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Timing and Duration of Release Affect Vegetation Development in a Young Ponderosa Pine Plantation

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Abstract

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The density and development of greenleaf manzanita, other shrubs, and graminoids were evaluated in a young ponderosa pine plantation on a poor site in northern California from 1988 through 1997. Manual grubbing to a 5-foot radius created treatment regimes that lasted for 3 to 6 years and vegetation recovery times of 4 to 10 years. The duration and timing of the grubbing constituted the treatments. Greenleaf manzanita was the dominant shrub in the former brushfield and again dominated after site preparation and release. In 1988 its density in the control averaged 123,500 plants per acre; in 1997 density had declined to 44,450 plants per acre, but its foliar cover had increased to 34,600 ft² per acre and its height to 3.2 feet—values that were significantly larger than counterparts in any other treatment. Early release provided pine seedlings with a significant advantage in average height and diameter if continued each year for the first 3 years and first 6 years. However, manually grubbing the last 3 of the first 6 years gave no biological advantage and was more expensive. Delaying grubbing for the first 3 years and then grubbing each year for the next 3 years (years 4 through 6) also provided pine seedlings with a significant growth advantage over counterparts in the control, but was expensive. Delayed grubbing usually is biologically ineffective, but on poor sites such as this, any release is beneficial.

Retrieval Terms: competing vegetation, northern California, plant succession, ponderosa pine seedlings, poor site, timing of release

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Density and development of greenleaf manzanita and several other shrubs and grasses that invaded a young conifer plantation were studied on a poor site at mid-elevation (4,750 feet) in northern California. In addition, survival and growth of planted ponderosa pine seedlings were quantified in four release treatments relative to this vegetation. A major influence on all the vegetation was the environment of the site, which is best characterized as harsh because of the rocky, droughty soil, exposed west aspect, and incessant wind.

This study differs somewhat from most studies that evaluate alternatives for controlling competing vegetation in young conifer plantations. In this study, we wished to document the recovery of the vegetation after a series of manipulations that were applied at different times and continued for various durations. We hypothesized that the amount of vegetation and when it was present, relative to site preparation and release, would affect the various species in the community and in turn affect the conifer seedlings. Thus, the manual grubbing and fertilizer that we applied served only to accomplish the treatments. The different times of application, their duration, and the plant community recovery times were the treatments. These were:

- Treat first 6 years (1988-1993), develop naturally last 4 years: **T-first-6**
- Fertilize first year, treat first 6 years (1988-1993), develop naturally last 4 years: **F-first-6**
- Treat first 3 years (1988-1990), develop naturally last 7 years: **T-first-3**
- Delay 3 years, treat next 3 years (1991-1993), develop naturally last 4 years: **T-second-3**
- No treatment after site preparation, develop naturally entire 10 years of the study (1988-1997): **Control**.

A greenleaf manzanita brushfield begets a greenleaf manzanita brushfield in spite of a good job of site preparation and release. This shrub was by far the most abundant and dynamic natural species in the study area. In the first growing season after treatment, density of greenleaf manzanita in the control was 123,500 plants per acre or 40 times more than that of the other shrubs and graminoids combined. When the study ended 10 years later, manzanita density (44,450 plants per acre) was 5 times greater, but its foliar cover (1,600 ft² per acre in 1988 and 34,600 ft² per acre in 1997) had increased from 11 to 23 times greater than the other shrubs and grasses combined. Among treatments at the end of the study, greenleaf manzanita was significantly taller and wider in the control than in all others.

Graminoids, chiefly needlegrass, were significantly more dense in the T-first-3 treatment than in the control at the end of the study—confirming the inverse relationship between grasses and shrubs noted in earlier studies.

For ponderosa pine seedlings, immediate release for the first 3 and 6 years provided a significant increase in average stem diameter and height over counterparts in the control three growing seasons after treatment, and continued throughout the 10-year study. Grubbing each year for the first 6 years was not justified either biologically or economically. Delayed release, as in the T-second-3 treatment, also resulted in significantly larger stem diameters and more foliar cover than for pines in the control at the end of the study. This is contrary to findings in other studies and was not anticipated. However, a similar study has shown that on a poor site, the need for release is so strong that *any* release, regardless of timing, duration, or vegetation recovery time, is beneficial.

Introduction

*One farmer sows the barley soon
His neighbor sows them late,
But both see the charlock grow
As was their father's fate.*

(Van der Zweep 1981)

The early plant community typical of young plantations often is composed of competitive species (as evidenced by charlock), is diverse, and often variable because of different historical events (fire, windthrow), different regeneration strategies (seed and seedling banks, wind-borne seeds, rapid growth above and below ground; Grime 1979), and different successional mechanisms (facilitation, tolerance, inhibition; Connell and Slatyer 1977). Many species from many categories of vegetation, including conifers, hardwoods, shrubs, grasses, forbs, and ferns, comprise the plant community (McDonald 1999, McDonald and Fiddler 1993). Through natural selection over millions of years, many species are superbly adapted to dominate in newly disturbed areas. Land recently prepared for planting is nearly ideal: soil moisture levels are high and nutrients generally are plentiful. Competition to newly-planted conifer seedlings almost always develops quickly and becomes formidable. Seedling death or a slowed growth rate is the usual consequence of not treating the developing vegetation.

Clearly, the plant community needs to be manipulated to achieve conifer survival and development goals. One method to achieve this is to reduce the presence or vigor of the competing plants—a process called plantation release. But when should release be implemented, and how long should it be continued? Early studies provided some information on the lag between the visible decline of conifer seedlings and the effect of competing vegetation. Bentley (1967) recorded “noticeably lower vigor” of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) seedlings after four growing seasons on a poor site in northern California, even though the shrubs had been effectively treated with herbicide the previous year. In another northern California study on a good site, naturally seeded ponderosa pine seedlings growing with rapidly developing vegetation first showed signs of competition three growing seasons after site preparation (McDonald and Radosevich 1992). Fewer, shorter, and lighter colored needles became noticeable at this time. By the time the pines show visible signs of competition, it is too late. Several years of reduced growth ensue even if the pines are released immediately. This growth was not recovered for at least 31 years on a poor site (McDonald and Abbott 1997).

When does the effect of competition on planted conifer seedlings first become manifest? That depends on the kind, amount, and spacing of the competing species and also on the productivity of the site. Only one definitive study could be found. On a productive site in northern California, Radosevich (1984) evaluated the competitive interaction between greenleaf manzanita (*Arctostaphylos patula* Greene) and ponderosa pine seedlings in an experiment having several proportions of seedlings and shrubs. During the first growing season, no interference was observed between shrubs and seedlings, even though about 60 times more growth in terms of biomass took place on the shrubs than on the pines. Interference apparently began the second growing season. After three growing seasons, shrub growth was still about 35 times greater than pine seedling growth, but pine growth had decreased on all plots where manzanita was present. Also, after three seasons, manzanita was beginning to limit its own growth, especially where it was more abundant.

Although some empirical evidence is available, the relationship of the timing of release to the onset of competition on sites of different productivity is largely unknown. Effective timing of release could depend on the kind of plant species, the abundance of each, and their rate of development. Timing of release could

also be manifest in any of several comparisons, such as immediate versus delayed release or releasing for one timespan versus another. At some point, delayed release might not be more effective than never releasing, or releasing each year for several years might not be more effective than releasing for 1 or 2 years, depending on when the release took place. As part of a National Forest Service administrative study on alternative release methods (Fiddler and McDonald 1984), data were gathered from 1988 to 1997 on vegetation developing after site preparation in a control and on vegetation manipulated deliberately by fertilizing and by grubbing. Time of release, duration of release, and the timespan after release, or more specifically the "vegetation recovery times after disturbance by site preparation and release," were the treatments.

This paper reports the biological and economical results of these treatments in terms of the recovery of the plant community 2, 5, and 10 years after manipulation, and it quantifies the survival and growth of the ponderosa pine seedlings after immediate and delayed release.

Methods

Location and Site Characteristics

The study area is located on the Mt. Shasta Ranger District of the USDA Forest Service's Shasta-Trinity National Forests in T41N, R4W, sections 27 and 28. It is about 4 airline miles north of the town of Mt. Shasta and on a gentle slope at the base of the mountain that has a similar name. Before the study began, the area was a brushfield, and probably had been for scores of years. It had not always been a brushfield, however, as an occasional hard, blackened log indicated that at least some trees were present long ago. Scattered trees on a nearby hillside also suggest a past forest and provide clues as to the species makeup of the stand. Ponderosa pine probably was the most abundant species, followed by incense-cedar (*Libocedrus decurrens* Torr.) and California white fir (*Abies concolor* var. *lowiana* [Gord.] Lemm.). Scientific names of trees are from Little (1979) and for all other plant species from Hickman (1993).

Before the study began, the mature brushfield consisted of 4- to 5-foot tall plants of greenleaf manzanita and snowbrush (*Ceanothus velutinus* Dougl. ex Hook.), with occasional bitter cherry (*Prunus emarginata* [Hook.] Walp.), bitterbrush (*Purshia tridentata* (Pursh) DC.), and rabbitbrush (*Chrysothamnus* spp.). Prostrate mahala mat (*Ceanothus prostratus* Benth.) also was present but limited to small open areas among shrub clumps.

Site quality of the study area is low with height of dominant mixed conifers averaging about 50 feet in 50 years (Biging and Wensel 1984). The site is best described as harsh for the establishment and growth of conifer seedlings. The soil, which is closely related to the Neer series, is a skeletal, mesic Andic Xerochrept. It was formed in material weathered from volcanic ash and deposited over extrusive igneous rocks. It has a gravelly sandy loam texture and is about 3 feet deep. Large stones, gravel, and sand are abundant throughout. The elevation is about 4,750 feet, the slope averages 10 percent, and the aspect is west. The area is reasonably uniform with respect to slope, aspect, and soil. Precipitation averages about 40 inches per year, with about 60 percent falling as snow. Temperatures range from 20 °F to 85 °F with the average annual temperature being 48 °F. The growing season is about 100 days. Downslope-winds off of Mt. Shasta are common in all seasons of the year.

Shrubs in the study area were pushed into windrows with a brushrake-equipped tractor in spring 1986 and burned in the fall. Very little soil was displaced, and the windrows could scarcely be seen a few years later. The area also was cross ripped (perpendicular to slope) at about 10-foot intervals in the summer of 1986 (fig. 1). This operation broke up the dense mass of rocks and shrub roots and served to loosen the soil. It also created depressions perpendicular to the primary wind direction that filled with snow in the winter.



Figure 1—A portion of the study area showing the depressions perpendicular to the slope made by the ripper.

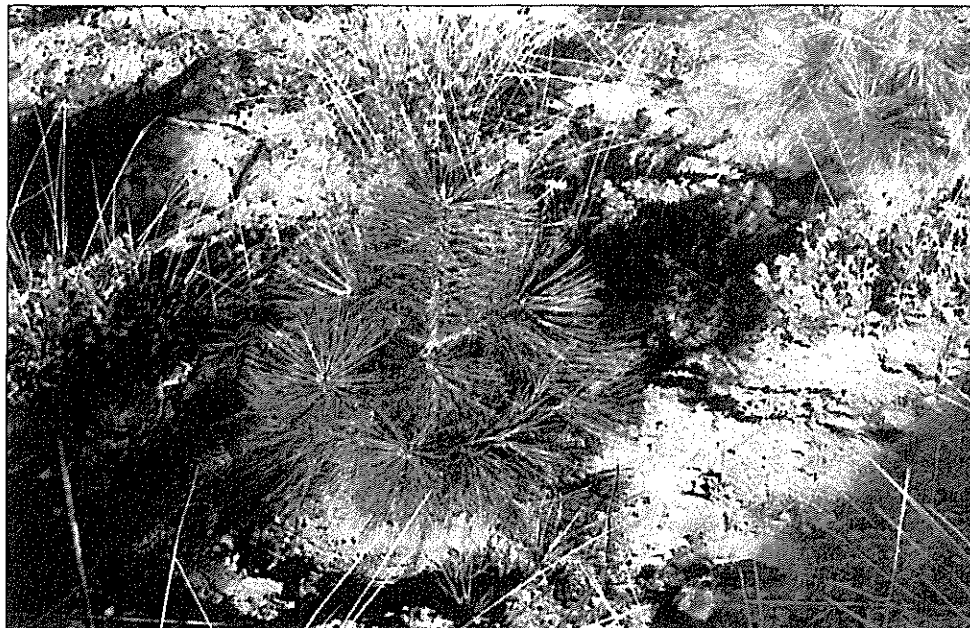


Figure 2—This 4-year-old ponderosa pine seedling in the control is surrounded by greenleaf manzanita plants from seed.

Ponderosa pine seedlings were raised in the Placerville Nursery and planted in the depressions created by the ripper in spring 1987. Spacing was 10 by 10 feet. Mortality of seedlings in all study plots at the end of the first growing season was estimated at less than 5 percent. The plant community when the study began consisted almost entirely of plants that had originated from dormant seeds in the soil and from windblown seeds. Virtually no competition from sprouting root burls was present. In addition to the planted ponderosa pine seedlings, the early plant community consisted almost entirely of greenleaf manzanita seedlings (fig. 2) and a few plants of the other shrub species noted earlier. A few grasses (fig. 3) and forbs also were present.

Insects were commonplace in the plantation and affected the growth and form of the pine seedlings. The principal species were the pine needle-sheath miner (*Zelleria hainbachii* Busch) (Stevens 1959) and the gouty pitch midge (*Cecidomyia piniinopsis* Osten Sacken) (Bedard and others 1989). Several animals, including ground squirrels (*Spermophilus* spp.) and rabbits (*Lepus* spp.), were occasionally seen in the study area.

Figure 3—A typical T-first-6 subplot in fall 1990. Stems of needlegrass are readily seen.



Study and Design

The experimental design was completely randomized with five treatment categories, including a control and four replications, each referred to as a “plot.” A replicate (plot) was rectangular and consisted of about 0.1 acre on which were about 40 ponderosa pine seedlings surrounded by at least 2 rows of buffer (seedlings receiving similar treatment). The study began in 1988 and ended in 1997. Treatments and treatment dates were:

- Treat first 6 years (1988-1993), develop naturally last 4 years: **T-first-6**
- Fertilize first year, treat first 6 years (1988-1993), develop naturally last 4 years: **F-first-6**
- Treat first 3 years (1988-1990), develop naturally last 7 years: **T-first-3**
- Delay 3 years, treat next 3 years (1991-1993), develop naturally last 4 years: **T-second-3**
- No treatment after site preparation, develop naturally entire 10 years of the study (1988-1997): **Control**.

Treatment consisted of grubbing all vegetation in a 5-foot radius around selected pine seedlings with hand tools. The cost of each treatment both initially and for retreatment was calculated from hourly records and \$8.74 per hour—the rate for a WG-1 laborer, U.S. Department of Labor as of June 1993. No allowance for travel, equipment, or overhead was included. The fertilizer, which was applied in early summer 1987, was a slow-release variety and contained 14 percent each of nitrogen, phosphorus, and potassium. Each sampled seedling received 76 grams of fertilizer in a 6-inch deep hole located about 4 inches uphill from it.

Sampling

Of the 40 ponderosa pine seedlings in each plot, 25 that appeared to have good potential of becoming harvestable trees were selected and tagged. Chlorotic and misshapen seedlings that would be removed in the first precommercial thinning were excluded. Stem diameter (recorded at 12 inches above mean

groundline), stem height, 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 needle length were measured on each. Unfortunately, limitations in budget and staffing affected sampling, and some remeasurements were not taken. All vegetation was periodically checked for injury from abiotic agents, animals, and insects.

Sampling intensity for evaluating vegetation other than pines was five randomly selected subplots in each plot. Subplots were centered around ponderosa pine seedlings and encompassed 1 milacre (0.001 acre). The most abundant species were evaluated for density, foliar cover, and average dominant height (average of the three tallest stems measured from mean ground line to bud). More specifically, number of plants in each subplot were counted, foliar cover was visually estimated, and height was measured with a graduated pole. Because treatment in the T-first-6 and F-first-6 subplots was intensive and continuous, revegetation and competition to pine development were considered to be minor. Hence, data on manzanita, other shrubs, and graminoids were not recorded in these treatments during the study.

To test for treatment effects and significant differences among treatments, one-way analysis of variance of treatment means (fixed effect 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 period and year separately.

To quantify plant diversity, all species were noted on study plots when the study began and when it ended.

Results

Plant Diversity

Most early seral vegetation in young plantations in California and Oregon consists of a mixture of shrubs, forbs, and grasses, often from seed and from sprouts. In this study, only two classes of vegetation were prominent—shrubs and grasses. Conifer seedlings and forbs had either a minor presence or an ephemeral one. Revegetation of study plots was by 25 species from 2 regeneration strategies (Grime 1979). These were persistent seed bank (dormant seeds in soil) and wind-blown seeds.

With minor exceptions, the natural plant species in the study area were found in all treatments. The plant community on all plots at the end of the first growing season after treatment in 1988 consisted of 19 species and at the end of the study in 1997 was 16 species. The natural plant community at the beginning of the study consisted of no conifer seedlings, 7 species of shrubs, 10 forbs, and 2 graminoids. By the end of the study, vegetation in the study plots included a few natural seedlings of 2 conifer species (ponderosa pine, California white fir), 7 shrubs, 5 forbs, and 2 graminoids. Those forbs that remained were notably few and small. No alien species were found during the study in spite of musk thistle (*Carduus nutans* L.) being present in the nearby area.

Greenleaf Manzanita

This evergreen, fast-growing shrub was remarkable for its early abundance and its dominance in the study area. Early observers consistently noted “myriads of seed capsules and new plants” and “countless numbers of tiny new seedlings” on study plots. Manual grubbing, which removed scores of manzanita plants each year, seemed to facilitate a new crop of seedlings the following year.

Average density of greenleaf manzanita in the control was highest initially (1988) at 123,500 plants per acre and declined steadily to 44,450 plants per acre ten growing seasons after treatment (1997) (table 1). Foliar cover and height

increased steadily throughout the study period and reached 34,600 ft² per acre and 3.2 feet tall in 1997. During the 10-year study, the average number of manzanita plants in the control decreased by 64 percent, but average foliar cover increased by more than 21 times and height by more than 6 times.

Among the three treatments where vegetation was quantified, more greenleaf manzanita plants (44,450 per acre), significantly more foliar cover (34,600 ft² per acre), and significantly taller plants (3.2 feet) were present in the control than in any other treatment at the end of the study (table 2). Significantly lower mean density, foliar cover, and height values occurred in the T-second-3 treatment than in the T-first-3 treatment.

Table 1—Density, foliar cover, and height, with standard errors (SE), of greenleaf manzanita, other shrubs, and grasses in the control, northern California, 1988-1997

Species	Year	Density	SE	Cover	SE	Height	SE
		-----plants/acre----		-----ft ² /acre-----		-----ft-----	
Greenleaf manzanita	1988	123,500	10,728	1,600	183	0.5	0.1
	1990	101,800	13,041	16,200	2,986	1.4	0.1
	1992	66,450	3,928	21,350	2,815	2.0	0.1
	1997	44,450	4,023	34,600	1,472	3.2	0.1
Other shrubs	1988	1,600	510	50	50	0.3	0.1
	1990	3,000	469	1,400	82	1.1	0.1
	1992	2,550	574	1,450	310	1.5	0.2
	1997	1,950	263	1,500	238	2.4	0.4
Graminoids	1988	1,450	741	100	58	1.5	0.1
	1990	13,300	4,394	900	300	1.6	0.3
	1992	14,700	5,730	200	200	1.5	0.2
	1997	6,850	3,193	T ¹	T	1.1	0.1

¹Trace.

Table 2—Average density, foliar cover, and height of greenleaf manzanita, other shrubs, and graminoids, by treatment, northern California, 1997

Species	Treatment	Density	Cover	Height
		plants/acre	ft ² /acre	ft
Greenleaf manzanita	Treated first 3 years	32,200 a ¹	12,550 b	2.6 b
	Treated second 3 years	1,500 b	1,650 c	1.8 c
	Control	44,450 a	34,600 a	3.2 a
	Standard error	5,374	2,164	0.2
	F ratio	16.95	60.19	22.97
	P value	0.0009	0.0001	0.0003
Other shrubs	Treated first 3 years	1,200 a	900 a	2.0 a
	Treated second 3 years	1,200 a	650 a	0.8 b
	Control	1,950 a	1,500 a	2.4 a
	Standard error	295	251	0.3
	F ratio	2.14	3.03	9.32
	P value	0.1730	0.0988	0.0064
Graminoids	Treated first 3 years	21,350 a	400 ab	1.2 a
	Treated second 3 years	12,100 ab	900 a	1.5 a
	Control	6,850 b	T ² b	1.1 a
	Standard error	3,072	219	0.1
	F ratio	5.71	4.26	2.88
	P value	0.0250	0.0500	0.1079

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

²Trace.

Other Shrubs

Of the six shrub species, other than greenleaf manzanita, that were present from the beginning to the end of the study, bitterbrush was by far the most common and the most evenly distributed. Rabbitbrush and squaw carpet were the next most abundant. However, even when combined, the other shrubs were few and their foliar cover and height were low relative to greenleaf manzanita.

Average density of other shrubs in the control was 1,600 plants per acre in 1988, peaked at more than 3,000 plants per acre in 1990, and declined steadily to 1,950 plants per acre in 1997 (table 1). Foliar cover and height increased steadily from 50 to 1,500 ft² per acre and from 0.3 to 2.4 feet tall, respectively, at the end of the study. For the 10 years of the study, the average number of other shrubs in the control increased by 22 percent, average foliar cover increased by 30 times, and height increased by 8 times.

Among treatments, the plots that had the longest recovery time since disturbance (the control) had the highest average density (1,950 plants per acre), highest foliar cover (1,500 ft² per acre), and highest average height (2.4 feet) (table 2). However, average height of the other shrubs in the control differed significantly only from that in the T-second-3 treatment. If time since disturbance was 7 years, as in the T-first-3 treatment, or 4 years, as in the T-second-3 treatment, mean density and foliar cover did not significantly differ between them, but height did. Other shrubs were significantly taller in the T-first-3 plots (2.0 feet) than counterparts in the T-second-3 plots (0.8 foot).

Graminoids

As early as October 1987, a few plants of needlegrass (*Achnatherum nelsonii* [Scribner] Barkwort) (formerly *Stipa*; Hickman 1993) and cheatgrass (*Bromus tectorum* L.) were recorded as invading the study plots. They were noted as increasing in June 1988 and invading newly-grubbed plots in 1990. By fall 1990, the established needlegrass clumps were described as "difficult to grub out." Some cutting of grass by rodents was noted in fall 1987 and 1990.

Graminoids in the control numbered 1,450 per acre in 1988 with only minor amounts of foliar cover (table 1). However, by 1990, density had increased to more than 13,000 plants per acre with 900 ft² of foliar cover per acre and an average height of 1.6 feet. By 1992, density had peaked at 14,700 plants per acre before declining to 6,850 plants per acre at the end of the study in 1997. Average foliar cover and height also declined and by the end of the study were only a trace and 1.1 feet, respectively.

Among treatments in fall 1997, the treatment with the longest time since disturbance (control) had significantly lower density (6,850 plants per acre) than counterparts in the T-first-3 treatment (21,350 plants per acre) that had 7 years since last disturbance, and it had significantly less foliar cover than plants in the T-second-3 treatment (900 ft² per acre) that had 4 years since disturbance (table 2). Average height did not differ statistically among treatments.

Forbs

Although too few and poorly distributed to analyze statistically, the forbs in the study area contributed in a small way to the plant community. The most abundant species were from the genera *Lilium* and *Phacelia*. The forbs never formed patches of single species, as is common in newly disturbed areas. Rather, they tended to occur as single plants or in aggregations of 5 to 10. By the end of the study, forbs were found on only 12 of the 100 milacre subplots, numbered 460 per acre, and had only a trace of foliar cover and an average height of 0.8 foot. Most were present beneath crowns of the largest trees or in small openings among the manzanita plants.

Ponderosa Pine

Life for ponderosa pine seedlings in this plantation is best described as a struggle. Damage has been almost continuous and from several sources. As early as January 1988, about 15 percent of the pine seedlings in the study area were noted as damaged by winterburn. Winterburn occurs when the ground is frozen, no water intake by the plant is possible, and the wind pulls most of the moisture from the needles. Of the damaged seedlings, a few had 50 percent of foliage browned, but most had about 30 percent. Severe damage from winterburn also was noted in 1993 and 1994. In August 1993, pines in the control were recorded as dying from suppression. By August 1994, many trees in the control were either dead or had dead tops. Winterburn and suppression were the likely causes. Insect damage was first noted in the summer of 1995 when the tips of pine branches were browned "on everything sticking out of the brush." The survey of 1996 recorded increased mortality and at least some insect damage on 80 percent of pines in the study area. By fall 1997, the combination of winterburn, suppression, and insects had killed, damaged, or reduced the growth of almost all pines in the control. Unfortunately, almost all pines in one plot in the T-first-3 treatment were decimated by insects. Dead and deformed tops, brown needles, narrow crowns, and a general lack of vigor characterized the pines in this plot.

Mortality of pine seedlings began in 1993 and continued through 1997. Insect attack on the already suppressed and winterburned seedlings apparently was too much, and the seedlings perished from the combination of causes (fig. 4). At the end of the study, percent survival by treatment was:

Treatment	Average	Standard error
T-first-6	95	2
F-first-6	85	6
T-first-3	95	2
T-second-3	97	3
Control	57	14

An analysis of variance of transformed (arcsin) values indicated that survival was significantly higher in all treatments than in the control.

Among treatments, 24 to 67 percent of surviving seedlings were deformed. Values did not differ among treatments at the 5 percent level. "Deformed" was defined as death of the terminal shoot and replacement by one or more shoots—an event that caused a crooked stem. Percent deformed with standard errors by treatment was:

Treatment	Average	Standard error
T-first-6	29	10
F-first-6	41	8
T-first-3	49	20
T-second-3	24	10
Control	67	6

Average stem diameter, measured at 12 inches above mean groundline, first differed significantly in 1990 when pines in the T-first-6, F-first-6, and T-first-3 treatments differed significantly from pines in the control (table 3). By the end of the study in 1997, average diameter of pines in the T-first-6 and T-first-3 treatments continued to differ significantly from those in the control, but the diameter of seedlings in the F-first-6 treatment no longer differed significantly from those in the other treatments. The diameter of pines in the T-second-3 treatment also differed significantly from counterparts in the control. In 1997, pine diameter ranged from 3.7 inches in the T-first-6 treatment to 1.4 inches in the control.

Mean stem height also first differed significantly among treatments in 1990 and among the same treatments as stem diameter. By the end of 1997, however, the only significant differences in stem height were between pines in the T-first-6 and T-first-3 treatments (8.7 and 8.3 feet, respectively) and the control (3.6 feet) (table 3).

Foliar cover relationships, which suffered from missing data early in the study, became meaningful in 1992 when average values in the T-first-3 treatment (11,100 ft² per acre) differed significantly from those in the control (2,500 ft² per acre) (table 3). In 1997, however, foliar cover in the T-first-6 (27,700 ft² per acre) and T-second-3 (22,050 ft² per acre) treatments differed significantly from counterparts in the control (3,400 ft² per acre). The heavy insect damage in one plot of the T-first-3 treatment decreased foliar cover and caused a lower treatment mean.

Table 3—Average stem diameter and height, foliar cover, and needle length of ponderosa pine seedlings, by treatment, northern California, 1988-1997

Treatment	1988	1990	1992	1997
Diameter (inches)				
Treated first 6 years	0.39 a ¹	1.15 a	2.05 a	3.70 a
Fertilize, treat first 6 years	0.42 a	1.08 a	-	3.02 ab
Treated first 3 years	0.44 a	1.20 a	2.07 ab	3.36 a
Treated second 3 years	0.33 a	0.70 b	1.49 bc	3.21 a
Control	0.35 a	0.68 b	1.02 c	1.40 b
Standard error	0.03	0.06	0.14	0.37
F ratio	1.91	15.61	13.56	5.51
P value	0.1684	0.0001	0.0004	0.0062
-----Height (feet)-----				
Treated first 6 years	0.79 a	3.00 a	5.11 a	8.68 a
Fertilize, treat first 6 years	0.72 a	2.98 a	-	6.83 ab
Treated first 3 years	0.85 a	3.11 a	5.22 a	8.34 a
Treated second 3 years	0.79 a	2.28 b	3.73 ab	7.44 ab
Control	0.79 a	2.18 b	2.83 b	3.58 b
Standard error	0.05	0.14	0.36	1.06
F ratio	1.15	9.39	10.18	3.70
P value	0.3719	0.0005	0.0013	0.0274
-----Foliar cover (ft ² per acre)-----				
Treated first 6 years	-	-	-	27,700 a
Fertilize, treat first 6 years	-	-	-	16,800 ab
Treated first 3 years	-	-	11,100 a	20,100 ab
Treated second 3 years	200 a	2,950 a	6,750 ab	22,050 a
Control	250 a	2,400 a	2,500 b	3,400 b
Standard error	67.7	211	1,481	3,667
F ratio	0.27	3.39	8.43	55.08
P value	0.6202	0.1151	0.0087	0.0096
-----Needle length (inches)-----				
Treated first 6 years	6.07 a	7.53 a	7.04 a	-
Fertilize, treat first 6 years	6.11 a	7.28 a	-	-
Treated first 3 years	6.05 a	7.55 a	6.54 a	-
Treated second 3 years	5.94 a	5.74 b	6.75 a	-
Control	5.62 a	5.39 b	4.56 b	-
Standard error	0.16	0.18	0.22	-
F ratio	1.54	33.14	25.34	-
P value	0.2418	0.0001	0.0001	-

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

Figure 4—Mortality of ponderosa pine seedlings on a poor site: (A) pine height growth becomes less and less relative to that of the manzanita; (B) insects kill the top and upper branches of weakened seedlings; and (C) even though well above the manzanita, the seedling is dead by age 10.

A



B





C

Needle length, which was used as an indicator of future treatment effectiveness, first differed statistically among treatments in 1990 (*table 3*). Average needle length of pines in the T-first-6, F-first-6, and T-first-3 treatments were significantly longer than those in the control. By fall 1992 (the last year that data were taken), needles were significantly longer in the T-first-6, T-first-3, and T-second-3 treatments than in the control. Needle length ranged from 4.6 to 7.0 inches among treatments.

Production and Cost

The amount of time to manually grub a 5-foot radius around each pine seedling was relatively small when the competing vegetation was young and not yet established. Because grubbing in the T-first-6 and T-first-3 treatments was performed annually, each subsequent grub took about the same amount of time. With time, however, more and more plants, particularly shrubs on subplot edges, expanded their root crowns into the treated space or had stems that leaned into it, which required additional labor to remove. Consequently, grubbing the last year in the T-first-6 treatments and the T-second-3 treatment was more time consuming. Total time to grub the treatments was:

Treatment	Time (hours)
T-first-6	52.2
T-first-3	24.9
T-second-3	63.8

Grubbing the vegetation in the T-second-3 treatment was very difficult. Four-year-old manzanita plants often had roots that exceeded 5 feet in length. Grass plants did not have long horizontal roots, but large masses of spreading roots. Both had to be loosened around their perimeter first and then grubbed out. If placed on a per-acre basis, the T-first-6 and F-first-6 treatments each cost about \$130 per acre, the T-first-3 treatment about \$62, and the T-second-3 treatment more than \$159 per acre to manually grub.

Discussion and Conclusions

Before this study began, the area was a brushfield composed primarily of greenleaf manzanita and a few other species of shrubs. Ten years after site preparation, the plant community in the control is approaching pre-study conditions. It consists of short, discolored, and deformed ponderosa pine seedlings whose crowns are just above a near-solid mass of shrubs. With a combined density of more than 46,000 plants per acre, foliar cover of 36,100 ft² per acre and a height of 3 feet, the shrubs will again dominate in the near future. Although perennial needlegrass is present, its future among and under the shrubs is precarious.

In plots with a longest treatment duration (6 years), the pines generally were taller and wider than pines in the other treatments. The crowns of pines in the T-first-6 treatment were closing or had closed at the end of the study, and the competing vegetation was leaning away from them toward the sunlight. The needlegrass component of the community in this treatment is likely to decline and be relegated to only a trace in the near future (McDonald and Abbott 1997).

Timing of competition is important. A large number of competing plants early in the study constitutes more competition to the pine seedlings than does a large number of plants after the pines have become established. The T-first-6 treatment and the control are an example. In the T-first-6 treatment, each crop of shrubs was eliminated before it could become established and competitive; in the control, the shrubs became established, developed well, and significantly reduced pine growth. At the end of the study, the pines in the T-first-6 treatment were negatively impacting the shrubs that were present (*fig. 5*); in the control the shrubs were negatively impacting the pines.

Figure 5—Ten years after treatment, this ponderosa pine in the T-first-6 treatment is still benefiting from shrub removal as shown by the vegetation-free area beneath the tree crown.



McDonald and others (1992) showed that ponderosa pine needle length is a good indicator of pine growth, and thus was a useful gauge of treatment effectiveness in the future. More specifically, 1-year-old needles, measured 2 to 4 years after treatment, were strongly related to treatment response for at least 7 years after treatment. Seven years was the longest timespan evaluated. In this study, needles measured 2 and 5 years after the treatment began accurately portrayed pine growth-treatment relationships. In 1992, the longest needles were on pines in released treatments, and the shortest were in the unreleased control.

In the T-first-3 and T-second-3 plots, which had a short treatment duration (3 years), but varying times since disturbance (7 and 4 years), the treatment area at the end of the study consisted of pines in the center of little circles inhabited by shrubs and graminoids in a sea of taller shrubs. The 5-foot treatment radius was no longer 5 feet because of the growth of adjacent vegetation. In a few instances, the treated circles were becoming difficult to see—a process that will accelerate in the near future. Nevertheless, the pines are likely to dominate here, albeit with a lower growth rate than that of counterparts with less competition.

By the end of the 1990 growing season, pine diameter, height and needle length in the T-first-3 treatment were significantly larger than counterparts in the control, and continued throughout the study. Foliar cover of pines, which significantly differed from those in the control in 1992 did not differ from them in 1997. Apparently, the large number of manzanita and grass plants that invaded after the last grubbing was beginning to have an effect.

The growth of pines in the T-second-3 treatment was better than expected. A possible reason involves the competitive interaction between shrubs and perennial grass. Results from a long-term study nearby (McDonald and Abbott 1997) showed that perennial needlegrass had lower density and development if growing with shrubs. However, the number of new shrubs from dormant seeds in the soil was much less if grass was present. Close examination of *table 2* indicates low values of greenleaf manzanita density, foliar cover, and height in the T-second-3 treatment and relatively high values for grass density and height. Perhaps the graminoids negatively affected the shrubs and the shrubs negatively affected the graminoids, both to the benefit of the pines. A more compelling reason is that when the need for release is strong, as it is on poor sites, any release is helpful (Fiddler and McDonald 1999). Timing of release, duration of release and vegetation recovery times are secondary.

A major reason for analyzing and presenting the results of this study in terms of time since disturbance and duration of treatments was to reinforce the hypothesis, based on findings in earlier studies (McDonald and Fiddler 1990, 1995), that early release is more cost-effective than repeated release or delayed release. Delaying release almost always means larger plants and often large, deep masses of roots. The T-first-3 and T-second-3 treatments were a direct test of early versus delayed release. Biologically the two treatments did not differ statistically from each other. But economically they did. Manual grubbing in the T-first-3 treatment cost less than half of that in the T-second-3 treatment.

The role of the slow-release fertilizer that was applied in June 1987 is not clear. Diary records indicated that no effect was visible the following year, but by fall 1990, “needles were noticeably greener on fertilized trees.” By June 1996, needles on fertilized seedlings were described as more numerous, longer, and with better color than those in other treatments—a finding that was repeated in the 1997 measurements. Thus, the needle characteristics suggested good growth, but average diameter, foliar cover, and height, although about twice that of the control, did not differ significantly from it.

The different treatments, which spanned plant recovery times of 4 to 10 years, created similar plant communities, but with different amounts of the same species that further differed in terms of development. Although the community has not changed greatly, one major component—ponderosa pine—now is part of

the community. These seedlings, other than in the control, are plentiful, established, and have potential to outgrow the competing vegetation. Restoring the arboreal component, which historically has been part of the community, should create a forest stand, and a more desirable and sustainable vegetative assemblage.

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