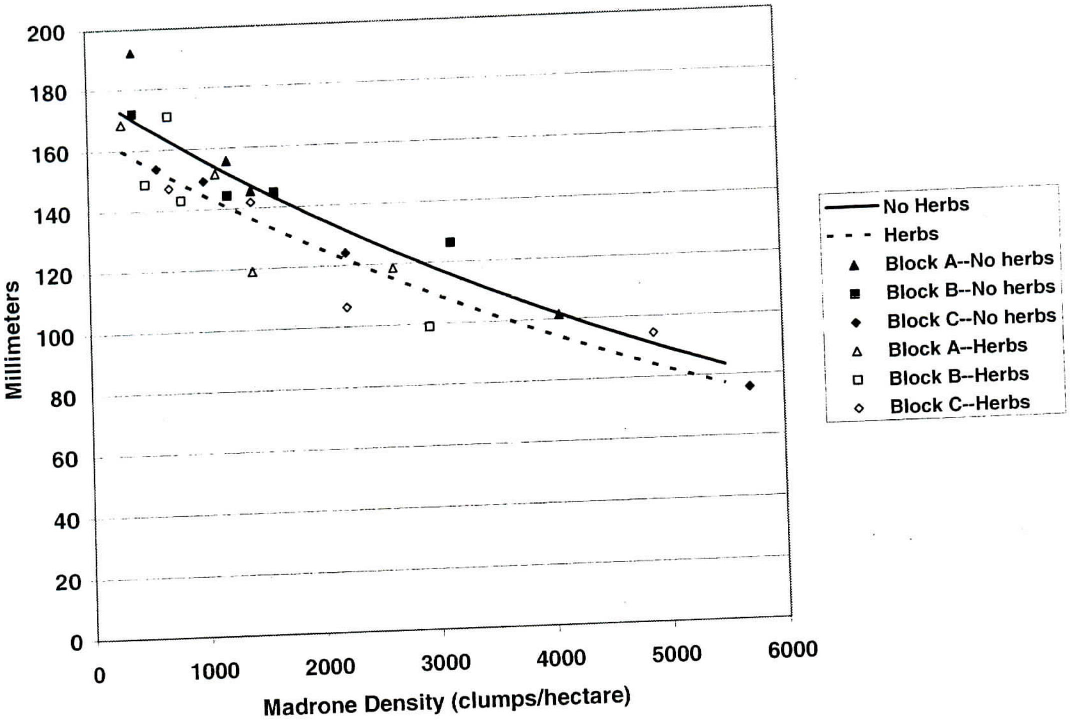

Figure 7. Diameter at breast height at age 23 by madrone density (year 23) for Douglas-fir in the madrone study.

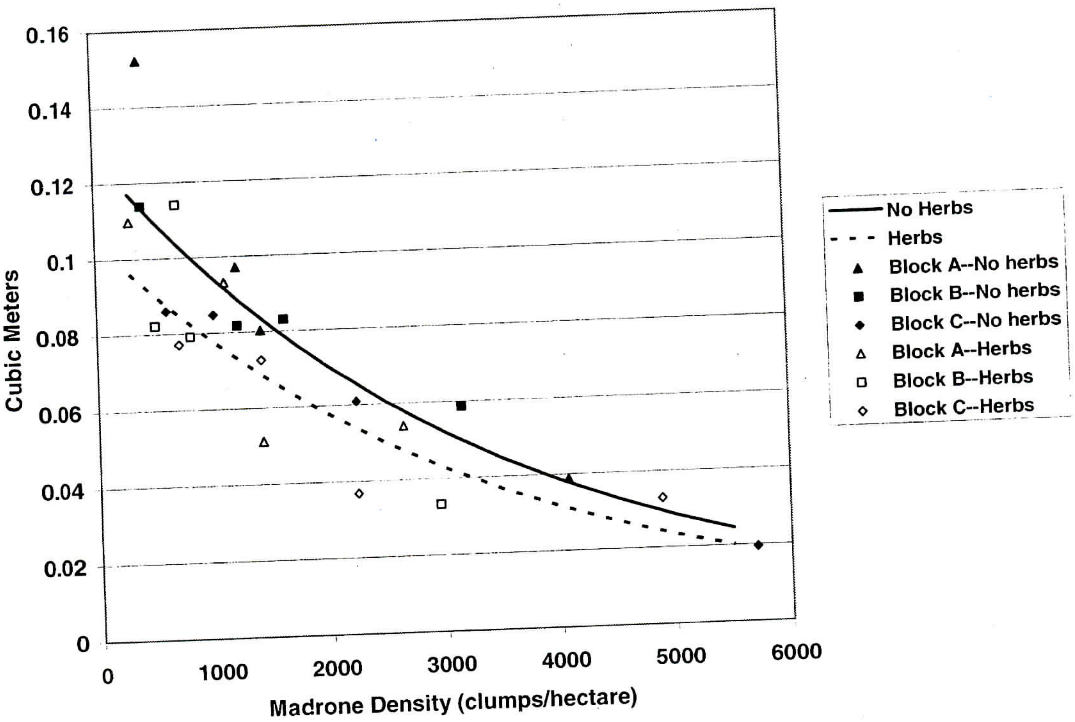

Figure 8. Volume at age 23 by madrone density (year 23) for Douglas-fir in the madrone study.

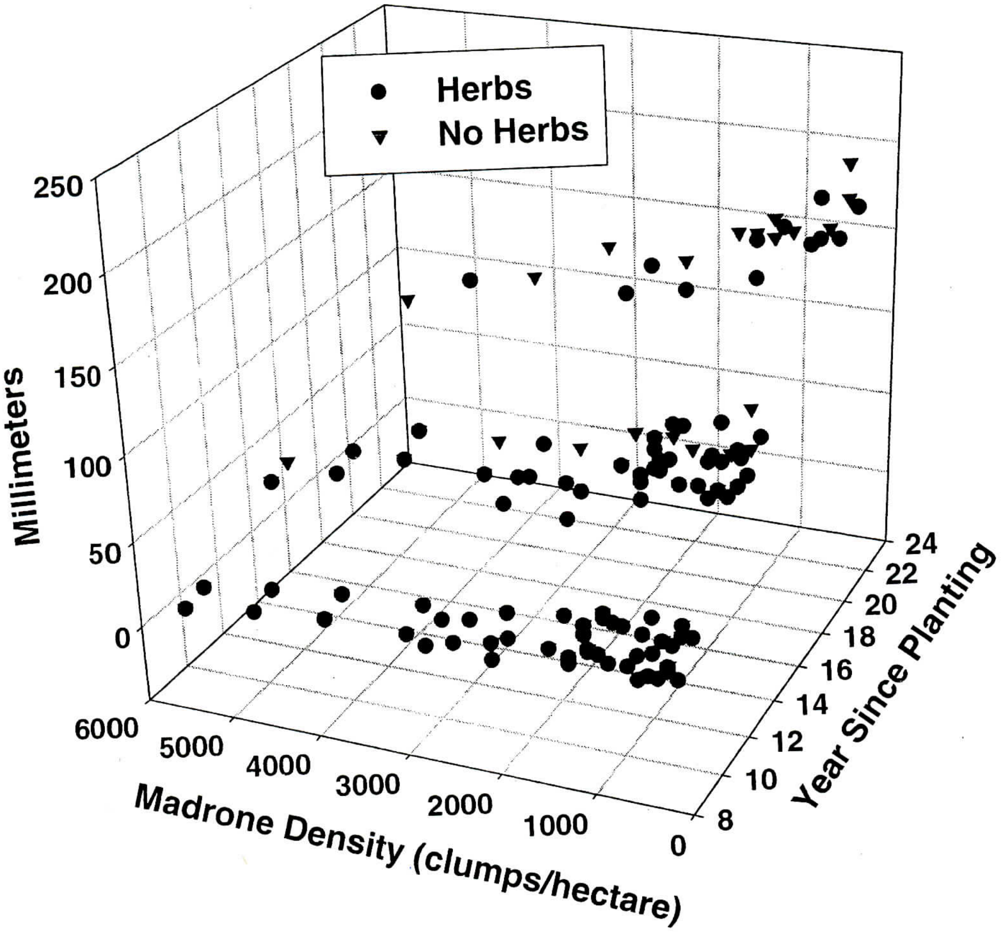

Figure 9. Diameter at breast height plot means in time for Douglas-fir in the madrone study.

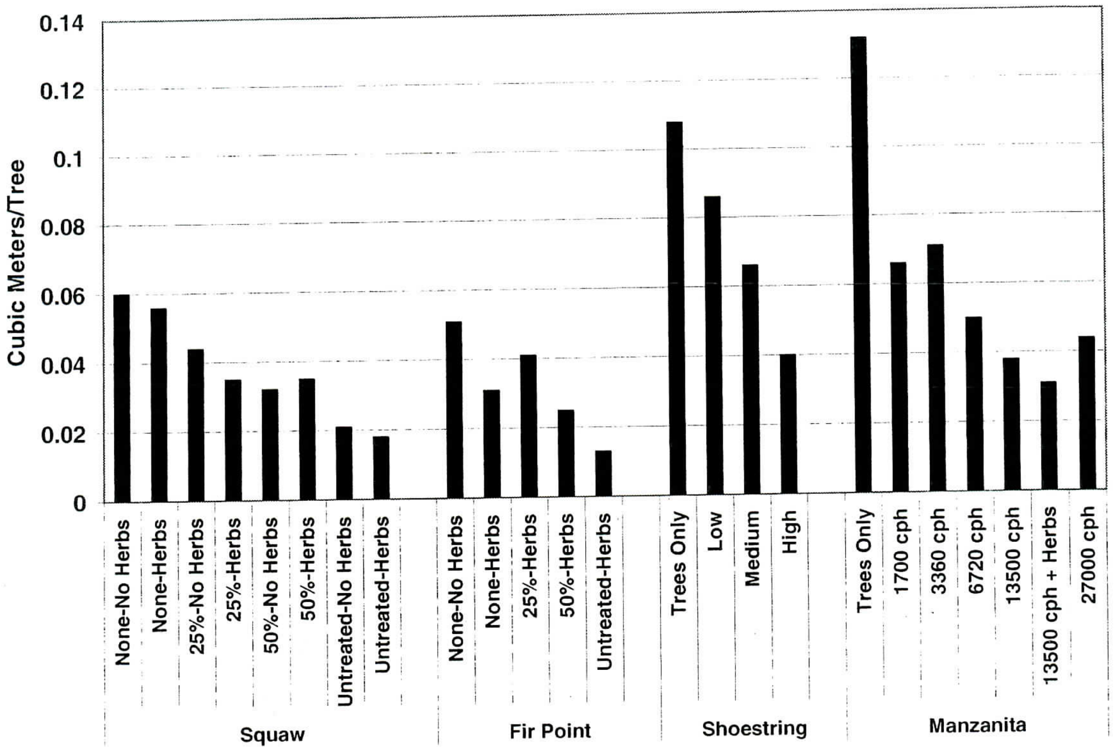

Figure 10. Treatment means for volume/tree for Douglas-fir age 22 (Squaw),age 21 (Fir Point), and age 23 (Shoestring) and ponderosa pine age 22 (Manzanita). Volumes are calculated from Bruce and DeMars (1974) for Squaw and Fir Point and from Walters et al. (1985) for Shoestring and Manzanita.

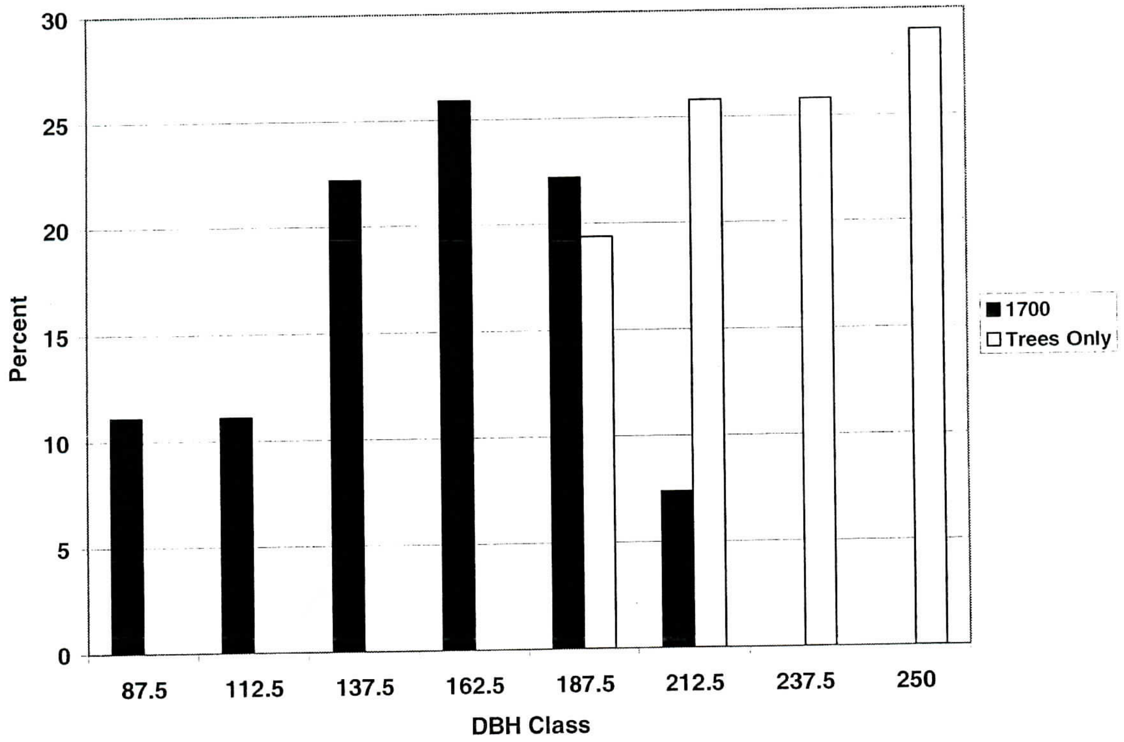

Figure 11. Ponderosa pine diameter at breast height at age 22 frequency distribution for 2 treatments in the manzanita study. DBH class labels are midpoints of 25 mm classes, except for >250, which includes all trees 250 mm or larger. In the legend, 1700 refers to the initial density of 1700 manzanita sph.