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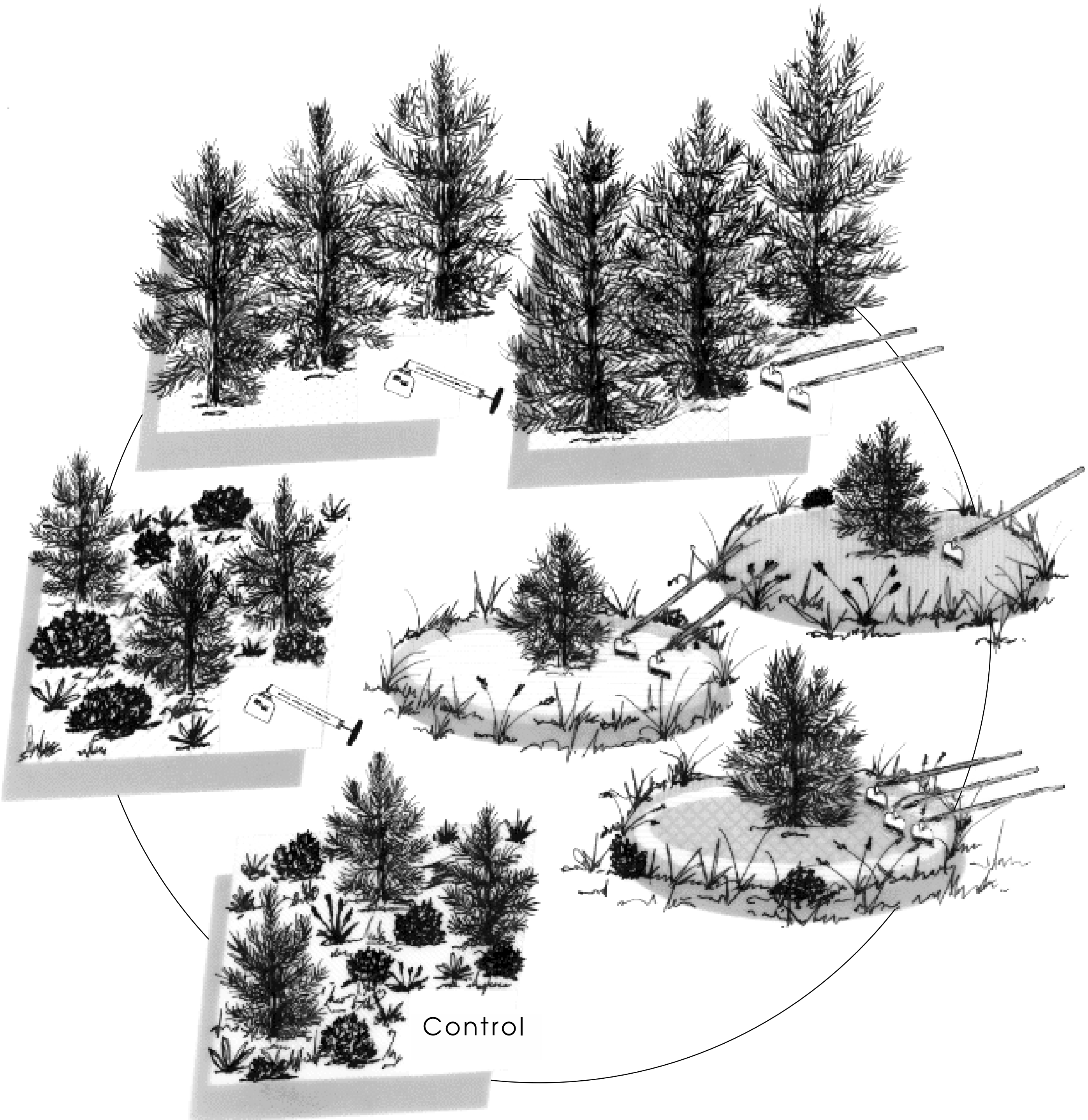
Development of a Mixed Shrub–Ponderosa Pine Community in a Natural and Treated Condition

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



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Abstract

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On a medium site in northern California, a mostly shrub community was treated by two manual release techniques and by two herbicides, to study its development in both a natural (control) and treated condition. Survival and growth of planted ponderosa pine seedlings were quantified for 8 to 11 years after initial treatment applications. Treatments included manual release in a 4-foot radius around pine seedlings one, two, and three times; grubbing the entire one-seventh acre plot two times; applying 2,4-D and Velpar herbicides to the entire plot one time; and a control. Data are presented for the most abundant species (greenleaf manzanita), second most abundant species (snowbrush), by the two species combined, and by all 10 shrub species combined. At the end of the study in 1990, manzanita was the most abundant species with 15,267 plants per acre, cover of 24,800 ft^2, and height of 5.4 feet. Ponderosa pine developed best in plots where the entire area was grubbed twice (mean diameter at 12 inches above ground of 6.3 inches) and in the Velpar-treated plots (mean height of 14.2 feet). The cost of grubbing the entire area twice was almost $1,700 per acre. Applying Velpar, including cost of the the chemical, was about $100 per acre. Site preparation without subsequent release led to a brushfield similar to that present before the study began.

Retrieval Terms: cost, greenleaf manzanita, manual and chemical release, northern California, ponderosa pine seedlings, shrub community

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

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In Brief

Conifer plantations characteristically occupy areas that have been severely disturbed by wildfire or timber harvest, often where slash was windrowed and usually burned, and where most remaining vegetation was uprooted and removed. Soil surfaces in these areas often are bare and temporarily devoid of most plants and animals. Available site resources, however, are high because large quantities of organic material are incorporated into the soil through harvesting and site preparation, and large amounts of moisture are absorbed by this organic matter. Warm temperatures and added moisture cause a rapid buildup of microorganisms that decompose organic material and liberate nutrients. In this unstable and rapidly changing environment, plants of many species often become abundant. Competition the first 5 years on productive sites often is intense and early densities of some species cannot be sustained. Consequently, the normal progression in the revegetation of disturbed areas is toward increasingly smaller numbers of taller and wider plants—a condition noted for shrubs in the untreated control in this study.

In treated plots, the amount of shrubs and other vegetation is a product of the kind and number of treatments. In turn, the amount of growth by planted ponderosa pine seedlings is a function of the amount of competing vegetation that remains and its rate of recovery. Amount and competitive potential of new vegetation also is important. Consequently, the treatment that best controls competing vegetation soon after planting almost always is best for ponderosa pine seedling growth. Early treatment denies competing plants the chance to recover or to utilize the high levels of site resources typically present after disturbance.

The four manual and two chemical treatments evaluated in this study created a plant community dominated either by planted pines or greenleaf manzanita and a few other shrubs. Forbs and grasses were virtually absent after 5 years. The most effective treatments (applying Velpar in liquid form or grubbing the entire area two times) created the pine community; the other treatments led to communities of pines and shrubs. Doing nothing (no treatment after site preparation) was rapidly leading to a plant community much like that before the study began—essentially a brushfield—with the exception that planted pine seedlings were present.

The most effective treatments with rapidly growing pines have high potential to create a forest similar to that present before the man-caused fires 50–120 years ago caused the brushfield. A forest probably is the more natural, stable, and desired condition. Certainly, the forest has more opportunities to provide a broad array of amenities and commodities needed by society than a brushfield. In ecosystem management, however, various amounts of shrubs, which provide berries, forage, and cover for wildlife, could be valuable. If mixes of pines and shrubs are desired, the study treatments show how to attain them and the costs of doing so. Costs ranged from $37 per acre for applying 2,4-D one time to almost $1,700 per acre for grubbing the entire plot two times. Cost-effective treatments that promote rapid growth of conifer seedlings have a place in ecosystem management. A mature forest, for example, may be needed a century from now in a particular area, and knowledge on how to get it established and growing at the potential of the site will be useful.

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- Participation with other agencies in human resource and community assistance programs to improve living conditions in rural areas
- Research on all aspects of forestry, rangeland management, and forest resources utilization.

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Introduction

Recent surveys indicate that Americans are vitally concerned about the use of natural resources and the environment. Most people regard the forest as a valuable resource and want it to be present and to provide a full range of amenities and commodities for future generations. To this end, increased emphasis is being placed on ecosystems, and particularly on their sustainability. This presupposes, probably with merit, that if the ecosystem is sustained, all the organisms in it, from the smallest to the largest, will also be sustained.

As forest management shifts toward forest ecosystem management, the need for knowledge on plant species and plant communities that develop naturally or after a deliberate manipulation is increasingly important. Manipulation could be for a variety of reasons: to create a future forest, to provide an economic crop, to grow plants along with trees whose seeds would be critical to wildlife, or simply to provide a broad base of species and age classes and thus be in position to provide amenities and commodities that will be needed in the future.

In forestry, unfortunately, much knowledge has been generated on economic species (the trees), but little is available on the uneconomic species, which often are disparagingly referred to as "weeds." However, as Ralph Waldo Emerson observed in 1879: a weed is "a plant whose virtues have not yet been discovered." In 1994, Jack Ward Thomas, the chief of the Forest Service, acknowledged in his first testimony to Congress that we have much to learn about ecosystems, and that "we have no option but to move forward on the basis of what we know." Furthermore, "We must quickly adapt to new information and new understanding as it becomes available" (Thomas 1994). Acquiring new information on uneconomic species is necessary for implementing ecosystem management.

To increase knowledge on the ecology of several widespread plant species and on a plant community that is commonplace in California and Oregon, information was collected on the growth dynamics and competitive relationships of vegetation reoccupying a bulldozed brushfield in northern California. Planted ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) seedlings were part of the plant community. As part of a National Forest Service Administrative Study on alternative release methods (Fiddler and McDonald 1984), data were gathered from 1981–1990 on vegetation developing naturally in an untreated control and on vegetation manipulated deliberately by several manual and chemical treatments.

This paper reports the results of these treatments and denotes the density and development of the two most abundant shrubs in the plantation both alone and combined. It also quantifies the diameter and height of the pine seedlings and shows when these parameters in each treatment differed statistically from those in the control and other treatments. Treatment costs and biological responses then are combined to show cost effectiveness—a measure that provides managers with options suited to their particular goals, constraints, and budgets.

Methods

Location and Site Characteristics

The study area, located on the Hat Creek Ranger District of the Lassen National Forest, is about 50 airline miles east of Redding, California. It also is located about 1 mile west of Logan Lake, a shallow meadow-lined ephemeral lake that historically has been a favorite camping place of hunters and stockmen. Fire scars and District records indicate that fire has been frequent in the area, sometimes originating near the lake. Fire probably was responsible for changing the predominately ponderosa pine forest (similar to that nearby) to a 250-acre brushfield with only an occasional pine. Before harvest of these remnant trees and site preparation on about 90 acres, most of the area was occupied by a dense mass of shrubs that averaged 10 feet tall and was nearly impenetrable to man or beast (*fig. 1*). Scattered California white firs (*Abies concolor* var. *lowiana* [Gord.] Lemm.) were slowly emerging from the shrubs.

After harvest in 1975 the woody shrubs and a little slash were pushed into contoured windrows with a brushrake-equipped bulldozer and burned in fall 1976. Very little soil was windrowed, and after 3 or 4 years, the windrows were barely visible.

Ponderosa pine seedlings from a local seed source were raised in the USDA Forest Service Nursery at Placerville and outplanted as 1–0 seedlings in mid–May 1977. Spacing was 8 by 10 feet. An excellent job of planting was done, and survival in the fall of 1979, when we began the study, was about 80 percent.

The plant community when the study began consisted mostly of plants that originated from dormant seeds in the soil and from windblown seeds. A few large *Arctostaphylos* and *Ceanothus* burls escaped the site preparation and contributed rapidly growing sprouts to the community as well. In addition to the planted ponderosa pine seedlings, the most abundant vegetation in the plantation was greenleaf manzanita (*Arctostaphylos patula* Greene) with snowbrush (*Ceanothus velutinus* Dougl. ex Hook.) a distant second. Scattered individuals and small aggregations of Sierra chinkapin (*Castanopsis sempervirens* [Kell.] Dudl.) and snowberry (*Symphoricarpos* spp.) plus six other species of woody shrubs also were present. Other vegetation included six species of forbs and two grasses, none of which were abundant.

Figure 1—Part of the Logan Lake study area in 1984. Note the mature brushfield with scattered California white firs in the background, the 8-year-old shrub community typical of the study area and treated plot in the middleground, and tops of ponderosa pine seedlings in the foreground.

Site quality of the study area is medium with height of dominant ponderosa pines averaging about 55 feet in 50 years (Biging and Wensel 1984). The soil, which is closely related to the Crozier series, was formed from andesitic parent material. It has a cobbly loam texture and is about 3 feet deep. Stones, cobbles, and large boulders are abundant throughout. The elevation is about 5,000 feet, the slope is 15 percent, and the aspect is east. The area is remarkably uniform with respect to slope, aspect, and soil. Precipitation averages about 36 inches per year, with about 70 percent falling as snow. Temperatures range from 19 °F to 80 °F with the average annual temperature being 43 °F. The growing season is 122 days.

Study and Design

The experimental design was completely randomized with one-way treatment structure. Seven treatments, including the control, were each replicated three times. A replicate (plot) consisted of about one-fifth acre on which were about 40 ponderosa pine seedlings surrounded by two to three rows of buffer (seedlings receiving similar treatment). Treatments and treatment dates were:

Manual grub

4-foot radius one time, installed September 1979,

4-foot radius two times, September 1979, November 1982;

4-foot radius three times, September 1979, November 1982, June 1985;

Entire plot August 1980, July 1984;

Chemical spray

2,4-D, September 1982;

Velpar, March 1983;

Control

Treatments were not considered complete until repeat applications had been performed.

The manual release treatments were designed to test the effect of removing competing vegetation one or more times from a fixed radius around crop trees and from the entire plot. Vegetation was grubbed below the root crown and sheared if leaning into the 4–foot radius or into the plot. The chemical treatments were the herbicides 2,4-D and Velpar, which for various reasons were not applied until before the 1983 growing season.[1] When the study began, 2,4-D was the foliage-active herbicide most often applied to forest plantations in California, and Velpar was a soil-active herbicide (possibly with some foliage activity) just beginning to be used in conifer plantations in the state.

The 2,4-D was applied directly in ester form from a backpack apparatus and a carbon-dioxide pressurized boom at the rate of 3 pounds acid equivalent per acre. Nozzles on the boom were the same as those used in helicopter application, hence rate of application and droplet size were similar. The boom, which covered a 9-foot swath, was held about 12 inches above the shrubs and the spray was directed downward. Trial runs with water determined the proper walking speed needed to apply the correct amount of herbicide to each plot. The entire seventh-acre plot and half the buffer were sprayed. Guides were used to ensure even coverage and no overlap. Because the buds were hard, the likelihood of spray damage was slight, and the seedlings were not covered. Spraying took place in clear, calm weather between 7 and 9 a.m. PST.

[1]This paper neither recommends the pesticide uses reported nor implies that the pesticides have been registered by the appropriate state governmental agencies.

Velpar L was applied to entire plots at a rate of 2 pounds acid equivalent per acre from standard backpack sprayers. Care was taken to insure that spray coverage was uniform without skips or overlaps. Substantial rain fell on May 22, 1983, which helped carry the chemical into the soil.

The cost of installing each treatment both initially and for retreating was calculated from hourly records and the current wage—$8.74 per hour—the rate for a WG-1 laborer, U.S. Department of Labor, as of June 1993.

Sampling

In each plot, 30 of the best ponderosa pine seedlings, identified as potential crop trees, were given a metal tag that was moved several times during the study to keep from strangling tagged branches. As their name implies, these were well developed seedlings that had good potential of becoming harvestable trees. On each of the sample seedlings, stem diameter and height were measured. Diameters were recorded at 12 inches above mean groundline. The seedlings were checked for injury from chemicals, animals, and insects.

Sampling intensity for evaluating other vegetation and foliar cover of pines in the control was five randomly selected subplots in each plot. Subplots were centered around ponderosa pine seedlings in all treatments. For plots where the entire area was treated (manual, 2,4-D, Velpar, and control), a square 1 milacre (0.001 acre) frame was used. For radius plots, sampling took place only in the treated area. Vegetation was measured for density, 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]), and average dominant height (average of the three tallest stems measured from mean ground line to bud).

Data were statistically analyzed as soon as possible after each measurement. To test for treatment effects and significant differences among treatments, one-way analysis of variance of treatment means (fixed model, Steel and Torrie 1980) and Tukey tests were applied (SAS Institute Inc. 1988). Statistical significance in all tests was at $\alpha = 0.05$. Data were gathered from permanent plots measured each year, and where analyses of means from repeated measurements are concerned, the data are not truly independent. The α levels or type I errors given for various tests apply to each measurement and year separately.

To quantify plant diversity, all species were noted when the study began, after 5 years, and at the end of the study.

Internal moisture stress of ponderosa pine, greenleaf manzanita, and snowbrush seedlings was determined to help explain growth differences among treatments that became apparent early in the study. Xylem sap tension was measured with a Scholander pressure chamber (Scholander and others 1965) on August 17, 1982, a typical cloudless day near the end of summer. At this time of year, the seedlings were physiologically stressed because of high moisture deficits.

Sampling of sap tension began well before dawn and continued through late afternoon. Because of time and distance considerations, only one replication was sampled. For this reason and because of the ever-changing amount of xylem sap tension in the plant, no statistical analysis of differences among treatments was attempted. Sampling intensity was three randomly selected seedlings of each species in each treatment. Consequently, three twigs of each species were tested in the pressure chamber at five measurement times throughout the day. Each twig was placed in a sealed plastic bag. The elapsed time between cutting and placement in the chamber did not exceed 3 minutes. Every third sample was measured twice in the chamber as a check on technique and working order of the equipment. "Plant moisture stress" in atmospheres is used in this paper to express pressure chamber values (Waring and Cleary 1967) because it is positive, direct reading, and most familiar to foresters and biologists.

Results

Plant Diversity

The plant community at the beginning of the study consisted of planted ponderosa pine, 10 species of shrubs, 6 forbs, and 2 grasses. Numerous tall dead stems of bull thistle (*Cirsium vulgare* [Savi] Ten.) and woolly mullein (*Verbascum thapsus* L.) indicated that plants of these species had been abundant the third and fourth years after site preparation but had then declined (*fig. 2*). After 5 years the community consisted of the same species with three additional forbs. By the end of the study in fall 1990, these same species were present. However, the forbs and grasses were so few and small that one had to search to find a single plant. This was true of some of the shrub species as well. The pines, greenleaf manzanita, and snowbrush, plus occasional snowberry, chinkapin, and two species of rabbitbrush (*Chrysothamnus* spp.), so dominated the plantation that plants of other species were becoming both diminutive and scarce.

One forb species that became abundant for a short but critical time was woolly nama (*Nama Lobbii* Gray), a low, spreading, shallow-rooted forb. It becomes established in sunny, exposed environments and is intolerant of shade (Nord and Leiser 1974). In a previous study, McDonald and Oliver (1984) noticed that woolly nama invaded shortly after an effective treatment removed almost all competing plants, quickly became dense, and excluded shrub seedlings. In this study, it became present in the plots where the entire area was grubbed twice. Many plants were noticed after the first grubbing, but it was not until after the second in July 1984 that the species became abundant. Thus, it probably excluded new shrub seedlings germinating from buried seeds and those recently distributed from nearby plants by birds and animals for about 5 years. It disappeared as quickly as it appeared, probably because of shade from pine crowns.

Greenleaf Manzanita

This evergreen, fast-growing shrub was the most abundant woody species in the plantation. After site preparation, viable seeds in the soil germinated by the thousands. Because greenleaf manzanita is a widespread and commonplace competitor in many pine plantations in California and southern Oregon, several relationships are presented for it. To show its recovery after site preparation, density, foliar cover, and height are presented in the control for 1981–1990. To show its response to the various treatments, density, cover, and height are presented for 1990 or after 14 growing seasons.

Density of greenleaf manzanita in the control was highest in 1981 at 26,000 plants per acre and declined thereafter (*table 1*). Foliar cover and height steadily increased from the beginning to the end of the study. From 1981 through 1990, the number of manzanita plants in the control had decreased an average of 41 percent, but cover had increased by 174 percent and height by 157 percent.

By fall 1990, manzanita density was significantly higher in the control than in any other treatment (*table 2*). Density also was significantly higher in plots grubbed only once to a 4-foot radius than in radius plots treated three times, with the entire area grubbed two times, or treated with Velpar one time. In the latter two treatments, number of manzanita plants numbered 400 or less with virtually no foliar cover and little height. These were observed to be newer, younger

A

B

Figure 2—(A) Numerous tall stems of woolly mullein and a few bull thistle (foreground) are present in the control in 1980, but in 1981 (B) few could be seen.

plants that had less time to grow and in many instances were dominated by taller pines or shrubs along plot edges. The trend in foliar cover was generally similar to that of density with large amounts of cover in the control and in plots grubbed to a 4-foot radius one time. Cover of greenleaf manzanita was intermediate in plots grubbed two and three times or treated with 2,4-D, and lowest where the entire area was grubbed twice or sprayed with Velpar. Manzanita plants were significantly shorter if the entire area was grubbed twice or sprayed with Velpar.

Snowbrush

Although snowbrush is a widespread and commonplace competitor in many conifer plantations in California and southern Oregon, ecological information, particularly density and development data, are needed for it (Conard and others 1985). Snowbrush is a hardy, fast-growing shrub with many adaptations (Hanes 1981, McDonald 1982) that make it a serious competitor to conifer seedlings in plantations. Mature plants form large burls with dormant buds that sprout vigorously if the aboveground plant parts are damaged. Moreover, the deep-rooted burl is resistant to removal by site preparation (McDonald and Fiddler 1989). The species also produces large and frequent seedcrops. Competition with pine seedlings in the study area was in the form of scattered root crown sprouts, seedlings from seeds in the soil, and seedlings from new seeds carried into the area by birds and rodents.

In fall 1981, density of snowbrush plants in the control was more than 1,800 plants per acre with more than 5,500 ft^2 of foliar cover and 2.1 feet of height (*table 1*). By fall 1990, density had decreased 21 percent and cover was 55 percent lower, but height had increased by 57 percent.

By fall 1990, density of snowbrush was highest in plots treated with 2,4-D followed by plants in the control (*table 2*). Density was lowest in plots where the entire area was treated two times. For foliar cover, the only significant difference was between plants treated with 2,4-D and all the other treatments. Snowbrush developed best in 2,4-D plots, probably because manzanita cover had been reduced substantially there. Snowbrush height did not differ significantly among treatments.

Greenleaf Manzanita and Snowbrush

Because these two species often are found together, are evenly distributed throughout the plantation, and frequently produce large seedcrops having high value to wildlife, they are presented as a combination.

In the control, density of manzanita and snowbrush decreased 40 percent from 1981 through 1990, and foliar cover and height increased 87 and 120 percent respectively *(table 1)*.

In treated plots, statistically significant differences among treatments for density included: (a) plants were more numerous in the control than in any other treatment; (b) plants in radius plots grubbed one and two times, and treated with 2,4-D were more abundant than in other treatments; and (c) plants in entire area grubbed or Velpar plots were fewer than in other treatments *(table 2*). Statistically significant differences among treatments for cover were quite similar to those for density. For height, only plants in plots with the entire area grubbed twice or treated with Velpar differed from all other treatments.

All Shrubs Combined

Most early seral vegetation in young plantations in California and Oregon almost always consists of a mixture of shrubs, forbs, and grasses, sometimes with an admixture of hardwoods. Rarely is this vegetation dominated by a single class of plants (McDonald and Redosevich 1992). Thus it is of interest to ecologists to

Table 1—*Density, cover, and height, with standard errors (SE), of greenleaf manzanita, snowbrush, manzanita and snowbrush, and combined shrubs in the control, Lassen National Forest, 1981-1990*

Year	Density	SE	Cover	SE	Height	SE
	---- *Plants/acre* ----		------- *Ft²/acre* ------		------- *Ft* ------	
			Greenleaf manzanita			
1981	26,000	2,731	9,067	794	2.1	0.2
1984	16,800	1,825	19,800	1,112	4.0	0.3
1985	16,533	1,576	22,467	1,556	4.3	0.2
1990	15,267	1,092	24,800	1,610	5.4	0.3
Difference (pct)	-41		+174		+157	
			Snowbrush			
1981	1,867	370	5,533	1,288	2.1	0.2
1984	1,733	392	7,733	1,275	3.2	0.2
1985	1,533	110	7,400	1,099	3.3	0.2
1990	1,467	139	2,467	628	3.3	0.3
Difference (pct)	-21		-55		+57	
			Manzanita and Snowbrush			
1981	27,867	2,885	14,600	877	2.0	0.1
1984	18,533	1,943	27,533	772	3.6	0.2
1985	18,067	1,607	29,867	1,404	3.8	0.2
1990	16,733	1,148	27,267	1,915	4.4	0.3
Difference (pct)	-40		+87		+120	
			Combined Shrubs			
1981	28,600	3,245	14,733	1,042	1.8	0.1
1984	19,200	3,156	27,533	803	3.1	0.2
1985	19,400	2,070	29,933	1,491	3.2	0.2
1990	17,733	1,773	27,267	1,907	3.7	0.3
Difference (pct)	-38		+85		+106	

have knowledge of a plant community dominated only by shrubs, albeit from two regeneration strategies (Grime 1979). These were rapid aboveground expansion by vegetatively produced sprouts and regeneration from a persistent seed bank (dormant seeds in soil). Combining all shrubs also allows inclusion of poorly distributed species such as snowberry and Sierra chinkapin, and fairly rare species such as gooseberry (*Ribes* spp.) and silktassel *(Garrya fremontii* Torrey).

In fall 1981, density of combined shrubs in the control was 28,600 plants per acre with more than 14,700 ft^2 of foliar cover and 1.8 feet of height *(table 1)*. By fall 1990, density had decreased 38 percent, but cover and height had increased 85 and 106 percent, respectively *(table 1)*.

Among treatments in fall 1990, the same relationships noted earlier were generally present: for density, the treatment having the most shrubs was the control; the least, Velpar. However, many combinations of treatments differed from other combinations that had not occurred before *(table 2)*. For foliar cover, the relationships among treatments were similar to those for manzanita and snowbrush combined. Only minor increases in cover were noted. This same similarity also was reflected in the average dominant height of combined shrubs. However, height was either less than or only slightly larger than greenleaf

Table 2—*Density, cover, and height of greenleaf manzanita, snowbrush, manzanita and snowbrush, and combined shrubs, Lassen National Forest, 1990*

Treatment	Density	Cover	Height
	Plants/acre	*Ft²/acre*	*Ft*
Greenleaf manzanita			
Manual			
4-ft radius 1 time	6,585 b[1]	16,348 b	4.3 b
4-ft radius 2 times	2,368 ab	8,087 cd	4.1 b
4-ft radius 3 times	693 a	3,177 ac	4.6 b
Entire area 2 times	400 a	0 a	0.5 a
Chemical			
2,4-D 1 time	4,600 ab	7,400 acd	4.4 b
Velpar 1 time	333 a	67 a	1.1 a
Control	15,267 c	24,800 e	5.4 b
Standard error	1,092	1,610	0.3
Snowbrush			
Manual			
4-ft radius 1 time	924 bc[1]	2,080 a	3.7 a
4-ft radius 2 times	520 ab	1,098 a	3.7 a
4-ft radius 3 times	289 ab	578 a	2.8 a
Entire area 2 times	0 a	0 a	—
Chemical			
2,4-D 1 time	1,600 d	5,133 b	3.1 a
Velpar 1 time[2]	0 a	0 a	—
Control	1,467 cd	2,467 a	3.3 a
Standard error	139	628	0.3
Manzanita and Snowbrush			
Manual			
4-ft radius 1 time	7,510 b[1]	18,428 bc	4.0 b
4-ft radius 2 times	2,888 ab	9,185 ac	4.0 b
4-ft radius 3 times	982 ac	3,755 ad	4.2 b
Entire area 2 times	400 a	0 a	0.5 a
Chemical			
2,4-D 1 time	6,200 bc	12,533 cd	3.7 b
Velpar 1 time[2]	333 a	67 a	1.1 a
Control	16,733 d	27,267 b	4.4 b
Standard error	1,148	1,915	0.3
Combined Shrubs			
Manual			
4-ft radius 1 time	10,745 cd[1]	18,428 bc	3.2 b
4-ft radius 2 times	7,221 abc	9,416 cd	3.0 b
4-ft radius 3 times	4,448 abc	4,044 ad	3.0 b
Entire area 2 times	2,867 abc	0 a	0.6 a
Chemical			
2,4-D 1 time	10,000 bd	12,600 cd	2.5 bc
Velpar 1 time[2]	467 a	67 a	1.0 ac
Control	17,733 d	27,267 b	3.7 b
Standard error	1,773	1,907	0.3

[1]For each species and combination, treatment means in each column followed by the same letter do not differ statistically at the 0.05 level

[2]No snowbrush present in plots before or during study

manzanita or snowbrush alone or combined—indicating the shorter stature of the additional shrubs.

Ponderosa Pine

Death of ponderosa pine seedlings was less than one per treatment during the study period. Despite the presence of numerous deer, and a few sightings of rabbits and ground squirrels early in the study, damage to ponderosa pine seedlings also was negligible.

Statistically significant differences among treatments for ponderosa pine stem diameter, measured at 12 inches above mean ground line, first showed up in fall 1985. Mean stem diameter of pines treated with 2,4-D was significantly smaller than counterparts in plots that had been entirely grubbed two times *(table 3)*. In fall 1990, pine seedlings in entire-grubbed plots and those treated with Velpar had the largest average diameter. These two treatments, which did not differ from each other, differed from most other treatments (*fig. 3*). Significant differences among treatments for stem height were not present until fall 1990. Seedlings in plots treated with Velpar, entire area grubbed, and 4-foot radius grubbed three times differed significantly from seedlings in the control, 2,4-D plots, and those grubbed to a 4-foot radius one and two times (*table 3*).

The ratio of height to diameter helps explain the effect of treatment. In those plots where the entire area was grubbed, for example, the height-diameter ratio decreased from initial values and then held steady throughout the study period; in the control, the ratio generally increased; and in the 4-foot radius treatments the ratio decreased and then remained steady. The treatments with the lowest values at the end of the study period were entire area grubbed and Velpar—suggesting that stem diameter was expanding faster than stem height. The

Table 3—***Stem diameter and height of ponderosa pine seedlings, by treatment, Lassen National Forest, 1981-1990***

Treatment	1981	1984	1985	1990
Diameter		*inches*		
Manual				
4-ft radius 1 time	1.09 a[1]	2.21 a	2.52 ab	3.67 b
4-ft radius 2 times	—	2.31 a	2.65 ab	4.04 b
4-ft radius 3 times	—	—	2.70 ab	4.38 bc
Entire area 2 times	—	2.58 a	3.18 a	6.33 a
Chemical				
2,4-D 1 time	—	1.61 a	1.89 b	3.20 b
Velpar 1 time	—	2.30 a	2.94 ab	6.08 ac
Control	0.97 a	1.91 a	2.14 ab	2.92 b
Standard error	0.13	0.23	0.26	0.35
Height		*feet*		
Manual				
4-ft radius 1 time	2.81 a	5.37 a	6.16 a	8.77 b
4-ft radius 2 times	—	5.37 a	6.23 a	9.86 b
4-ft radius 3 times	—	—	6.35 a	10.16 ab
Entire area 2 times	—	5.65 a	6.86 a	14.00 a
Chemical				
2,4-D 1 time	—	4.07 a	4.81 a	8.34 b
Velpar 1 time	—	5.04 a	6.28 a	14.19 a
Control	2.74 a	5.21 a	5.90 a	.66 b
Standard error	0.26	0.50	0.58	0.84

[1]For each year, treatment means followed by the same letter do not differ significantly at the 0.05 level.

Figure 3—Ponderosa pine seedlings in the various treatments in August 1984: (*top*) entire plot grubbed two times, (*middle*) 4-foot radius grubbed two times, and (*bottom*) control.

highest ratios were in the control and in plots treated with 2,4-D—suggesting that stem diameter was expanding slower than stem height.

Plant Moisture Stress

Predawn minimum moisture stress of greenleaf manzanita was lowest (6.4 atmospheres) in the grub entire area treatment, intermediate (6.5 atmospheres) in the control, and highest (10.2 atmospheres) in plots grubbed to a 4-foot radius. Maximum moisture stress followed a similar trend and was lowest in plots treated by grubbing the entire area (17.0 atmospheres), intermediate in the control (20.7 atmospheres), and highest in plants within the 4-foot radius (23.8 atmospheres) (*fig. 4*). Maximum stress was noted first (10:21 a.m. PST) in manzanita plants in the control, next in plants within the 4-foot radius (1:35 p.m. PST) and last in plants in which the entire plot was grubbed (2:17 p.m. PST). Manzanita plants in plots where the entire area had been grubbed twice had to endure less than half as long a period of high stress (more than 15 atmospheres) than plants in the other two treatments.

For snowbrush plants, predawn minimum moisture stress was lowest (6.3 atmospheres) in the grub entire area treatment, intermediate (6.5 atmospheres) in the control, and highest (8.0 atmospheres) in plots grubbed to a 4-foot radius. Maximum moisture stress rankings were similar. From lowest to highest, treatments were: entire area (16.3 atmospheres), control (17.8 atmospheres), and 4-foot radius (18.7 atmospheres) (*fig. 4*).

Predawn minimum moisture stress of ponderosa pine seedlings was lowest (5.8 atmospheres) in the grub entire area treatment, intermediate (7.7 atmospheres) in the control, and highest (8.8 atmospheres) in plots grubbed to a 4-foot radius. The ranking of maximum moisture stress among treatments was similar in the entire area (14.8 atmospheres), 4-foot radius (17.2 atmospheres),

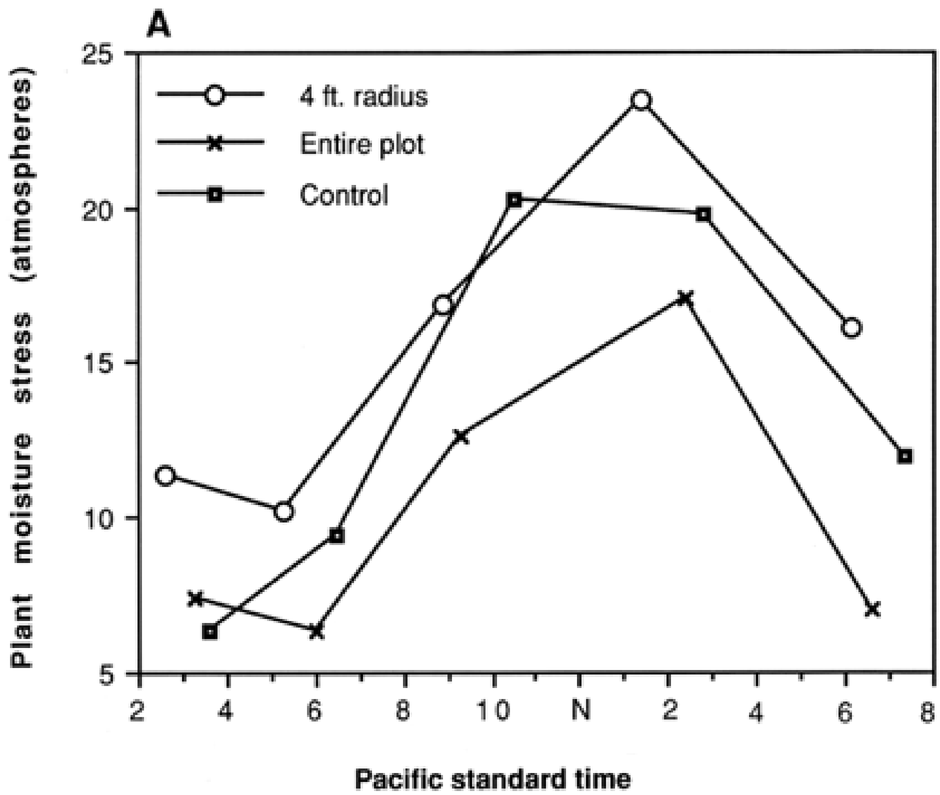
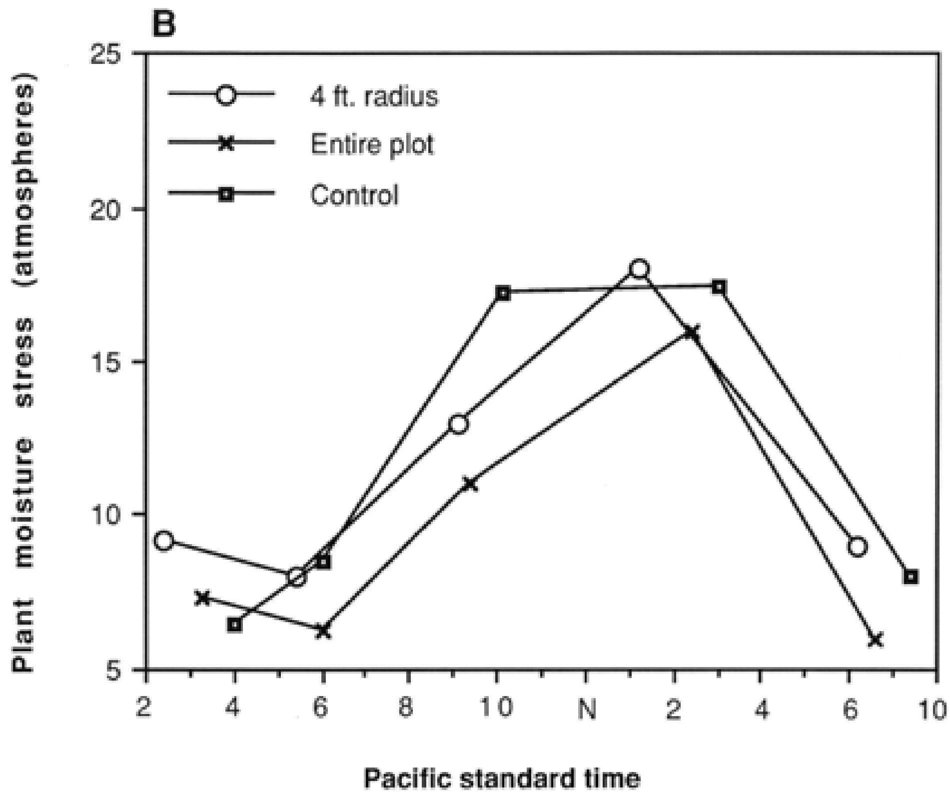
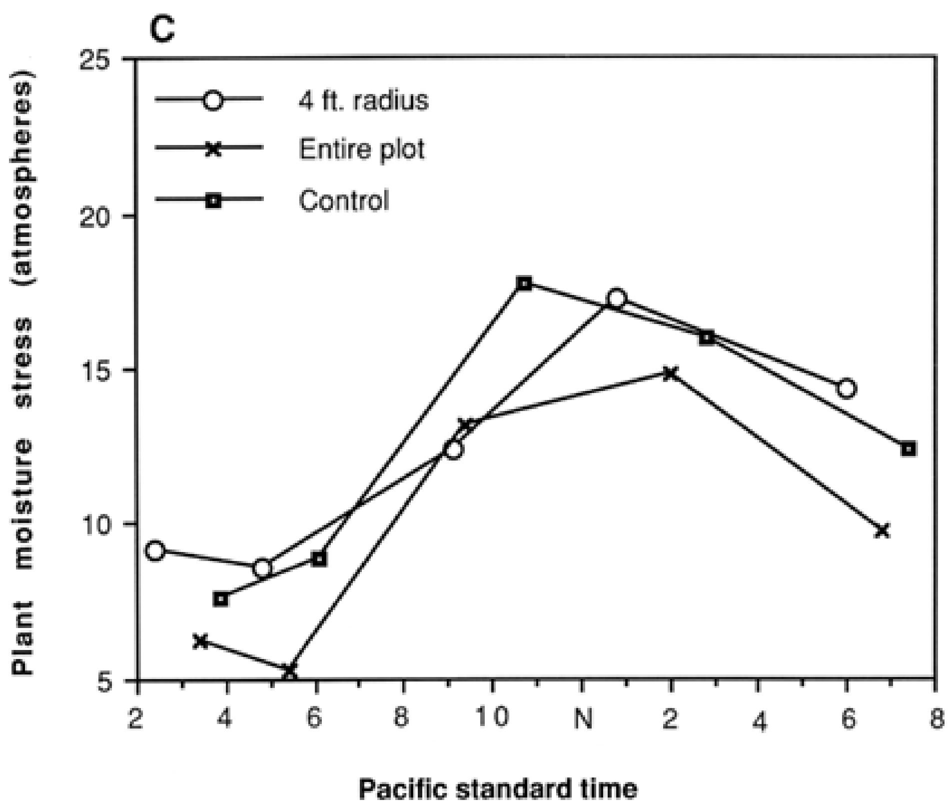


Figure 4—Diurnal trend of internal moisture stress on August 17, 1982 in (A) greenleaf manzanita plants, (B) snowbrush plants, and (C) ponderosa pine seedlings. Standard errors applicable to differences between treatments could not be estimated.


B
25
20
15
10
5
Plant moisture stress (atmospheres)
4 ft. radius
Entire plot
Control
2
4
6
8
10
N
2
4
6
10
Pacific standard time


C
25
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Plant moisture stress (atmospheres)
4 ft. radius
Entire plot
Control
2
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Pacific standard time

and control (17.7 atmospheres) (*fig. 4*). The onset of maximum stress occurred first in pine seedlings in the control (10:12 a.m. PST), next in plants within the 4-foot radius (1:22 p.m. PST) and last in plants in which the entire plot was grubbed (2:05 p.m. PST). Indeed, by being under 15 atmospheres of moisture stress (Cleary 1970), pine seedlings in the plots grubbed entirely two times probably achieved positive net photosynthesis the entire day while seedlings in the control did so from the time the stomates first opened shortly after first light (5:30 a.m. PST) until about 10:00 a.m. PST.

Production and Cost

Grubbing a 4-foot radius two or three times or grubbing the entire plot twice proved expensive. Waiting 4 years before grubbing the entire plot the second time allowed the shrubs to develop large rootstocks that were difficult and costly to remove. Spraying chemicals was the least expensive as shown in the following tabulation:

Treatment:	Laborer hours/acre	Dollars/acre
Manual		
4-ft radius, one time	24	210
4-ft radius, two times	59	516
4-ft radius, three times	99	865
entire plot, two times	194	1,696
Chemical		
2,4-D, one time	3	27
Velpar L, one time	3	27

Costs are for labor only and do not include overhead or the cost of the chemical. If the cost of the chemical was included, $10 should be added to the cost per acre for 2,4-D and $75 for Velpar L.

Discussion and Conclusions

In spring 1977 or the first growing season after site preparation, visual evidence and notes by Ranger District personnel indicated that revegetation began quickly. Buried, dormant seeds of greenleaf manzanita, snowbrush, and other shrub species germinated and produced many thousands of seedlings. A few remaining but damaged plants of snowbrush, snowberry, and Sierra chinkapin produced sprouts as well. Seeds of bull thistle and woolly mullein probably blew in on the wind in the fall and settled in pockets in the soil or caught on minor protrusions from it. Seedlings from these species and a few others formed the forb component of the plant community. Some grass seeds also were carried into the study area, probably by animals or the wind. A few tree seedlings, particularly of ponderosa pine and California white fir, also struggled to become established.

During the 1978 and 1979 growing seasons, competition for light and growing space intensified with inherently shorter species falling behind. Plants that could not compete well for soil moisture, the limiting environmental factor, were dying. Bull thistle (McDonald and Tappeiner 1986, Randall 1990) and woolly mullein (Semenza and others 1978) are biennials that typically produce plants that peak in density during the third and fourth growing seasons. At the end of the fourth growing season in 1980, the forbs, grasses, naturally-seeded conifer seedlings, and smaller shrubs were becoming short and scarce. They were too few and too poorly distributed to be analyzed statistically. By the end of the study, only 18 plant species had been found, causing this plantation to rank next to last in terms of species diversity (range of 17–41 species) in our National Administrative Study in young conifer plantations (McDonald and Fiddler 1993).

Analysis of the first full data set in 1981 showed that greenleaf manzanita constituted more than 90 percent of total plant density and 62 percent of foliar cover in the control. Density declined and then steadied at 86 percent. Foliar cover of manzanita steadily increased to 91 percent of total shrub cover in 1990. By 1984, average dominant height of manzanita was highest of any shrub in the plantation—an advantage that it maintained throughout the study. Snowbrush density ranged from 7 to 9 percent of total plant density in the control, but foliar cover, which initially amounted to 38 percent of total cover, decreased to 25 percent in 1985 and to 9 percent in 1990. Thus, while the number of snowbrush plants per acre remained almost constant, foliar cover decreased dramatically during the 10-year study record, especially during the last 5 years.

After subtracting manzanita and snowbrush from combined shrubs, the dynamics of the eight other shrub species in the control were discernible. Other shrubs increased from 3 to 6 percent of total shrub density, but contributed virtually nothing to foliar cover during the study period. That they were able to increase their number during the time of rapid manzanita expansion suggests that they have the capability to become established in small uncolonized areas and in the shade, but not to develop well either horizontally or vertically.

In the heavy competition and reduced soil moisture availability of the control, ponderosa pine seedlings typically sacrifice crown and needle development for height growth to avoid being overtopped. Consequently, their form tended to be tall with relatively narrow crowns. When foliar cover was expressed as a percentage of each acre occupied by vegetation, the proportion at the end of the study was manzanita, 57 percent; snowbrush, 6 percent; ponderosa pine, 28 percent; and rocks/bare ground, 9 percent.

On treated plots, we noted that shrub densities grubbed once early in the study tended to be fairly high and then to decrease with time, probably as a consequence of competition. If shrubs were treated later, as in the 2,4-D plots, density, which initially was high, also tended to decline naturally. If plots were treated two or three times, plant densities would build and then be reduced in a cycle created by each treatment. Foliar cover and height showed only one pattern—increase until treated, decline, and then increase again.

By fall 1990, the various treatments had all reduced the shrub component of the plant community to some degree. Except for 2,4-D, treatments that affected the entire plot area were more effective than grubbing to a 4-foot radius. From previous studies, we have found that the minimum effective radius is 5 feet—any lesser radius does not give the conifer seedlings time to develop the deep and extensive root system necessary to secure adequate soil moisture for growth at the potential of the site (Fiddler and McDonald 1984, McDonald and Fiddler 1989). Grubbing three times during a 6-year period significantly reduced manzanita density and foliar cover compared to grubbing one time *(table 2)*. But multiple grubbing did not significantly improve pine growth over that in the control.

For all shrubs combined, the chemical treatments provided a noteworthy contrast in effectiveness. Basically, 2,4-D was ineffective and Velpar was very effective. More than 21 times more shrubs were present in 1990 in 2,4-D plots than in Velpar plots and they had 188 times more foliar cover.

The cost and production data gathered in this study reflect the interplay between size of woody shrubs and the cost of eliminating most of them. Almost all of the shrubs on study plots originated from buried, dormant seeds in the spring after site preparation. Consequently, most shrubs were 3 years old when the first 4-foot radius was grubbed in September 1979, 4 years old when the entire plots were first grubbed in August 1980, and 6 years old when sprayed with Velpar early in 1983. For manual release, grubbing to a 4-foot radius cost more each time in spite of the fact that fewer shrubs were present in the increasingly shaded (by the pines) subplots. However, more and more vegetation along the sides of the grubbed area were leaning in and these required increased clipping. For those plots where the entire area was grubbed two times, waiting four growing seasons before performing the second round of treatment was costly. The crew foreman noted that shrubs were 3 feet tall and rootstocks were large and tough to grub. In contrast, spraying chemicals on 3-foot-tall shrubs was much less arduous.

Purely from a vegetation management viewpoint, the best conifer release treatment is one that effectively controls competing vegetation and does so in a timely manner—right after the conifer seedlings are planted and in the process of becoming established (McDonald and Oliver 1984, McDonald and Fiddler 1989). The first 3 years are important; the first year is critical. Seedlings must be free to vigorously expand their root systems in an ever-increasing volume of soil. In a southern Oregon study for example, roots of Douglas–fir (*Pseudotsuga menziesii* [Mirb.] Franco) seedlings were excavated and carefully measured relative to the amount and position of roots from competing vegetation. Results showed that the Douglas-fir roots expanded greatly in biomass and volume of soil occupied in the near-absence of competing vegetation, but developed scarcely at all if roots of competing species were present (Tesch and Hobbs 1989). In our study at Logan Lake, no treatment was applied until after the competing vegetation (and the planted seedlings) was at least 3 years old. Indeed, in one treatment (Velpar), the competing shrubs were 6 years old. Delaying treatment for 2 or 3 years is too long. Roots of competing plants not only become extensive and capable of capturing most of the available soil moisture, but they also cause manual grubbing to be much more expensive.

An ongoing objective of our National Administrative Study on vegetation management is to determine the timing of treatment effectiveness. In one trial with ponderosa pine in northern California, we were able to attain a statistically significant difference in ponderosa pine seedling diameter relative to the control two growing seasons after treatment of 4-year-old shrubs (McDonald and Fiddler 1990). This is the fastest that we have found statistical significance in our studies. Seedling diameter almost always provides a significant difference before seedling height. Although differences often are present, having a *statistical* difference at the 5 percent level is much harder to attain. In general, the longer the time the conifer seedling grows with a high level of competition, the longer it takes the difference between an effective treatment and the control to become statistically significant.

The interaction between level of competition and the effectiveness of the treatment also is important. Two related but different interactions occur. The first is caused by only moderate competition and the second by only a moderately effective treatment. If the competing vegetation is developing at only a moderate rate, the conifer seedlings in the control grow fairly well. Differences in conifer seedling growth between these seedlings and faster growing seedlings in effective treatments take a long time to become statistically significant. And, if the competition is strong but the treatment is only moderately effective, an interval of many years may be required before a statistically significant difference becomes apparent.

In this study, the interval between time of planting and first significance, which was for grubbing the entire area two times, occurred at 6 years for pine diameter and at least 7 years for pine height. The initial application was applied early enough, but the interval between the first and second applications was too long. Consequently, the total treatment is best described as moderately effective for strong competition.

"Replacement" vegetation, which becomes established after treatment, is of particular interest to ecologists and vegetation management specialists. It may contain some beneficial plants as in the case of woolly nama, or it may encourage a detrimental species that would vector in a destructive animal like pocket gophers (*Thomomys* spp.). Pocket gophers can destroy a young conifer plantation (Crouch 1986). Woolly nama was beneficial because it appeared to offer little competition to ponderosa pine seedlings, and it apparently interfered with the establishment of highly competitive shrub species. Consequently, it probably functioned as a biological control during a short but critical time after the treatment was applied. The fact that it did not appear after the third grubbing in the radius plots probably can be explained by the high amount of shade contributed by the "wall" of shrubs surrounding the subplots and by the expanding pine crowns. It did not become present on the bare ground in the Velpar plots either, probably because of the residual chemical in the soil and because of shade from tree crowns. Identifying beneficial replacement species, learning their biology, and developing propagation techniques for future use is a facet of vegetation management that has much promise.

Assuming that good site preparation fosters good pine seedling growth is unrealistic. Data for combined shrubs in the control and relative growth rates show this dramatically. In 1990, shrub density was more than 17,700 plants per acre, 3.7 feet tall, with interwoven crowns that covered more than 62 percent of the area so closely that they cast a solid shadow. Average pine height and diameter in the most effective treatments (Velpar, grub entire area two times) was 63 and 112 percent greater, respectively, than for counterparts in the control. Although almost all pine seedlings are alive in the control, their future is uncertain and probably precarious. Many have sparse crowns with only tufts of short current-year needles. Although ponderosa pine seedlings are noted for their capability to survive for two decades or more with high levels of competition, the odds for decreased growth and survival are high (McDonald and Oliver 1984).

Manual and chemical release created several vegetative assemblages, each with different amounts of the principal species, and with different developmental potentials. If the treatment was Velpar or grubbing the entire area two times, the future plant community would likely consist of ponderosa pines with a few scattered shrubs in the understory. The pines in these treatments should continue to grow rapidly as sunlight and soil moisture are fully utilized. If no treatment followed site preparation as in the control, the plant community of the future most likely would be dominated by large numbers of vigorous shrubs and scattered slow-growing pines. The other treatments would produce plant communities with various mixes of shrubs and pines having variable growth rates.

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