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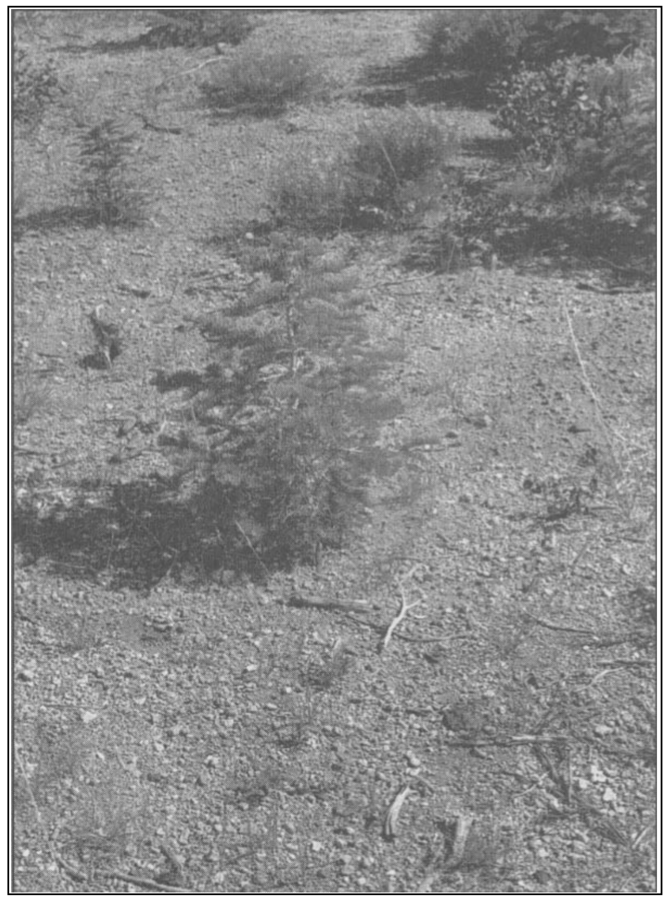
Research Paper
PSW-RP-233

Treatment Duration and Time since Disturbance Affect Vegetation Development in a Young California Red Fir Plantation

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



Publisher:

Albany, California
Mailing address:
PO Box 245, Berkeley CA
94701-0245

510 559-6300

http://www.psw.fs.fed.us

June 1997

Pacific Southwest Research Station

Forest Service
US Department of Agriculture

Abstract

McDonald, Philip M.; Fiddler, Gary O. 1997. **Treatment duration and time since disturbance affect vegetation development in a young California red fir plantation.** Res. Paper PSW-RP-233. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 14 p.

The density and development of greenleaf manzanita, snowbrush, goldenbush (rabbitbrush), and graminoids were evaluated in a young California red fir plantation in northern California from 1986 through 1995. Manual grubbing and herbicides 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 and spraying operations constituted the treatments. Species response was mixed: greenleaf manzanita had higher average values of density, foliar cover, and height when time since disturbance was longest, snowbrush density was lowest but cover and height were highest, and values for goldenbush and graminoids in general showed no trend. In the control at the end of the study, graminoids numbered 82,350 per acre, greenleaf manzanita 10,850, goldenbush 10,800, and snowbrush 1,850 plants per acre. Foliar cover of manzanita at 7,300 ft^2 per acre was more than that of all other naturally established species combined. Survival of red fir over all treatments after one growing season was 98 percent and after 10 seasons was 89 percent. Average height of red fir seedlings ranged from 3.2 feet with intensive release to 1.7 feet with no release. No release allowed greenleaf manzanita plants to be slightly taller than red fir seedlings and to place the seedlings in danger of being overtopped.

Retrieval Terms: competing vegetation, northern California, plant succession, red fir seedlings, timing of release

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In Brief

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This paper presents the density and development of several shrub and herbaceous species that invaded a young conifer plantation in interior northern California on a medium site at mid-elevation (5,600 feet). It also quantifies the survival and growth of planted California red fir seedlings relative to these invading species. A major influence on all the vegetation was the environment of the site, which was characterized by short, hot, dry summers and long, cold, snowy winters.

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 herbicide that we applied served only to accomplish the treatments. The different timings and durations were the treatments.

The treatments were:

Treat first 6 years (1986-1991), develop naturally last 4 years, designated as **T-first-6**;

Treat first 3 years (1986-1988), develop naturally last 7 years, designated as **T-first-3**;

Delay 3 years, treat next 3 years (1989-1991), develop naturally last 4 years, designated as **T-second-3**;

Control, not treated after site preparation, develop naturally entire 10 years of the study (1986-1995), designated as **Control**.

Research results and operational implications for forest land managers follow.

The plant community at the end of the study numbered 17 species plus an alien (yellow star thistle), which may or may not become established. Relative to the literature, this is a low number of species for red fir plantations in northern and central California.

Although the number of species was low, the number of plants that returned 4 to 10 years after grubbing and spraying was large. More than 100,000 plants per acre, 77 to 89 percent of which were grasses and sedges (graminoids), were present in each treatment at the end of the study.

Although the number of plants per acre at the end of the study was large, the amount of horizontal development as manifest in foliar cover was small—amounting to 13 to 33 percent among treatments.

The various shrub and herbaceous species indicated different density and developmental trends relative to treatment. For greenleaf manzanita at the end of the study, the two treatments with the longest recovery times resulted in the highest number of plants per acre; for snowbrush, the fewest; and for goldenbush and graminoids, a mixture. A longer recovery time also resulted in higher foliar cover for manzanita, snowbrush, and goldenbush, and taller plants of manzanita and snowbrush. Greenleaf manzanita excelled in the control, but the graminoids faltered, probably because of too much competition.

The growth strategy of California red fir was to grow tall with a thin stem and crown, and then to begin to channel resources to diameter growth. At the end of the study, average height of red fir ranged from 3.2 feet in the T-first-6 treatment to 1.7 feet in the Control. This was a statistically significant difference. Mean diameter of red fir did not differ statistically among treatments during the study.

The T-first-3 and T-second-3 treatments were designed specifically to test the significance of immediate versus delayed release of California red fir. However, significance was not determined, probably because 10 years is not enough time for growth relationships to develop. This is important. Studies that aim to determine red fir seedling diameter and height relationships relative to different timings and durations of treatment need to be longer than 10 years. Ten years may be adequate for ponderosa pine and Douglas-fir, but not enough for California red fir.

The forest land manager now has some idea of the species that could develop in a young red fir plantation and their density, development, and competitive potential relative to various timings and durations of manipulation. Survival and growth of planted California red fir seedlings also are indicated, as are beginning trends in statistical differentiation among treatments. Ecologically, the data presented in this study can contribute toward modelling early succession in this plant community.

Introduction

Competition from woody shrubs, forbs, and grasses in new plantations often is rapid and formidable. On the basis of information from 32 logged areas in northern and central California, Gordon and Bowen (1978) found that time since disturbance (site preparation) influenced the composition and development of the plant community. On the three cutting areas that had only one complete growing season, an average of 50 percent of the sample locations suitable for plants were already occupied. All other areas with longer histories (up to 12 years after disturbance) had 69 percent or more of the suitable locations occupied. Because early growth of red fir seedlings typically is slow and that of shrubs is often rapid, red fir seedlings often become suppressed. When this happens, the seedlings do not die, but become overtopped. They then slowly grow through the shrubs—a process that can take 30-50 years. "Neither this delay nor the frequently haphazard stocking are acceptable" (Laacke and Fiske 1983).

Plainly, competition must be controlled, and one method for doing so is release. But knowledge on when to release young California red fir (*Abies magnifica* A. Murr.) plantations to achieve dependable seedling survival and growth is lacking. Furthermore, the timing of release could be dependent on the species and number of plants that are present in young red fir plantations, how fast they develop, and their effect on red fir seedling survival and growth.

Timing of release is manifest in several comparisons such as immediate versus delayed release or releasing for one time span versus another. At some point, delayed release might be no more effective than never releasing, or releasing each year for several years might be no more effective than releasing for 1 or 2 years depending on when the release took place.

Shrinking budgets and a lack of resources have often caused release activities in young conifer plantations to be postponed until the third growing season. At such times the cry often is heard: "Where did all that grass and all those shrubs come from?" and "What will they do to the growth of my conifer seedlings?" Research in northern and central California on ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) has shown that release from competing vegetation the first year is critical, and that release during the first 3 years is worthwhile (Fiddler and McDonald 1987, McDonald and Fiddler 1989). However, release after 4 years generally is not cost-effective. The competing vegetation, which has become large and well established, is not only expensive to control, but it also has limited site resources to the conifer seedlings and slowed growth—a process from which it will take time for them to recover. Is release during the first 3 years also important for California red fir?

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 brush field in northern California. Planted California red fir 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 1986 to 1995 on vegetation developing after site preparation in a control and on vegetation manipulated deliberately by grubbing and applying a herbicide to create different time spans. The time spans, or more specifically "vegetation recovery times after disturbance by site preparation and release," are the treatments.

This paper reports the results of these treatments in terms of the recovery of the plant community 4, 7, and 10 years after manipulation. It also quantifies the survival and growth of California red fir seedlings after immediate and delayed release.

Methods

Location and Site Characteristics

The study area, located on land owned by Sierra Pacific Industries in the southern Cascade mountains, is about 25 airline miles northeast of McCloud, California. Vegetation in the area has been placed in the montane and subalpine region of the Sierra Nevada and Cascade Ranges by Rundel and others (1977) and in the white fir forest vegetation type (Gordon 1980). Before the study began, the area was a brush field, and probably had been for at least 50 years. It had not always been a brush field, however, as an occasional blackened stump and log in the study area indicated that it had once supported trees. The forest stand then probably was much like that in the nearby forest today. Here, California white fir (*Abies concolor* var. *lowiana* [Gord.] Lemm.) is the dominant species with California red fir second. Sierra lodgepole pine (*Pinus contorta* var. *murrayana* [Grev. & Balf.] Engelm.) and incense-cedar (*Libocedrus decurrens* Torr.) are occasional species along with willow (*Salix* spp.).

The mature brush field consisted of 4- to 5-foot tall plants of snowbrush (*Ceanothus velutinus* Dougl. ex Hook.), bitter cherry (*Prunus emarginata* [Hook.] Walp.), and greenleaf manzanita (*Arctostaphylos patula* Greene). Goldenbush (*Ericameria bloomeri* [A. Gray] J.F. Macbr.) [= *Haplopappus bloomeri* A. Gray] (Hickman 1993) was scattered throughout, and most abundant in small openings among these species.

Site quality of the study area is medium-poor with height of dominant California white firs averaging about 60 feet in 50 years (Biging and Wensel 1984). The soil, which is closely related to the Avis series, is an ashy-skeletal, frigid Dystric Xerorthent. It was formed from volcanic ash, usually deposited over and in fractured lava flow rock. It has a stony sandy loam texture and is about 5 feet deep. Stones, gravel, and sand are abundant throughout. The elevation is about 5,600 feet, the slope is 1 percent, and the aspect is east. The area is remarkably uniform with respect to slope, aspect, and soil. Precipitation averages about 55 inches per year, with about 80 percent falling as snow. Temperatures range from 20° F to 80° F with the average annual temperature being 43° F. The growing season is about 100 days.

A portion of the brush field was pushed into windrows with a bulldozer in spring 1985 and burned in the fall. Very little soil was displaced, and the windrows could scarcely be seen a few years later.

Container-grown California red fir seedlings were raised in the Ben Lomand Nursery and out planted as plugs in spring 1986. Spacing was 8 by 8 feet. Survival of seedlings in all study plots at the end of the first growing season was 98 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 red fir seedlings, the early plant community consisted of the same species of shrubs noted earlier, plus a few grasses and forbs. Several animals were present in the study area and had the potential to influence the plant community. Deer (*Hemionus* spp.) were prevalent in the study area. Ground squirrels (*spermophilus* spp.) also were numerous, and rabbits (*Lepus* spp.) were occasionally seen. Fortunately, no pocket gophers (Thomomys spp.) were present.

Study and Design

The experimental design was completely randomized with one-way treatment structure. Four treatments, including the control, were each replicated four times. A replicate (plot) consisted of about 0.1 acre on which were at least 40 California red fir seedlings surrounded by one to two rows of buffer (seedlings receiving similar treatment). The study began in 1986 and ended in 1995. Treatments and treatment dates were:

Treatments

Treat first 6 years (1986-1991), develop naturally last 4 years, designated as **T-first-6**;

Treat first 3 years (1986-1988), develop naturally last 7 years, designated as **T-first-3**;

Delay 3 years, treat next 3 years (1989-1991), develop naturally last 4 years, designated as **T-second-3**;

Control, not treated after site preparation, develop naturally entire 10 years of the study (1986-1995), designated as **Control**.

Plots in the T-first-6 treatment were treated by applying an herbicide to the entire plot plus the buffer. Plots in the T-first-3 and T-second-3 treatments were grubbed to a 5-foot radius. Vegetation was grubbed below the root crown with hand tools. The herbicide (Roundup)[1] (2 and 5 percent solutions) was applied directly with a backpack apparatus according to recommendations on the label. Lingering effects of the herbicide, if any, have not been documented. Spraying took place between 7 a.m. and 9 a.m. PST on clear days with little or no wind. A guide was used to ensure uniform coverage of the herbicide and to avoid overlapping and skipped areas. Crowns of entire plants were sprayed until wet. Plastic bags were used to cover red fir seedlings.

Grubbing and spraying were performed during the summer at a time when growth of the red fir seedlings had ceased, but that of the shrubs was continuing.

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

Sampling

Of the 40 California red fir 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 (measured at 12 inches above mean groundline) and height were measured on each. The seedlings were periodically checked for injury from chemicals, animals, and insects.

Sampling intensity for evaluating other vegetation was five randomly selected subplots in each plot. Subplots were centered around red fir seedlings and encompassed 1 milacre (0.001 acre). The most abundant species were evaluated 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). More specifically, number of plants in each subplot were counted, foliar cover was visually estimated, and height was measured with a graduated pole.

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. Rarely is this vegetation dominated by a single class of plants (McDonald and Radosevich 1992) and rarely is it just from seed. Thus it is of interest to ecologists to have knowledge of a plant community dominated by woody and herbaceous species—all from seed—but from two regeneration strategies (Grime 1979). These were regeneration from windblown seeds and from a persistent seed bank (dormant seeds in soil).

With minor exceptions, the plant species in the study area were found in all treatments. The plant community on all plots near the beginning of the study consisted of planted California red fir, 5 species of shrubs, 3 forbs, and 1 graminoid. By the end of the study, vegetation in the study plots included a few natural seedlings of 2 conifer species (not red fir), 5 shrubs, 6 forbs, and 4 graminoids for a total of 17 species. Two species of shrubs: bush chinquapin (*Chrysolepis sempervirens* [Kellogg] Hjelmq.) and bitter cherry, noted initially, could not be found at the end of the study. Bush chinquapin is not common in the area, but bitter cherry, which initially was present in all treatments, was. Its density in terms of seedlings per acre by year averaged over all treatments was:

1986	*1987*	*1988*	*1989*	*1990*	*1991*	*1995*
487	325	175	38	12	0	0

Most bitter cherry seedlings originated in 1986 and 1987. One new seedling was found in 1989. Seedlings were heavily browsed in 1987 and 1988, but browsing alone was not responsible for the complete demise of the species in the plantation. Competition-induced drought is more probable. One forb, known locally as woolly nama (*Nama* spp.), was present on two subplots in one treatment from 1988 through 1991, but disappeared thereafter. Ominously, 23 plants averaging 2.5 feet tall of the alien yellow star thistle (*Centaurea solstitialis* L.) were sampled on one subplot near the access road in 1995. Given the harsh winters, this species may have difficulty becoming established in the plantation.

Greenleaf Manzanita

Greenleaf manzanita, an evergreen, fast-growing shrub, was the most abundant species in the control in 1986 (3,400 plants per acre) and remained abundant throughout the study. In 1987 and 1988, we noted that "many greenleaf manzanita seedlings are becoming established in the study area, especially on the recently treated plots." Manzanita also was noted as being browsed in 1988, 1989, and 1990.

Average density of greenleaf manzanita in the control was highest in 1989 at 11,250 plants per acre and declined to 10,850 plants per acre in 1995 (*table 1*). Foliar cover and height increased throughout the study period and reached 7,300 ft^2 per acre and 1.8 feet tall in 1995. At the end of the study, manzanita cover was greater than for all other species combined. During the 10-year study (1986-1995), the average number of manzanita plants in the control increased 219 percent, cover increased by 7300 percent and height by 1700 percent.

Among treatments, manzanita density in 1995 portrays the recovery capability of the species at various times after grubbing and spraying. When the time since last disturbance was 4 years, as in the T-first-6 and T-second-3 treatments, density ranged from 3,950 to 5,450 plants per acre (*table 2*). When disturbance ended 7 years earlier as in the T-first-3 treatment, manzanita plants numbered more than 9,000 plants per acre. And when it ended 10 years earlier, as in the control, more than 10,800 plants per acre were present. Average foliar cover and height followed a similar trend. More than 5 times more foliar cover was present in plots grubbed and sprayed 7 years earlier than in those where disturbance had ended 4 years earlier; 67 to 100 percent more for the longer time span for manzanita height. Foliar cover and height of manzanita were significantly greater in the control than in any other treatment.

Snowbrush

Snowbrush, which is commonplace in California and Oregon, also is evergreen and considered to grow even faster than greenleaf manzanita. However, this

Table 1—Density, cover, and height, with standard errors (SE), of greenleaf manzanita, snowbrush, goldenbush, and graminoids in the control, northern California, 1986-1995

Year		Density	SE	Cover	SE	Height	SE
		------ *plants/acre* -----		-------ft^2/*acre* -----		------------ *ft* ----------	
Greenleaf manzanita	1986	3,400	1,476	0	0	0.1	0.0
	1989	11,250	4,181	900	265	0.5	0.1
	1991	10,300	3,047	2,400	622	0.8	0.1
	1995	10,850	3,953	7,300	998	1.8	0.1
	Difference (pct increase)	+219		+ huge		+1700	
Snowbrush	1986	750	206	50	50	0.1	0.1
	1989	4,050	618	500	100	0.4	0.1
	1991	3,600	716	1,050	189	0.7	0.1
	1995	1,850	359	1,800	408	1.5	0.1
	Difference (pct increase)	+147		+3500		+1400	
Goldenbush	1986	600	600	50	50	0.6	0.1
	1989	11,700	11,368	800	735	0.4	0.2
	1991	9,650	8,212	1,700	1,567	0.6	0.2
	1995	10,800	5,605	2,150	1,636	0.8	0.2
	Difference (pct increase)	+1700		+4200		+33	
Graminoids	1986	600	346	100	58	0.5	0.3
	1989	48,100	15,148	2,550	741	1.6	0.2
	1991	48,400	12,326	2,600	1,149	1.3	0.2
	1995	82,350	17,249	2,850	888	1.5	0.2
	Difference (pct increase)	+ huge		+2750		+200	

Table 2—Density, cover, and height of greenleaf manzanita, snowbrush, goldenbush, and graminoids after ten growing seasons by treatment, northern California

Treatment		Density	Cover	Height
		plants/acre	ft^2/*acre*	*ft*
Greenleaf manzanita	Treated first 6 years	3,950 a[1]	300 a	0.6 a
	Treated first 3 years	9,100 a	1,550 a	1.0 b
	Treated second 3 years	5,450 a	300 a	0.5 ac
	Control	10,850 a	7,300 b	1.8 d
	Standard error	3,632	632	0.1
Snowbrush	Treated first 6 years	4,400 a	100 a	0.4 a
	Treated first 3 years	3,550 a	800 ab	0.9 b
	Treated second 3 years	4,500 a	200 a	0.5 ab
	Control	1,850 a	1,800 b	1.5 b
	Standard error	1,224	307	0.2
Goldenbush	Treated first 6 years	10,500 a	1,100 a	0.9 a
	Treated first 3 years	14,550 a	1,800 a	1.0 a
	Treated second 3 years	15,350 a	1,600 a	0.9 a
	Control	10,800 a	2,150 a	0.8 a
	Standard error	4,268	893	0.1
Graminoids	Treated first 6 years	93,550 a	4,050 a	1.9 a
	Treated first 3 years	116,250 a	5,450 a	1.8 a
	Treated second 3 years	85,100 a	4,650 a	2.3 a
	Control	82,350 a	2,850 a	1.5 a
	Standard error	18,193	923	0.2

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

rating probably is based on sprout growth. In 1985, Conard and others noted that little was known about *seedling* development (as opposed to sprout development) in various environments. Published data on snowbrush seedling growth in plantations were scarce in 1996 as well. In our study, visual records indicated that many new snowbrush seedlings were becoming established in recently disturbed plots in 1987 and 1988. Snowbrush was lightly browsed in 1988 and 1990 and heavily browsed in 1989.

Average density of snowbrush in the control was 750 plants per acre in 1986, peaked at more than 4,000 plants per acre in 1989, and declined steadily to 1,850 plants per acre in 1995 (*table 1*). Snowbrush foliar cover and height increased steadily and reached 1,800 ft^2 per acre and 1.5 feet tall, respectively, at the end of the study. For the 10 years of the study, the average number of snowbrush plants in the control increased 147 percent, foliar cover increased 3500 percent, and height 1400 percent.

Among treatments, plots that had been disturbed last had the most plants, indicating recruitment of new seedlings after 6 years. In 1995, for example, the most snowbrush seedlings were in T-first-6 and T-second-3 plots (*table 2*). Here the seedlings, although numerous, had the least cover (100-200 ft^2 per acre) and were shortest (0.4 to 0.5 feet tall). Plants in T-first-3 plots had at least 4 times more cover (800 ft^2 per acre) and roughly twice as much height (0.9 feet) as counterparts in plots that had been disturbed last. No disturbance after site preparation as in the control resulted in fewer plants but at least twice as much foliar cover (1,800 ft^2 per acre) and almost twice as much height (1.5 feet) as in any other treatment.

Goldenbush

Once called "rabbitbrush" and now Bloomer goldenbush or rabbitbrush goldenweed, goldenbush, like other species in the genera *Chrysothamnus*, *Haplopappus*, and *Ericameria*, is noted for its abundance and ability to grow well on poor sites (Sampson and Jespersen 1963). It is rated as a severe competitor to conifer seedlings in young plantations (Click and others 1989). Deep roots and heavy litterfall make it useful for erosion control (Deitschman and others 1974). It also has value as food for deer in late fall and early winter, but rates only fair-poor in palatability (Sampson and Jespersen 1963).

Seed production of goldenbush is reported to begin at age 2 with dispersal by wind as soon as seeds mature (Deitschman and others 1974). Good seed crops are produced almost every year; dispersion is wide; and once established, growth is rapid. Mozingo (1987) noted that rabbitbrush (goldenbush) is one of the first shrubs to invade a disturbed area. In our study, goldenbush seedlings were noted as being the first to reinvade the newly grubbed plots in the T-second-3 treatment. No browsing was noticed during the study.

In the control, average goldenbush density was relatively low in 1986 (600 plants per acre), peaked in 1989 (11,700 plants per acre), and then decreased slightly by 1995 (10,800 plants per acre) (*table 1*). Average foliar cover increased steadily from 50 to 2,150 ft^2 per acre and height erratically from 0.6 to 0.8 feet during the study.

Among treatments in 1995, time since disturbance did not appear to be a factor affecting density, foliar cover, or height. Density ranged from 10,500 to 15,350 plants per acre, foliar cover from 1,100 to 2,150 ft^2 per acre, and height from 0.8 to 1.0 feet (*table 2*). No differences among treatment means were statistically significant.

Graminoids

Almost all plants in this category were from the genera *Sitanion*, *Achnatherum* (formerly *Stipa*; Hickman 1993), and *Carex*. As early as fall 1986, a few grass plants were noted as invading recently sprayed plots. New grass seedlings also were mentioned as being present on most plots in 1988 and "flooding" into them in 1989. Some browsing was noted on grass in fall 1990.

Graminoids in the control numbered 600 per acre in 1986 with only minor amounts of foliar cover and height (*table 1*). However, by 1989, density had increased to more than 48,000 plants per acre with more than 2,500 ft^2 of foliar cover per acre and an average height of 1.6 feet. These values remained relatively similar through 1995 with the exception of graminoid density, which increased greatly to more than 82,000 plants per acre.

Among treatments in fall 1995, average density ranged from 82,350 to 116,250 plants per acre, foliar cover from 2,850 to 5,450 ft^2 per acre, and height from 1.5 to 2.3 feet (*table 2*). No statistical differences were found among treatments for density, foliar cover, or height.

California Red Fir

Damage to these conifer seedlings was surprisingly light. In spite of many sightings of deer in the study area, light browsing damage was noted only in 1987 and 1989. Visual records also indicated some terminal buds killed by late spring frost in 1991 and some needles burned by dry summer winds that fall. Mortality also was low. After one growing season 8 seedlings had died in the control, but none in the other treatments. Thus first-year survival for the entire study was 98 percent. Mortality, attributed to drought, was scattered among the treatments over time and no single event was noted. At the end of the study, percent survival by treatment was:

T-first-6	99
T-first-3	89
T-second-3	93
Control	76

Only one seedling died in the T-first-6 treatment during the 10-year study. Analysis of transformed survival values (arcsin) indicated that survival differed significantly between seedlings in the T-first-6 and control treatments. Overall, 10-year survival of red fir seedlings on all study plots in all treatments was 89 percent.

Average height of California red fir seedlings increased steadily in all treatments and by the end of the study in 1995 ranged from 3.2 feet in the T-first-

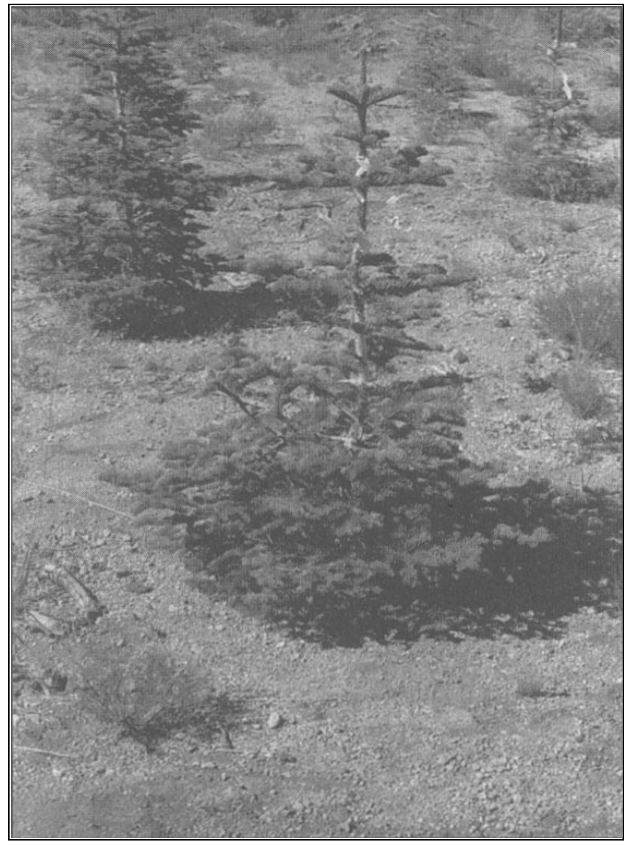
Table 3—Stem diameter and height of California red fir seedlings, by treatment, northern California, 1986-1995

Treatment	1986	1989	1991	1995
	Diameter (*inches*)			
Treated first 6 years	- a[1]	0.23 a	0.48 a	0.95 a
Treated first 3 years	- a	0.24 a	0.46 a	0.82 a
Treated second 3 years	0.10 a	0.23 a	0.40 a	0.70 a
Control	0.10 a	0.21 a	0.29 a	0.58 a
Standard error	0.03	0.02	0.05	0.09
	Height (*feet*)			
Treated first 6 years	0.53 a	1.30 ab	2.13 b	3.16 b
Treated first 3 years	0.56 a	1.46 b	2.12 b	2.77 ab
Treated second 3 years	0.52 a	1.15 ab	1.81 ab	2.48 ab
Control	0.56 a	1.04 a	1.29 a	1.71 a
Standard error	0.02	0.09	0.20	0.31

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

Figure 1—Relative development of California red fir seedlings and surrounding plant community, by treatment, fall 1995 (A) T-first-6, (B) T-first-3, (C) T-second-3, and (D) Control.

A



C

6 treatment to 1.7 feet in the control (*fig. 1*). Statistical differences among treatments for red fir height first became evident in fall 1989 with seedlings in the T-first-3 plots being significantly taller than those in the control (*table 3*). By 1991, seedlings in both the T-first-3 and T-first-6 plots were significantly taller than those in the control. By 1995, only seedlings in the T-first-6 plots differed significantly from those in the control.

B

D

Stem diameter, measured at 12 inches above mean groundline, increased slowly and by the end of the study ranged from 1.0 inch in T-first-6 plots to 0.6 inch in the control (*table 3*). Like stem height, diameter values for the T-first-3 and T-second-3 plots were intermediate in response. Mean diameter never differed significantly among treatments at the 5 percent level. However, differences were achieved in 1995 at the 8 percent level.

The ratio of height to diameter helps explain the effect of treatment. In all treatments from 1989 through 1995 the height-diameter ratio decreased, suggesting that stem diameter was expanding faster than stem height. In 1995, with the exception of the control, the lowest ratios were for the T-first-6 and T-first-3 treatments, with the highest ratio being in the T-second-3 treatment. Thus, stem diameter was expanding slower, relative to height in the T-second-3 treatment, than in the other treatments. Surprisingly, the treatment with the lowest ratio was the control. Unlike the overall strategy of California red fir seedlings, which is to grow tall and thin, that of stressed red fir seedlings seems to be to thicken stem diameter in place of height development (*fig. 2*).

Figure 2—Besieged by competing vegetation, this 10-year-old California red fir seedling has a relatively thick, short stem, and is in danger of being overtopped.

Discussion and Conclusions

A major need in forestry today is to develop knowledge on plant species and communities that develop after site preparation and after additional disturbance such as that incurred in release. Another need is to develop treatments and treatment schedules that provide consistent and reliable conifer seedling survival and growth rates.

As noted by Gordon and Bowen (1978), time since disturbance is an important factor affecting the amount of natural vegetation that develops in a given area. In this study, the grubbing and herbicide-application schedules resulted in plant community recovery times of 4 years in the T-first-6 and T-second-3 treatments, 7 years in the T-first-3 treatment, and 10 years in the control. Some general relationships, most of which were not statistically significant, indicate a young, dynamic plant community with species that have different density and developmental trajectories. For greenleaf manzanita in 1995, the two treatments with the longest recovery times resulted in the highest number of plants per acre; for snowbrush, the fewest; and for goldenbush and graminoids, a mixture. A longer recovery time also meant more foliar cover for all three shrub species, and taller plants for greenleaf manzanita and snowbrush. In the treatment with the longest recovery time (the control), greenleaf manzanita developed best in terms of density, foliar cover, and height. Foliar cover of snowbrush and goldenbush also excelled in the control. Graminoids, however, had lower density and development values in the control than in any other treatment, probably because of competition from the shrubs. McDonald and Abbott (1997) noted a similar relationship of grass to shrubs on a site of similar quality at a lower elevation near Mt. Shasta.

Time since disturbance has not caused a major change in the plant community during the first 10 years. Although trends seem to be developing, plant diversity, density, and development do not differ markedly among treatments. The same species, including forbs, are present. Although too few and poorly distributed to be statistically analyzed, the forbs do not seem to be losing ground to the shrubs and grasses. The species that were present initially are present at the end of the study, and their overall density and development are similar. One forb (*Monardella* spp.) actually increased in density, albeit erratically, to 1,200 seedlings per acre over all treatments during the study. Relative to other young plantations in our National Administrative Study, the 18 species recorded in this study (17 species plus 1 alien) caused it to rank next to last in plant diversity (range of 17-41 species) (McDonald and Fiddler 1993).

Time since disturbance also has not greatly affected plant density. Both on an individual species and a total vegetation basis, no marked differences were found. At the end of the study, more than 100,000 plants per acre were present in all treatments, with 77 to 89 percent being graminoids. Plant development, especially foliar cover and height of greenleaf manzanita and snowbrush, was where statistically significant differences among treatments were developing. Foliar cover and height were higher for treatments with longer recovery times (7 and 10 years) than for treatments with a shorter recovery time (4 years). But even then, total cover of all vegetation ranged from only 13 to 33 percent, indicating that much area, at least above ground, was unoccupied. Was similar area below ground unoccupied? Perhaps not, given the natural tendency of plants in harsh environments to occupy more space below ground than above.

At the elevation of the study, the soil becomes very dry, the winters are severe, and the growing season is short. Annual precipitation during the study was about normal for this location. During the study, precipitation in 1986, 1993, and 1995 was generally above normal; in 1987, 1988, and 1994 below normal; and in 1989 through 1992 about average.

The natural form and growth pattern of California red fir seedlings is to grow tall with a thin stem and crown (*fig. 3*). Height growth rates of 0.3 foot and diameter increments of 0.1 inch per year are common. Thus this conifer is best described as having slow seedling growth rates. Growth of California red fir, at least for the first 10 years, differs from that of ponderosa pine in amount and allocation. Height and diameter growth of ponderosa pine seedlings on a site of similar quality would be at least double these amounts. Ponderosa pine seedlings also tend to allocate a significant amount of resources to diameter growth at an early age. On a slightly better site in the southern Cascades of California,

Figure 3—Typical form of California red fir seedlings. Note the thin stem, narrow crown, and short internodes.

McDonald and Fiddler (1990) found that stem diameter of ponderosa pine seedlings at 12 inches above mean groundline differed significantly between most and least effective release treatments *before* differences in stem height occurred, and that this difference became statistically evident at the 5 percent level after only two growing seasons. In contrast, mean diameter of red fir in this study did not differ significantly among treatments after 10 years.

The density and developmental trends in the control suggest the future composition of a plant community that received only a minimum amount of manipulation. As in most other studies (see McDonald and Fiddler 1995 for example), shrub density at age 10 is flat or declining as weaker plants die and surviving plants become wider and taller. Certainly greenleaf manzanita with its relatively high density, foliar cover, and height values will be the dominant shrub in the control. Snowbrush, while not as numerous, has a tendency to grow tall and wide and will also be part of the future shrub community. Goldenbush, although numerous, is made up of mostly shorter plants, with many existing beneath taller plants. Its role in the future community will probably be that of occupying small openings among other species. The graminoids probably are scheduled for an eventual decline of major proportion. They apparently do not grow well with shrubs. Thus in the community of the future, they also will exist on the fringes of shrubs and in small openings.

The future species composition of plants in the treatments that received some form of release probably will be similar to that in the control. It is likely that the main effect of the manual grubbing and herbicide application was to postpone the development of the various components of the early successional plant community for 4 to 10 years. It will be interesting to see if the plant community in grubbed and sprayed plots a decade from now will be similar to that of the control in 1995.

Early removal of competing vegetation by site preparation and release denies undesirable plants the chance to utilize the high levels of site resources typically present after disturbance. Timing of release is critical. Early release allows the conifer seedlings to capture adequate site resources, become established, and grow well. They then should be able to stress the competing plants—not be stressed by them.

In this study, the T-first-3 and T-second-3 treatments were designed specifically to test early versus delayed release for California red fir. Unfortunately, the test was inconclusive, probably because more time is needed for diameter and height to develop and relationships to be clarified.

Nevertheless, results from this study indicated that California red fir seedlings in the T-first-6 and T-first-3 treatments were significantly taller than counterparts in the control in 1991. This, plus the significant difference in survival and height between the T-first-6 and control treatments in 1995, suggest that early removal of competing vegetation enhances the establishment and growth of California red fir seedlings.

However, early control of competing vegetation is not the only reason for the high red fir seedling survival values found in this study (98 percent after year 1; 89 percent after year 10). As noted earlier, survival was high in the other treatments and even in the control—much higher than that reported in the literature. For example, Click and others (1989) reported that average third-year survival (1982 through 1988) of planted red fir bare-root stock in the California region of the USDA Forest Service ranged from 5 to 54 percent, with that in the last 3 years averaging 35 percent. Drought, competing vegetation, and pocket gophers are major barriers to successful seedling establishment (Laacke and Fiske 1983). The most likely reason for the high survival values of California red fir seedlings in this study was excellence in every step in the nursery-planting-site preparation process, including high quality planting stock and storage procedures, and a good job of outplanting and site preparation.

An important factor when evaluating the timing of release is cost. Delaying release usually means larger plants and often large, deep roots. And if the plants become well established, then an additional round of treatments may be needed. Although costs were not recorded in this study, some general observations were noted: spraying took less time than grubbing, grubbing young small plants as in the T-first-3 treatment was much easier than initially grubbing the larger 3-year-old plants in the T-second-3 treatment, and additional treatment applications after the initial work as in the T-first-6 treatment will be much more expensive than a treatment such as T-first-3 that had fewer visits.

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 minor component—bitter cherry—is no longer present, and one major component—conifer seedlings—now is part of the community. California red fir seedlings in all treatments, with the possible exception of the control, are plentiful, well established, and have good 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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United States
Department
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**Pacific Southwest
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Research Paper
PSW-RP-233

Treatment Duration and Time since Disturbance Affect Vegetation Development in a Young California Red Fir Plantation

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