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Mechanical and Chemical Release in a 12-Year-Old Ponderosa Pine Plantation

Gary O. Fiddler **Philip M. McDonald**

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Abstract

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A 12-year-old ponderosa pine plantation on the Tahoe National Forest in northern California was mechanically treated with a Hydro-Ax in an attempt to increase the survival and growth of the planted seedlings. Other release methods were not feasible because the shrubs in the mixed-shrub community (greenleaf manzanita, mountain whitethorn, bittercherry, coffeeberry) were too large (3 to 5 feet tall) and well developed. Additional treatments were a chemical treatment, in which 2,4-D was applied to a portion of the study site that had been treated with the Hydro-Ax 1 year previously, and control. Eleven growing seasons after treatment (1993), average pine crown cover was statistically higher in the mechanical treatment (Hydro-Ax alone) than in the control. This was the only significant enhancement of pine growth by the Hydro-Ax alone. Mean pine diameter and height did not differ statistically from the control after 11 years. In contrast, the Hydro-Ax plus herbicide (chemical) treatment statistically increased pine crown cover, height, and diameter over the Hydro-Ax alone and the control. Mean crown cover was 104 percent greater in the treated trees than for pines in the control, height was 45 percent greater, and diameter was 47 percent greater. Relative costs were $225 per acre for the Hydro-Ax alone (mechanical) and $273 per acre for the Hydro-Ax + herbicide (chemical). Altogether, the most cost-effective treatment was Hydro-Ax + herbicide.

Retrieval Terms: cost, growth, mechanical release, mechanical and chemical release, ponderosa pine, shrub sprouts

The Authors

Gary O. Fiddler is a silviculturist assigned to the Silviculture Development Unit, Pacific Southwest Region, USDA Forest Service, with headquarters in San Francisco, and stationed at Redding, Calif. **Philip M. McDonald** is a research forester assigned to the Station's Vegetation Management Research Unit, with headquarters at Redding, Calif.

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Ecosystem management is emerging as the current approach to the management of natural resources on National Forests. In forest management, this translates into the need to know more about species other than the more commonly studied wood producers, such as commercial conifers and hardwoods. Values like wildlife habitat and scenic diversity have a prominent position in ecosystem management. Regardless of the desired products, manipulation of plant communities is often required to meet these future needs. Manipulation requires a healthy plant community to work with. This northern California study, located on the Nevada City Ranger District of the Tahoe National Forest, provides knowledge on species composition and development in a ponderosa pine plantation after a release treatment. An untreated control, mechanical release (Hydro-Ax alone), and chemical release (Hydro-Ax + herbicide) are contrasted.

In 1982 at age 12, when the study began, the ponderosa pine plantation was part of a plant community composed of the planted pines and four shrub species. Grass was almost nonexistent. There were more than 10,000 woody plants per acre on the site. Shrub foliar cover exceeded 19,000 square feet, and height varied from 1 to 3 feet. Ponderosa pine height ranged from 6 to 7 feet, and crown cover from 12 square feet to 14 square feet per tree. Conifer stocking averaged more than 200 trees per acre. The most common woody shrub was mountain whitethorn, with greenleaf manzanita a close second. A release treatment was applied to this plantation at the end of the 12th year.

Eleven growing seasons after this release, the plant community consisted of the same species that had been present before treatment, with the exception of a significant increase in the grass population, primarily in the chemical treatment and control. Grass density exceeded 1,246,000 plants per acre in the chemically treated areas. Greenleaf manzanita had replaced mountain whitethorn as the most abundant woody shrub. Ponderosa pine height had at least doubled in all treatments. Crown cover of ponderosa pine had increased significantly from pretreatment values, and now ranged from 47 to 96 square feet per tree. In the control, density and height of the woody shrubs increased during the study period, but foliar cover decreased by more than 50 percent.

The mechanical treatment alone did not significantly increase conifer growth over that in the control except for crown cover. In year 11, pine height and diameter were not significantly different between these two treatments. But the herbicide in conjunction with the Hydro-Ax increased all parameters of pine growth over that in the other treatments. This significant increase in pine growth cost 21 percent more than the mechanical treatment alone. Mechanical release alone is an ineffective treatment for releasing plantations of this age.

Introduction

Conifer plantations are an important component in ecosystem management, just as they are in forest management. In the latter, these plantations are the beginning point for all forest management that will follow, whether this management takes the form of release, precommercial or commercial thinning, pruning, or other cultural activities leading up to final harvest of the stand. In ecosystem management, these plantations furnish some of the building blocks that will be molded and manipulated into the types of stands required to satisfy future needs. These needs may take the form of wildlife habitat, vegetative diversity, scenic values, or other more commodity-oriented values, such as wood production.

The establishment of plantations is often not an easy task. Almost all new plantations in California will be invaded by weeds in the form of hardwoods, woody shrubs, grasses, and forbs (Fiddler and McDonald 1990). This invasion usually occurs early in the life of the plantation, and without proper release treatments, the competition between the planted conifers and these weeds continues until crown closure. That this competition is detrimental to survival and growth of the planted conifers is well established (Gjerstad and Glover 1992, Stewart and others 1984). Another accepted research finding is that in order for the planted conifers to develop at or near the potential of the site, they must be released from competing vegetation early in the life of the plantation, probably in the first or second year after the conifer seedlings are outplanted (McDonald 1982, McDonald and Fiddler 1986, Newton and Preest 1988).

Despite these findings, many untreated plantations that are 10 years of age or older can be found in the western United States. What should be done with them? If they are left to grow in an untreated condition, loss of growth or death is likely. Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) has demonstrated its ability to survive despite extreme competition, but at the cost of decreased growth. The fact that pine saplings are taller than the surrounding vegetation does not guarantee that the ponderosa pines are growing at the potential of the site. Considering all these factors, should these older plantations be released?

If the answer is yes, a release method must be chosen. Several of the more commonly used methods are not effective when the competing vegetation is as old and well developed as that found in this study. Manual methods are prohibitively expensive when trying to control older weeds, and grazing by cattle or sheep is at best marginally effective. Even herbicides alone are ineffective for controlling tall, well-developed shrubs.

The most commonly used release treatment in older plantations on National Forest land in northern California uses a mechanical chopper, similar in principle to a lawn mower, which cuts the vegetation close to the ground and leaves the chopped stems and leaves on site. The question is: does this operation reduce the competing vegetation long enough to increase the growth of the conifer saplings?

This paper reports on the effectiveness of mechanical chopping as a release treatment. In addition, a treatment in which the mechanically cut shrubs were sprayed with a herbicide 1 year after cutting was evaluated. Cost and production data are included for all treatments. Pine growth response in diameter, height, and crown cover to these treatments and an untreated control, as well as responses of the treated and untreated shrub community, are reported.

Methods

Study Location and Environment

This study is part of a National Administrative Study on vegetation management in young conifer plantations started in 1980 in northern California (Fiddler and McDonald 1984). The study area, known as Big Tunnel, is located on the Nevada City Ranger District of the Tahoe National Forest, about 20 miles east of Nevada City, Calif. Before timber harvest, the study site supported a forest of ponderosa pine, California white fir (*Abies concolor* var. *lowiana* Gord. Lemm.), and incense-cedar (*Libocedrus decurrens* Torr.). The understory consisted of scattered individuals of greenleaf manzanita (*Arctostaphylos patula* Greene), mountain whitethorn (*Ceanothus cordulatus* Kell.), and California black oak (*Quercus kelloggii* Newb.). Forbs and grasses were small and few in number.

After timber harvest in 1970, logging slash and woody shrubs were pushed into windrows with a brushrake and burned. Ponderosa pine seedlings from a local seed source were raised at the Forest Service nursery at Placerville, Calif., and hand planted as 1-year-old, bare-root stock in May 1971. A spacing of 10 by 10 feet resulted in about 430 planted trees per acre. Survival at the end of the first growing season was 90 percent.

In early 1983, 13 years after site preparation, the area had a dense cover of greenleaf manzanita, mountain whitethorn, bitter cherry (*Prunus emarginata* Dougl.), and coffeeberry (*Rhamnus purshiana* DC.) resulting mostly from new seedlings and sprouts from plants in the previous stand. Height of this cover ranged from 1 to 3 feet. The most common shrubs were greenleaf manzanita and whitethorn. Grass (mostly *Acnatherum* sp. Hickman 1993) was present on the site, but in fairly small numbers.

Elevation of the study site is 4600 feet with slopes of 5 to 10 percent, and aspects of northeast, northwest, and south. The climate is characterized by warm, dry summers and cool, moist winters. Mean annual precipitation varies from 35 to 70 inches with about 50 percent falling as snow. The mean January temperature is 35 °F, mean July temperature is 70 °F, and the mean annual temperature varies from 50 to 58 °F. The frost-free season is from 130 to 225 days.

The soil is of the McCarthy series. It is moderately deep, well drained and formed from material weathered from andesitic mudflows. The soil is sandy loam or loam throughout, and may be gravelly or cobbly.

Based on the height-age relationship of dominant mixed conifer trees, site quality of the study area before harvesting was 40 feet in 50 years (Dunning and Reineke 1933). As a whole, the study area is remarkably uniform in terms of slope and site quality.

Treatments and Study Methods

The study, begun in fall 1982, includes data recorded through 11 growing seasons.

The experimental design was complete randomized block with one 3-level treatment. Differences among treatments were detected by analysis of variance and Tukey tests. Because information is gathered from permanent plots, the data are not truly independent from year to year. The α levels or type I errors apply to each measurement and year separately. The overall error rate could increase by as much as the given amount for each measured variable each year.

Treatments, each replicated three times (3 blocks), included mechanical, chemical (mechanical plus a herbicide), and a control. A replicate consisted of about one-seventh acre on which 30 to 40 ponderosa pine saplings were surrounded by two or three rows of buffer (saplings receiving the same treatment). Twenty of these pines per replication were flagged for measurement of height, stem diameter at 4.5 feet above mean ground line, and crown cover. Those chosen were thrifty saplings that had good potential of becoming harvestable trees; small, misshapen and discolored saplings were not part of the study.

Sampling intensity for competing vegetation was nine randomly selected plots in each replication. Plots were centered around conifers and were 1 milacre (0.001 acre) in size. Competing vegetation was measured for density and average dominant height (average of the three tallest stems measured from mean ground line to bud). Foliar cover (the sum of shadows that would be cast by leaves and stems of individual species expressed as a percentage of the land surface [Daubenmire 1968]) was determined by ocular estimate. Values less than 0.5 square foot per species in each plot were not recorded.

Mechanical treatment consisted of cutting the woody shrubs with a Hydro-Ax[1]—a machine with a large rotary cutting head in which there are two free-swinging blades (*fig. 1*). The cutting head is mounted on a vehicle similar in size to a medium-sized log skidder. The Hydro-Ax resembles a common rotary lawnmower, but cuts an 8-foot swath. With experienced operators, as was the case on the study, the Hydro-Ax works efficiently on slopes up to about 40 percent, and production rates of 3 to 4 acres per day are common. Current (1995) costs range from $135 to $225/acre. Severed material remains in place. Cutting was done September 1982.

Chemical treatment consisted of applying 3 pounds acid equivalent of 2,4-D[2] in 10 gallons of solution per acre to the foliage of sprouting shrubs the first year after cutting. The herbicide was applied in July 1983 using a carbon dioxide pressurized boom. Nozzles on the boom were the same type as those used in helicopter application; hence, rate of application and droplet size were similar to those used in helicopter application of herbicides. The boom, which covered a 9-foot swath, was held about 12 inches above the shrubs, and the spray was directed downward. The system was calibrated using trial runs with water to

[1]Trade names and commercial products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

[2]This paper neither recommends the herbicide uses reported nor implies that the herbicides have been registered by the appropriate governmental agencies.

Figure 1—A Hydro-Ax showing cutting head.

determine the proper walking speed at which to apply the correct amount of herbicide to each replication. The entire seventh-acre replicate, plus half of the width of the buffer, was sprayed. The area treated around each pine had at least a 5-foot radius. Workers guided the applicator at each side of the swath to ensure even coverage and no overlap.

A control served to show the response of naturally developing vegetation and its effects on the ponderosa pines.

Production data were gathered for each treatment. The basis for production was hourly records; the basis for costs was $90.00 per hour (the 1995 rate for equipment of the type used on the study) and $11.13 per hour (the rate for a Laborer-1, U.S. Department of Labor, as of June 1995).

Statistical analysis of density, cover, and height of combined shrubs tested whether the treatments differed from the control and each other, and whether they continued to do so in spite of shrub regrowth.

Results

As forest management moves toward ecosystem management, knowledge and information on the dynamics and composition of plant communities, in addition to the conifer component, become desirable. Results are most useful when presented both for individual and groups of species, because competition to the conifer saplings results from the interaction of the different species found in the weed community, not from individual members of it. Data on survival, stem diameter, height, and cover are presented for the planted ponderosa pine saplings, and information on density, foliar cover, and height for bittercherry, greenleaf manzanita, whitethorn, coffeeberry, combined shrubs, and grass is reported.

Ponderosa Pine

No ponderosa pine saplings died during the life of the study (1982 to 1993). An early concern about damage to the conifers from flying debris generated by the Hydro-Ax proved to be unwarranted. In addition, no damage to conifers from the machine itself was noted.

The gouty pitch midge (*Cecidomyia piniinopis*) attacked the conifers in 1985, causing branch flagging in 1986. Only the tips of the affected branches showed any damage. Trees in each treatment were attacked by this insect; those in the chemical treatment were attacked the fewest number of times. Studies located on sites similar to Big Tunnel have experienced damage from the gouty pitch midge (McDonald and Oliver 1984), but damage and loss of growth in this study appeared minimal (Schultz 1986).

Differences among treatments in ponderosa pine crown cover were evident in 1983, the first growing season after initial treatment. Tukey analysis showed cover of the pines was significantly larger ($p < 0.05$ unless otherwise stated) in the mechanical treatment than in the control (*table 1*). The chemical was applied in July 1983, after the growing season was over; therefore, only two of the treatments could affect conifer growth in 1983: the mechanical treatment and the control. By 1985, however, pine diameter and height were significantly greater in the chemical treatment than in the control. This difference continued through 1993. In 1986, pine cover in the chemical treatment was larger than in the control and continued this way through 1993. In 1986, pine diameter in the chemical treatment became significantly larger than in the mechanical treatment, a trend that continued through 1993. By 1988, pine height in the chemical treatment exceeded that in the mechanical treatment and continued through 1993. Pine height was never greater in the mechanical treatment than in the control. In 1986 and 1988, pine diameter was significantly greater in the mechanical treatment than in the control, but this difference had disappeared by 1993.

Bittercherry

Density and height of this species never differed significantly among the treatments during the study (*table 2*). Density in the control increased to a high of 2,037 plants per acre in 1985, but decreased to 1,133 plants by study end in 1993. Height in the control increased from 3.9 feet to 4.3 feet, a gain of 11 percent. For 1985, 1986, and 1988, bittercherry foliar cover was significantly smaller in the chemical treatment than in the control. This difference had disappeared by 1993. Foliar cover was never significantly different between the mechanical treatment and the other two treatments. In general, this species showed a trend of relatively constant density, decreasing foliar cover, and slightly increasing height. The more robust plants that had existed early in the study were declining and becoming tall and spindly with sparse foliage.

Greenleaf Manzanita

Except for whitethorn, greenleaf manzanita was the most abundant shrub species when the study started. By 1988, it was the most common woody shrub in the study. In the control, density generally increased throughout the study and was 66 percent larger by 1993 (*table 3)*. Density was significantly less in the chemical treatment than in the mechanical treatment starting in 1985 and continuing through 1993. Density never differed between the mechanical treatment and the control. Foliar cover in the control increased from 6,037 square feet per acre in 1983 to 9,333 square feet per acre in 1986 before declining to 6,867 square feet per acre by 1993, a net gain of 14 percent. Foliar cover was significantly less in the chemical treatment than in the control in 1985, 1986, and 1988, but by 1993 there were no differences among the three treatments. The mechanical treatment and

Table 1—*Average diameter, crown cover, and height of ponderosa pine, Big Tunnel Plantation, Tahoe National Forest, California, 1983-1993*

Year	Treatment	Diameter	Cover	Height
		inches	*ft²/tree*	*ft*
1983	Mechanical	1.55 a[1]	13.86 a	6.98 a
	Chemical	[2]		
	Control	1.33 a	11.67 b	6.70 a
	Standard error	0.05	0.28	0.17
1985	Mechanical	2.43 ab	24.91 a	8.75 ab
	Chemical	2.94 a	27.93 a	9.89 a
	Control	2.02 b	18.53 a	8.24 b
	Standard error	0.10	1.91	0.26
1986	Mechanical	2.87 a	33.78 ab	9.68 ab
	Chemical	3.60 b	41.22 a	11.11 a
	Control	2.40 c	24.55 b	9.12 b
	Standard error	0.09	3.02	0.31
1988	Mechanical	3.77 a	41.68 ab	11.99 a
	Chemical	4.83 b	52.35 a	14.53 b
	Control	3.07 c	31.43 b	11.12 a
	Standard error	0.08	3.74	0.45
1993	Mechanical	7.56 a	67.76 a	18.99 a
	Chemical	9.51 b	96.20 b	24.19 b
	Control	6.49 a	47.23 c	16.68 a
	Standard error	0.32	3.52	0.87

[1]For each year, treatment means in each column followed by the same letter do not differ significantly according to a Tukey Test ($\alpha = 0.05$).

[2]Treatment not complete until chemical applied.

Table 2—*Average density, cover, and height of bittercherry, Big Tunnel Plantation, Tahoe National Forest, California, 1983-1993*

Year	Treatment	Density	Cover	Height
		plants/acre	*ft^2/acre*	*ft*
1983	Mechanical	2,889 a[1]	1,333 a	1.97 a
	Chemical	2,481 a	704 a	1.63 a
	Control	1,444 a	2,185 a	3.88 a
	Standard error	866	315	0.65
1985	Mechanical	3,111 a	1,963 ab	3.40 a
	Chemical	1,296 a	296 a	2.05 a
	Control	2,037 a	3,074 b	4.11 a
	Standard error	825	402	0.66
1986	Mechanical	2,741 a	2,037 ab	4.10 a
	Chemical	1,222 a	111 a	2.26 a
	Control	1,444 a	3,333 b	4.85 a
	Standard error	544	481	0.76
1988	Mechanical	2,926 a	1,592 ab	4.94 a
	Chemical	1,074 a	0 a	3.37 a
	Control	1,555 a	2,148 b	4.96 a
	Standard error	556	368	1.05
1993	Mechanical	2,667 a	267 a	4.13 a
	Chemical	1,733 a	0 a	4.12 a
	Control	1,133 a	733 a	4.31 a
	Standard error	596	249	0.52

[1]For each year, treatment means in each column followed by the same letter do not differ significantly according to a Tukey Test (α = 0.05).

Table 3—*Average density, cover, and height of greenleaf manzanita, Big Tunnel Plantation, Tahoe National Forest, California, 1983-1993*

Year	Treatment	Density	Cover	Height
		plants/acre	*ft^2/acre*	*ft*
1983	Mechanical	5,000 a[1]	2,370 a	1.09 a
	Chemical	5,259 a	2,481 a	1.04 a
	Control	3,444 a	6,037 a	3.94 b
	Standard error	763	1,255	0.40
1985	Mechanical	4,852 a	4,000 ab	2.27 a
	Chemical	1,037 b	259 a	0.74 b
	Control	3,592 a	8,814 b	4.24 c
	Standard error	499	1,129	0.28
1986	Mechanical	4,481 a	4,592 ab	2.75 a
	Chemical	926 b	111 a	0.91 b
	Control	3,444 ab	9,333 b	4.50 c
	Standard error	541	1,203	0.22
1988	Mechanical	4,852 a	4,444 ab	3.66 a
	Chemical	814 b	0 a	1.66 b
	Control	3,407 ab	7,703 b	5.03 c
	Standard error	550	1,298	0.26
1993	Mechanical	9,733 a	3,200 a	3.90 a
	Chemical	1,400 b	0 a	2.02 b
	Control	5,733 ab	6,867 a	5.15 a
	Standard error	1,263	1,792	0.35

[1]For each year, treatment means in each column followed by the same letter do not differ significantly according to a Tukey Test (α= 0.05).

the control never differed in foliar cover. Mean height increased throughout the study in the control, resulting in a gain of 31 percent. Height in the chemical treatment was significantly less than in the control in every year of the study. There was also a significant difference in this parameter between the chemical treatment and the mechanical treatment in every year except 1983. Height differed between the mechanical treatment and the control in every year except 1993. Without treatment, this species tended to increase in density, foliar cover, and height throughout the study. With mechanical treatment, trends in density, foliar cover, and height were similar to those in the control; but when a herbicide was applied to the cut shrubs, density and foliar cover declined.

Whitethorn

This was the most abundant plant species when the study began but relinquished this position in 1988. Density increased from 3,778 plants per acre in 1983 to 4,533 in 1993 in the control (*table 4*). Height showed a net gain of only 3 percent despite large increases during the middle years of the study. Foliar cover decreased from 8,888 square feet per acre in 1983 to 1,200 square feet per acre by the close of the study, a decrease of 86 percent. There were never any significant differences among treatments in density or cover. Differences in height among the treatments began to disappear by 1988 and had completely disappeared by 1993. During the study, this species tended to increase in density and slightly in height, but decrease greatly in foliar cover.

Coffeeberry

As was the case with whitethorn in the control, density and height of this species showed a net increase during the study, but foliar cover decreased significantly (*table 5*). Density increased 236 percent, height increased 20 percent, and foliar

Table 4—***Average density, cover, and height of whitethorn, Big Tunnel Plantation, Tahoe National Forest, California, 1983-1993***

Year	Treatment	Density	Cover	Height
		plants/acre	*ft²/acre*	*ft*
1983	Mechanical	3,000 a[1]	3,481 a	1.09 a
	Chemical	3,518 a	3,000 a	1.09 a
	Control	3,778 a	8,888 a	2.78 b
	Standard error	389	192	0.03
1985	Mechanical	2,741 a	5,666 a	2.33 a
	Chemical	2,148 a	2,259 a	1.38 b
	Control	3,888 a	8,407 a	3.04 c
	Standard error	358	1,443	0.09
1986	Mechanical	2,778 a	4,963 a	2.62 a
	Chemical	1,963 a	1,519 a	1.47 b
	Control	3,592 a	6,703 a	3.16 c
	Standard error	390	1,059	0.08
1988	Mechanical	2,667 a	2,815 a	3.29 a
	Chemical	1,926 a	666 a	2.00 b
	Control	3,148 a	3,852 a	3.28 a
	Standard error	410	759	0.15
1993	Mechanical	3,200 a	1,067 a	2.95 a
	Chemical	3,067 a	0 a	2.60 a
	Control	4,533 a	1,200 a	2.86 a
	Standard error	505	590	0.16

[1]For each year, treatment means in each column followed by the same letter do not differ significantly according to a Tukey Test ($\alpha = 0.05$).

cover decreased 92 percent. Density showed no significant differences among treatments until 1993, at which time there was a difference between the chemical treatment and the control. A difference in foliar cover in 1985 between these same two treatments had disappeared by 1986. In 1985, a significant difference in height among treatments was recorded. This difference disappeared in 1986. In 1988, there was a significant difference in height between the mechanical and the chemical treatment. This difference was gone by the end of the study in 1993.

Combined Shrubs

As noted earlier, competition to the conifer seedlings results from the interaction of the different species in the plant community. Data on a combination of shrub species best show this relationship. The density, foliar cover, and height of the four shrub species present in all replications (greenleaf manzanita, whitethorn, bittercherry, and coffeeberry) were aggregated and presented as "combined shrubs" (*table 6*).

In the fall of 1983, after one full growing season, combined shrubs in the control numbered 10,073 plants per acre, had 19,517 square feet of foliar cover, and were 3.3 feet tall. By the end of the 1993 growing season, density in the control had increased 60 percent to 16,133 plants per acre. During this same period, height had increased to 3.8 feet, a 14 percent increase. But foliar cover had decreased to 9,000 square feet per acre, a decline of 54 percent. Density in the chemical treatment was significantly less than in the mechanical treatment every year of the study, except 1983; by 1993 density in the chemical treatment was significantly less than in both other treatments. Foliar cover in the control was significantly larger than in the other treatments through 1986, but by 1988, foliar cover in the mechanical treatment did not differ significantly from that in the

Table 5—***Average density, cover, and height of coffeeberry, Big Tunnel Plantation, Tahoe National Forest, California, 1983-1993***

Year	Treatment	Density	Cover	Height
		plants/acre	*ft^2/acre*	*ft*
1983	Mechanical	8,925 a[1]	1,518 a	1.61 a
	Chemical	3,074 a	1,037 a	1.27 a
	Control	1,407 a	2,407 a	2.28 a
	Standard error	4,298	200	0.93
1985	Mechanical	5,666 a	2,185 ab	2.89 a
	Chemical	667 a	333 a	1.96 b
	Control	3,333 a	2,333 b	3.44 c
	Standard error	1,499	391	0.05
1986	Mechanical	3,741 a	2,556 a	3.84 a
	Chemical	555 a	259 a	2.50 a
	Control	3,370 a	2,296 a	3.73 a
	Standard error	1,142	550	0.29
1988	Mechanical	2,852 a	1,407 a	4.33 a
	Chemical	518 a	74 a	2.23 b
	Control	1,889 a	1,444 a	4.02 ab
	Standard error	643	365	0.38
1993	Mechanical	2,733 ab	0 a	3.54 a
	Chemical	1,467 a	0 a	1.85 a
	Control	4,733 b	200 b	2.74 a
	Standard error	614	0	0.56

[1]For each year, treatment means in each column followed by the same letter do not differ significantly according to a Tukey Test ($\alpha = 0.05$).

control; foliar cover in the chemical treatment was significantly less than in the other treatments in 1985, 1986, and 1988. By 1993 there was no significant difference in foliar cover among the treatments. Height increased every year in the chemical treatment and was always significantly shorter in this treatment than in the other two, except in 1983, when it did not differ from that in the mechanical treatment. Heights in the control and the mechanical treatment peaked in 1988, at which time they began to decline. From 1986 through the end of the study, height in the control and the mechanical treatment did not differ.

Grass

Grasses were not an important component of the study area before the study began. Their numbers were few and the grasses were small and scattered. This situation did not change until 1985, when grass density showed a significant increase in the chemical treatment. A density in excess of 14,000 plants per acre was recorded at the end of this growing season (*table 7*). This significant difference in density between the chemical treatment and the other two treatments disappeared in 1986 and 1988. However, in 1993, density differed significantly between the chemical and mechanical treatments. Density never differed between the control and the mechanical treatment. Foliar cover and height never differed significantly among the treatments. The grass component reached a height of almost 3 feet before declining to less than 1 foot by 1993. This component, whose numbers were so small at the start of the study as to be considered minor, had 1,246,667 plants per acre by 1993 in the chemical treatment. There was a steady increase in density in the chemical treatment for every year of the study. This increase resulted in 85 times more grass plants in 1993 than in 1985.

Table 6—*Average density, cover, and height of combined shrubs (greenleaf manzanita, whitethorn, bittercherry, coffeeberry), Big Tunnel Plantation, Tahoe National Forest, California, 1983-1993*

Year	Treatment	Density	Cover	Height
		plants/acre	*ft²/acre*	*ft*
1983	Mechanical	19,813 a[1]	8,703 a	1.37 a
	Chemical	14,332 a	7,222 a	1.23 a
	Control	10,073 a	19,517 b	3.28 b
	Standard error	4,491	390	0.33
1985	Mechanical	16,369 a	13,813 a	2.66 a
	Chemical	5,148 b	3,148 b	1.30 b
	Control	12,850 ab	22,628 c	3.73 c
	Standard error	2,055	528	0.18
1986	Mechanical	13,740 a	14,147 a	3.26 a
	Chemical	4,666 b	2,000 b	1.51 b
	Control	11,851 ab	21,665 c	4.00 a
	Standard error	1,435	1,130	0.22
1988	Mechanical	13,295 a	10,258 a	4.02 a
	Chemical	4,333 b	741 b	2.08 b
	Control	9,999 b	15,147 a	4.34 a
	Standard error	857	1,185	0.30
1993	Mechanical	18,333 a	4,533 a	3.58 a
	Chemical	7,667 b	0 a	2.48 b
	Control	16,133 a	9,000 a	3.75 a
	Standard error	1,113	1,790	0.20

[1]For each year, treatment means in each column followed by the same letter do not differ significantly according to a Tukey Test ($\alpha = 0.05$).

Cost and Production

Cost data for the chemical and mechanical treatments were obtained from inspection reports that were compiled during the execution of the service contract under which the work was accomplished. Equipment production rates for applying the treatments came from Nevada City Ranger District records. Cost and production data for herbicide application came from project records.

Although based on rates for smaller areas, the cost and production rates gathered from this study compared favorably with rates generated by contracts for similar work on large areas awarded on several National Forests in northern California. These data were expected to be similar because both the contracts and this study shared similar terrain, woody plant species, treatment types, and worker motivation.

The chemical treatment was more expensive than the mechanical treatment because of chemical cost and labor required to apply the herbicide:

Treatment	*Production rate*	*Cost*
	Hours/acre	Dollars/acre
Mechanical	2.5	225
Chemical	5.5	273

Dollars per acre are for labor, equipment time, and chemical; they do not include overhead. Costs are updated to 1995 rates for labor and equipment of the type used on the study.

Table 7—***Average density, cover, and height of grass, Big Tunnel Plantation, Tahoe National Forest, California, 1985-1993***

Year	Treatment	Density	Cover	Height
		plants/acre	*ft²/acre*	*ft*
1985	Mechanical	1,555 a[1]	222 a	1.92 a
	Chemical	14,739 b	2,666 a	2.76 a
	Control	0 a	0 a	—
	Standard error	1,559	931	—
1986	Mechanical	1,259 a	37 a	1.05 a
	Chemical	209,423 a	2,296 a	1.84 a
	Control	0 a	0 a	—
	Standard error	95,376	802	—
1988	Mechanical	1,481 a	0 a	1.00 a
	Chemical	383,702 a	1,370 a	2.30 a
	Control	1,481 a	0 a	0.90 a
	Standard error	97,809	446	—
1993	Mechanical	0 a	0 a	—
	Chemical	1,246,667 b	0 a	0.59 a
	Control	44,000 ab	0 a	0.85 a
	Standard error	107,970	0	—

[1]For each year, treatment means in each column followed by the same letter do not differ significantly according to a Tukey Test ($\alpha = 0.05$).

Discussion and Conclusions

Conifer plantations function as the building blocks for both forest and ecosystem management. Both management strategies require thrifty stands of trees (usually conifers) that can be manipulated into the species composition and stand structure needed for future uses. Growth of these plantations has to be at an acceptable rate, that rate depending on future needs, whether the final product is a tangible commodity such as boards or an amenity such as scenic value. These stands must be thrifty if they are to survive for the many decades required to produce these desired results. To remain thrifty, most plantations in northern California must be released at least once during their lifetime; the best time for this release is early in the life of the plantation, usually within the first 1-3 years after outplanting. But often, the most opportune time for release is lost, and managers must consider how to treat older plantations. The size and amount of woody shrubs in these older plantations dictate mechanical treatment of some kind. Manual treatments are too expensive, and grazing and chemical treatments are usually not effective in controlling plants of this size.

Eleven growing seasons after treatment, mechanical release applied to a 12-year-old ponderosa pine plantation increased crown cover of the conifer saplings by 43 percent over that in the untreated control. Cost of this mechanical treatment was $225 per acre. Pine height and diameter were not significantly different between the mechanically treated areas and the control after the 11 growing seasons. In a variation to the mechanical treatment, herbicide was applied to the severed shrubs 1 year after the cutting operation. This herbicide application, including chemical and labor to apply the chemical, cost $48.29 per acre. The cost of the herbicide application added to the cost of mechanically cutting the shrubs totaled about $273 per acre. This additional $48 per acre resulted in a significant dividend to the growth of the conifers. By 1993, pine crown cover in the chemical treatment was significantly larger than in the other two treatments, increasing by 104 percent over the control and 42 percent over the mechanical treatment alone. Pine diameter and height also differed significantly in the chemical treatment when compared to the other treatments. Diameter in the chemical treatment was 47 percent larger than in the control and 26 percent larger than in the mechanical treatment. Pine height was 45 percent greater in the chemical treatment than in the control and 27 percent greater in the chemical treatment than in the mechanical treatment.

Grass plants, in large numbers, became established in the chemical treatment early in the study. Grass is shorter and probably less competitive to conifer trees of the size in the study than the woody shrubs that it replaced. Less competition meant more site resources would be available to the pine saplings.

For these plantations, releasing with mechanical treatment alone resulted in a significant increase in ponderosa pine cover, with no increase in conifer diameter or height. This significant increase in crown cover did not appear until the 11th year after treatment. When the mechanical treatment was enhanced by applying a herbicide 1 year later, at an additional cost of 21 percent, all parameters of pine growth were significantly increased over those in both the mechanical treatment alone and in the control. Mechanical release alone was not an effective or cost-efficient release method for these older plantations.

The Big Tunnel site indicated that untreated and mechanically treated ponderosa pines survived for at least 11 years, but whether they would grow to the size needed to meet future demands is doubtful. Ecosystem management and forest management depend upon building blocks being more predictable than this.

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