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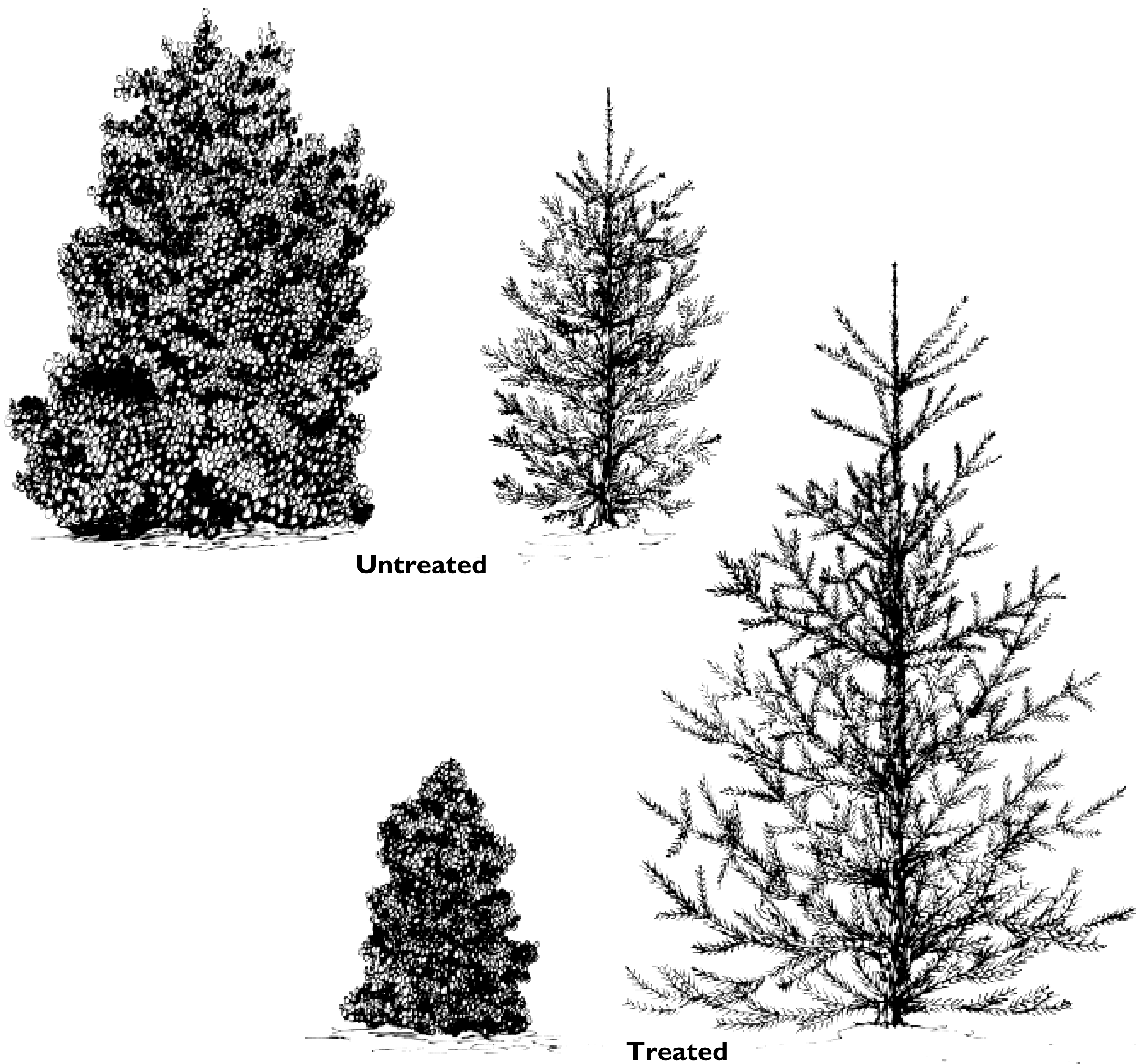
Development of a Mixed Shrub–Tanoak–Douglas-fir Community in a Treated and Untreated Condition

Philip M. McDonald   Gary O. Fiddler



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Abstract

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On a medium site in northern California, a tanoak-mixed shrub community was given several treatments (manual release two and three times, a combination chainsaw and cut surface herbicide treatment, two foliar herbicides, and a tank mix of the two herbicides) to study its development in both a natural (control) and treated condition. The herbicides were 2,4-D, Garlon 3A, and Garlon 4, each applied two times. Survival of planted Douglas-fir seedlings was recorded for 11 years and growth was quantified for 9 years after the last treatment application. In addition to Douglas-fir, data are presented individually for the two most abundant species (tanoak and snowbrush), for greenleaf manzanita, and for the hardwood tree and shrubs combined. At the study's end in 1992, combined vegetation in the control had a mean density of 1,800 plants per acre, foliar cover of 23,700 ft^2 per acre, and height of 11.2 feet. In contrast, combined tree and shrubs in the most effective treatment for controlling them—cut and spray Garlon 3A—had a mean density of 150 plants per acre, foliar cover of 150 ft^2 per acre and height of 5.9 feet at study end. And because competition for site resources was low, Douglas-fir seedlings developed best in this treatment. Mean Douglas-fir diameter was 4.6 inches at 12 inches above mean ground line, height averaged more than 21 feet, and mean foliar cover was 39,850 ft^2 at the end of the study. The cost was $227 per acre. The treatment response data, cost information, and plant community relationships provide the forest land manager with knowledge on how to attain some specific plant communities in the future, and their developmental potentials.

Retrieval Terms: Douglas-fir seedlings, manual and chemical release, northern California, shrubs, tanoak sprouts

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Contents

In Brief

Most conifer plantations in California are located in areas that have been created by wildfire or timber harvest. In many instances, the preharvest stands are devoid of conifers or poorly stocked with them and have a large component of hardwoods and shrubs. A forestry goal is often to create a new stand with a higher conifer component. How to limit the hardwoods and shrubs in the new stand is a problem, especially on steep ground, because few treatment alternatives are available. Falling the hardwoods and burning them and the conifer slash is the most practical. If this technique is effective, the soil surface is mostly bare mineral soil with scattered burned logs on it. If the broadcast burn takes place in the spring when the debris and litter layers are dry, but the organic material next to the soil is wet, an unburned layer remains to protect the soil, at least for a year or two.

Bare mineral soil does not last long, however, because many native hardwoods and shrubs have a regeneration strategy of rapid expansion after disturbance (Grime 1979). This is manifest in extensive sprouting from the root crown or burl. Each sprout captures a portion of the parent tree's root system, and fueled by water and nutrients from it, develops rapidly. Rapid regrowth and concomitant capture of site resources combine to make establishment and subsequent development of conifer seedlings difficult, if not impossible.

In this atmosphere of burgeoning competition, natural conifer seedlings from seed produced by adjacent trees would have difficulty becoming established. Planted conifer seedlings would fare no better. If conifers are to regain their place as the dominant vegetation, manipulation by humans has to be done. Specifically, the hardwood and shrub sprouts have to be reduced in number and vigor. Treating them as soon as possible after broadcast burning is cost effective. Early treatment denies competing plants the chance to recover from damage sustained in harvesting and site preparation. It also prevents them from using the high levels of site resources typically present after disturbance. And because they are young and small, they are easier to treat at a lower cost. The two manual treatments, three chemical treatments, and combination of manual and chemical treatment evaluated in this study created a plant community dominated either by planted Douglas-fir, or with various proportions of Douglas-fir, tanoak, and snowbrush. Several other shrubs, forbs, and grasses were present, but never became abundant.

The most effective treatments (chainsaw and spray cut surfaces with Garlon 3A herbicide two times, and foliar spray with 2,4-D plus Garlon 4 two times) created a plant community whose foliar cover was 99 and 95 percent Douglas-fir at the end of the study. A moderately effective treatment, such as manually releasing a 5-foot radius around Douglas-fir seedlings three times, led to a community whose foliar cover had the proportion of 33 percent tanoak, 14 percent snowbrush, and 53 percent Douglas-fir seedlings at the study's end. Applying no further treatment after broadcast burning, as in the control, created a plant community whose foliar cover was evenly distributed among tanoak, snowbrush, and Douglas-fir. The future of this community, however, is in doubt as the Douglas-fir seedlings are so slender that they would fall over if not supported by the shrubs and hardwoods. Precedent suggests that the Douglas-fir component here is likely to be much reduced in the future.

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Retrieval Terms: Douglas-fir seedlings, manual and chemical release, northern California, shrubs, tanoak sprouts

Consequently, the trend in the control is toward a plant community much like that before harvest or one composed primarily of hardwoods and shrubs.

The most effective treatments in this study led to a full component of rapidly growing Douglas-firs with potential to create a stand composed of mostly conifers. The moderately effective treatments created a mixed stand of vegetatively propagated tanoak trees, snowbrush shrubs, and slower growing planted Douglas-fir seedlings. The untreated control promoted a stand composed mostly of hardwoods and shrubs. These different plant communities, developmental potentials, and associated treatment costs give the forest land manager of the future choices for manipulating the vegetation in the landscape. And if one treatment is not politically or economically desirable, another treatment may attain the desired condition.

Introduction

As ecology becomes more important in forestry, knowledge about plant species and plant communities that develop naturally or after a deliberate manipulation is increasingly needed. 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 able to provide values and commodities that will be needed in the future. In forestry, much knowledge has been generated on economic species (conifer trees), but little is available on the currently uneconomic hardwoods, shrubs, forbs, and grasses.

What is known is that growth of Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) seedlings can be reduced to a fraction of their potential by competing vegetation, and that dramatic increases have occurred when this vegetation was removed. Gratkowski and Lauterbach (1974) recorded height increases of 170 to 255 percent for Douglas-fir seedlings 6 years after herbicide release in the Cascade Range of Oregon. The competing vegetation was primarily the tall variety of *Ceanothus*. Peterson and Newton (1982) measured third-year growth of 5-year-old Douglas-fir seedlings growing with *Ceanothus* and several herbs. Volume growth of treated conifers was 258 percent greater than untreated seedlings when shrubs were controlled and 415 percent greater when both shrubs and forbs were effectively treated. McDonald and Fiddler (1986) found that the mean diameter of Douglas-fir seedlings (measured at 12 inches above mean ground line) in the most effective of several treatments was 86 percent greater than that of untreated seedlings after 5 years. Competition in this instance also was mostly from a species of *Ceanothus*. Several other studies have shown dramatic increases in growth of Douglas-fir seedlings after release from other vegetation, particularly sprouting hardwoods (McDonald and others 1994, Tappeiner and others 1992).

In ecosystem management, every combination of every species could have value at some place in the landscape at some time. The chief of the USDA Forest Service, Jack Ward Thomas, acknowledged that we have much to learn about ecosystems, but "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). A strong need to develop new information on individual species and their interrelationships is implicit.

To increase knowledge about the ecology of several widespread plant species and a plant community that is commonplace in California and Oregon, information was collected on the species composition and developmental potentials of vegetation reoccupying a clearcut-harvested and broadcast-burned area in northern coastal California. Data were gathered both for vegetation developing naturally in an untreated control and for vegetation that was manipulated deliberately by several manual and herbicide treatments. Planted Douglas-fir seedlings were part of both plant communities. Natural seedlings had little chance of becoming established. This, one of the earliest studies that we installed, was part of a National Forest Service Administrative Study on alternative release methods (Fiddler and McDonald 1984).

This paper reports results on the competitive interaction of vegetation in a recently disturbed plant community. It portrays the growth dynamics of vegetatively propagated trees and shrubs and suggests that these dynamics, plus those of planted Douglas-fir seedlings, limited other plant species from becoming established or developing well. The study describes the density and development of the most abundant hardwood and shrub species and quantifies the growth of the Douglas-fir seedlings. Timing of treatment effectiveness and cost of the treatments is also presented. The variety of species proportions, growth potentials, costs, and treatments provide ecosystem managers with choices that should be useful in the future.

Methods

Location and Site Characteristics

The study area, located on the Gasquet Ranger District of the Six Rivers National Forest, was about 10 airline miles east of Crescent City, California. It comprised about 60 acres in two homogeneous units about 2 miles apart. Before clearcut-harvesting in 1978-79, the area supported a patchy stand of Douglas-fir intermixed with hardwoods and clumps of tall shrubs. After the merchantable conifers were harvested, the hardwoods, which were 3 to 6 inches in diameter, were cut. They and the conifer slash were broadcast burned in fall 1979. Most of the slash and hardwoods were consumed, leaving a soil surface that was mostly mineral soil with scattered burned logs on it.

The area was planted at an 8- by 8-foot spacing in February 1981 with 2-0 Douglas-fir seedlings from the USDA Forest Service's Humboldt Nursery. Because damage from deer (*Odocoileus* spp.) was common in the area, each seedling was fitted with a 24-inch vexar leader protector. Although a good job of planting was done, survival in the fall of 1981, when we began the study, was 70 percent.

The plant community when the study began consisted mostly of plants that originated from root crowns and dormant seeds in the soil. Many hardwood and shrub burls were present, which promptly sprouted. Rapidly growing sprouts comprised the early after-burning plant community. The second summer after site preparation, shrub seedlings and a few forbs from windblown seeds became established. In addition to the planted Douglas-fir seedlings, the most abundant vegetation in the plantation was tanoak *(Lithocarpus densiflorus* [Hook. & Arn.] Rehd.) and snowbrush *(Ceanothus velutinus* var. *hookeri* M. Johnston) with greenleaf manzanita *(Arctostaphylos patula* E. Greene) a distant second. Oregongrape *(Berberis* spp.), yerba santa *(Eriodictyon californicum* [Hook. & Arn.] Torrey), and beargrass *(Xenophyllum tenax* [Pursh] Nutt.) (family Liliaceae) were locally dense. A few forbs and bracken fern *(Pteridium aquilinum* [L.] Kuhn var. *pubescens* L. Underw.) were widely scattered throughout the study area. No grasses were recorded.

Snowbrush, which formerly was called *Ceanothus velutinus* var. *laevigatus*, has recently been given a new variety name *(hookeri)* (Hickman 1993). It is found near the Pacific coast from northern California northward to British Colombia. It grows at low elevations, and differs from the inland variety, primarily by its taller stature. Although common in many conifer plantations in California and southern Oregon, ecological information, particularly density and development data, are needed for it (Conard and others 1985). Variety *hookeri* is a hardy, fast-growing shrub with many adaptations (Hanes 1981, McDonald 1982) that help it to be a strong competitor to conifer seedlings in plantations. Mature plants form large burls with dormant buds that sprout vigorously if the aboveground plant parts are damaged. The species also produces large and frequent seedcrops. Fire stimulates germination, but disturbance without fire can lead to the presence of seedlings (Conard and others 1985).

Based on the height-age relationship of Douglas-fir, site quality of the study area before burning is medium (King 1966). The soil is derived from Mesozoic sedimentary rocks and classifies taxonomically as Haploxeralfs, Haploxerults, and Xerochrepts. The soil is best characterized as rocky, well drained, and with only a small amount of clay in the profile. The elevation is 2,550 feet, slopes range from 25 to 80 percent, and the aspect is southeast. Precipitation averages about 110 inches per year, with about 75 percent falling as rain. In spite of heavy annual rainfall, the summers are dry with little precipitation falling between June and mid-September.

Study and Design

This study presents data on Douglas-fir seedlings, a hardwood, two shrubs, and the hardwood and shrubs combined collected during 1982-1992. It includes information gathered on plant species developing naturally in the control and after receiving a range of release treatments.

The experimental design was randomized block with four blocks and seven treatments per block. Thus, each treatment was replicated four times. A replicate (plot) consisted of one-fourth acre on which were about 40 Douglas-fir seedlings surrounded by two or three rows of buffer (seedlings receiving similar treatment). Treatments and installation dates were:

- Manual release (pull and chainsaw)
  5-foot radius two times, August 1981, October 1982
  5-foot radius three times, August 1981, October 1982, April 1984
- Chemical release
  2,4-D, two times, entire plot, September 1981, May 1984
  2,4-D plus Garlon 4, two times, entire plot, September 1981, May 1984
  Garlon 4, two times, entire plot, September 1981, May 1984
- Manual and chemical release
  Chainsaw and Garlon 3A, two times, entire plot, September 1981, May 1984
- 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 two and three times from a fixed radius around crop trees. Because small snowbrush seedlings were intermixed with taller vegetation, they were hand-pulled before the sprouts were cut with chainsaws. For manual and chemical release, the vegetation was first cut by chainsaws as close to ground level as possible and then followed (within 0.5 hour) by chemical application to the cut surfaces. Vegetation was sheared if leaning into the 5-foot radius or into the plot.

The chemical treatments were the herbicides 2,4-D (ester), the amine form of Garlon (3A), and the ester form of this same chemical (Garlon 4).[1] When the study began, 2,4-D was the foliage-active herbicide most often applied to forest plantations in California, and Garlon was a new cut-surface and foliage-active herbicide recommended for use in young conifer plantations threatened by broad sclerophyll vegetation. Sclerophyllous vegetation is characterized by species having tough leathery leaves that do not wilt, and that often have waxy or pubescent coverings. The 2,4-D and two formulations of Garlon were applied directly to the vegetation from backpack sprayers. Garlon 4, with and without 2,4-D, and 2,4-D alone were mixed with water and diesel oil. Garlon 4 and 2,4-D were combined and applied as a tank mix, not one chemical followed by the other. Garlon 3A was mixed only with water. Because the chemicals were aimed

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

directly at the competing vegetation, the likelihood of chemical drift was minimal. The Douglas-fir seedlings were not covered during treatment.

The cost of 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, 20 Douglas-fir seedlings that qualified as potential crop trees were identified and tagged. As "crop tree" implies, these were well developed seedlings that had good potential of becoming harvestable trees. On each sample seedling, 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 Douglas-firs in the control was five randomly selected subplots in each plot. Subplots were centered around Douglas-fir seedlings in all treatments. For plots where the entire area was treated (manual plus chemical, chemical, and control), a square 1 milacre (0.001 acre) frame was used. For manually released 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).

To statistically test for treatment effects and significant differences among treatments, a two-way analysis of variance of treatment means (mixed model, no interaction [Steel and Torrie 1980]) and a Tukey test were used (SAS Institute Inc. 1988). It was assumed that the block-treatment interaction equalled zero. 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 recorded when the study began and at the end of the study.

Internal moisture stress of Douglas-fir seedlings and tanoak sprouts was determined to help explain growth differences among treatments that became apparent early in the study. Snowbrush was evaluated for internal moisture stress, but only in the control. Xylem sap tension was measured with a Scholander pressure chamber (Scholander and others 1965) on August 25, 1984, a typical cloudless day near the end of summer. At this time of year, the seedlings should have been under maximum physiological stress because of high moisture deficits.

Sampling of sap tension began just after dawn and continued through late afternoon. Time and distance considerations mandated that only one replication be 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 to minimize moisture changes while en route to the pressure chamber. 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" is expressed in atmospheres (Waring and Cleary 1967) because it is a direct reading and familiar to foresters and biologists.

Results

Plant Diversity

The plant community at the beginning of the study consisted of planted Douglas-fir, three species of hardwoods, six species of shrubs, eight forbs, one fern, and no grasses. Seeds of bull thistle *(Cirsium vulgare* [Savi] Ten.), woolly mullein *(Verbascum thapsus* L.), willow herb *(Epilobium* spp.), and groundsel *(Senecio* spp.) 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. Not until about midway through the study was grass noticed. It tended to be widely scattered in the study area. After 11 years the community consisted of the same species with one additional shrub and one species of grass. However, the forbs, grass, and some of the shrubs were so few and small that they were difficult to find. Douglas-fir, tanoak, snowbrush, greenleaf manzanita, and, in places, bracken fern so dominated the plantation that plants of other species were becoming both diminutive and scarce.

Tanoak

This hardwood tree species was present in all plots and was by far the most abundant of the arborescent vegetation. After cutting and burning, each stump sprouted, and by the end of the first growing season in 1982, tanoak clumps in the control averaged 900 per acre with foliar cover of 3,850 ft^2 per acre and an average height of 3.2 feet *(table 1).* By the end of the study in 1992, tanoak clump density decreased by 6 percent, but mean foliar cover had increased by 205 percent to 11,750 ft^2 per acre, and average height by 244 percent to 11.0 feet.

On treated plots in 1992, tanoak density was lowest in plots treated by cutting plus Garlon 3A and with Garlon 4, and highest in plots treated by manual release three times, applying 2,4-D, and in the control *(table 2).* These differences were statistically significant at the 5 percent level. Tanoak foliar cover in cut and spray (Garlon 3A) plots, 2,4-D plus Garlon 4, and Garlon 4 alone differed significantly from clumps in the control. Tanoak clump height did not differ significantly among treatments.

Snowbrush

The presence of variety *hookeri* in the study area was in the form of numerous root crown sprouts, seedlings from seeds in the soil, and possibly seedlings from new seeds carried into the area by birds and rodents.

In fall 1982, density of snowbrush plants in the control was 950 plants per acre with only 150 ft^2 of foliar cover and 2.3 feet of height *(table 1).* By fall 1992, density had decreased 5 percent but mean foliar cover and height had increased manyfold, to 11,850 ft^2 per acre and 11.5 feet, respectively.

On treated plots in fall 1992, density of snowbrush was significantly lower in plots treated by cut and spray (Garlon 3A) and Garlon 4 than in the control *(table 2)*. For foliar cover, all three treatments with Garlon were significantly lower than for counterparts in the control. Snowbrush height did not differ significantly among treatments.

Table 1—*Density, cover, and height, with standard errors (SE), of tanoak, snowbrush, greenleaf manzanita, and combined tree and shrubs in the control, 1982-1992*

Species and Year	Density	SE	Cover	SE	Height	SE
	------ *Plants/acre* ------		---------- *Ft²/acre* ---------		-------- *Ft* ------	
Tanoak						
1982	900	301	3,850	728	3.2	0.4
1984	1,000	253	8,250	824	4.9	0.5
1987	950	225	10,400	1,513	6.7	1.0
1992	850	163	11,750	1,967	11.0	1.5
Difference (pct)[1]	–6		+205		+244	
Snowbrush						
1982	950	449	150	98	2.3	0.2
1984	950	181	1,400	251	2.5	0.3
1987	900	172	7,900	1,373	6.3	1.0
1992	900	158	11,850	2,127	11.5	1.7
Difference (pct)[1]	–5		+7800		+400	
Greenleaf Manzanita						
1982	150	202	50	102	0.6	0.2
1984	150	123	300	94	1.4	0.3
1987	200	92	100	219	3.2	0.1
1992	50	57	100	57	5.8	0.2
Difference (pct)[1]	–67		+100		+867	
Combined Tree and Shrubs						
1982	2,000	712	4,050	733	2.3	0.3
1984	2,100	346	9,950	886	4.0	0.4
1987	2,050	326	18,400	2,105	6.3	0.9
1992	1,800	237	23,700	2,661	11.2	1.3
Difference (pct)[1]	–10		+485		+387	

[1]Difference between 1982 and 1992 values expressed as a percent increase or decrease.

Greenleaf Manzanita

This evergreen, normally fast-growing shrub was expected to be the most abundant woody species in the plantation. After site preparation, viable seeds in the soil usually germinate by the thousands. But that did not happen in this study. Virtually all plants originated from root crown sprouts. In the control, mean plant density, which was low to begin with, decreased 67 percent to only 50 plants per acre *(table 1).* Foliar cover began low and ended low. Mean height increased from 0.6 to 5.8 feet during the study.

For the various treatments, low density and development values were characteristic. Manzanita density and height did not differ significantly among treatments *(table 2).* For all chemical treatments and manual release to a 5-foot radius three times, the manzanita plants were either absent or so small that they had less than 0.5 ft² cover. These treatments differed significantly from manual release two times and the control.

Combined Tree and Shrubs

Most early seral vegetation in young plantations in California and Oregon almost always consists of mixtures of vegetation that include grasses, forbs, shrubs, and hardwoods. Rarely is this vegetation dominated by a single class of plants (McDonald and Radosevich 1992), or by plants from a single regeneration strategy, in this instance rapid expansion of vegetatively produced sprouts (Grime 1979).

Table 2—*Density, cover, and height of tanoak, snowbrush, greenleaf manzanita, and combined tree and shrubs in treated and control plots, Six Rivers National Forest, 1992*

Species and Treatment	Density	Cover	Height
	Plants/acre	*Ft²/acre*	*Ft*
Tanoak			
Manual			
5-ft radius two times	637 ab[1]	6,571 ab	8.5 a
5-ft radius three times	1,081 a	7,902 ab	8.1 a
Chemical			
2,4-D	850 a	4,850 ab	8.3 a
2,4-D + Garlon 4	450 ab	350 a	5.4 a
Garlon 4	150 b	2,100 a	7.0 a
Manual and chemical			
Cut and spray (Garlon 3A)	0 b	0 a	– a
Control	850 a	11,750 b	11.0 a
Standard error	163	1,967	1.5
Snowbrush			
Manual			
5-ft radius two times	166 ab[1]	3,105 ab	9.0 a
5-ft radius three times	416 ab	3,382 ab	10.2 a
Chemical			
2,4-D	300 ab	2,450 ab	11.5 a
2,4-D + Garlon 4	250 ab	1,200 a	7.2 a
Garlon 4	50 a	100 a	14.5 a
Manual and chemical			
Cut and spray (Garlon 3A)	50 a	150 a	7.6 a
Control	900 b	11,850 b	11.5 a
Standard error	158	2,127	1.7
Greenleaf Manzanita			
Manual			
5-ft radius two times	111 a[1]	333 a	4.4 a
5-ft radius three times	111 a	28 b	1.4 a
Chemical			
2,4-D	0 a	0 b	– a
2,4-D + Garlon 4	0 a	0 b	– a
Garlon 4	50 a	0 b	2.5 a
Manual and chemical			
Cut and spray (Garlon 3A)	100 a	0 b	5.0 a
Control	50 a	100 a	5.8 a
Standard error	57	57	0.6
Combined Tree and Shrubs			
Manual			
5-ft radius two times	917 ab[1]	10,009 a	7.9 a
5-ft radius three times	1,608 a	11,312 ab	8.3 a
Chemical			
2,4-D	1,150 ab	7,300 a	8.4 a
2,4-D + Garlon 4	700 ab	1,550 a	6.3 a
Garlon 4	250 b	2,200 a	9.1 a
Manual and chemical			
Cut and spray (Garlon 3A)	150 b	150 a	5.9 a
Control	1,800 a	23,700 b	11.4 a
Standard error	237	2,661	1.4

[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.

In fall 1982, mean density of combined tree and shrubs in the control was 2,000 plants per acre with more than 4,000 ft^2 of foliar cover and 2.3 feet of height *(table 1).* By fall 1992, density had decreased 10 percent, but cover and height had increased 485 and 387 percent, respectively *(table 1).*

Among treatments in 1992, the same relationships found for tanoak and snowbrush were generally present: for density, the treatment having the most shrubs was the control; the least, cut and spray with Garlon 3A and Garlon 4 *(table 2).* For foliar cover, the control had 23,700 ft^2 per acre with the next closest amounts being in the two manually released radius treatments. Significantly more cover occurred in the control than in any other treatment except 5-foot radius three times. No significant difference among treatments occurred for height of combined tree and shrubs.

Douglas-fir

Total mortality of Douglas-fir was two seedlings from 1982 through 1992. Survival after the initial losses in 1980-1981 averaged 99 percent with no statistically significant differences among treatments. Despite the presence of deer, and a few sightings of rabbits and a bear early in the study, damage to Douglas-fir seedlings also was negligible. The vexar protectors caused minor early distortion to a few leaders, which was not discernible by the end of the study.

Statistically significant differences among treatments for Douglas-fir showed up first for foliar cover in 1984 *(table 3).* Foliar cover was significantly greater in plots treated by 2,4-D plus Garlon 4 than in manually released treatments. By fall 1987, statistically significant differences among treatments were present for foliar cover, stem diameter at 12 inches above mean ground line, and stem height *(fig. 1).* This trend continued through 1992. In 1992, mean stem diameter of Douglas-fir seedlings treated by cut and spray (Garlon 3A), 2,4-D plus Garlon 4, and Garlon 4 alone differed significantly from seedlings in the control. Foliar cover also followed this trend. For mean height of Douglas-fir seedlings, only those in the cut and spray (Garlon 3A) treatment differed significantly from counterparts in the control. The treatment that led to the greatest Douglas-fir growth was to spray freshly cut surfaces with Garlon 3A. The gain from this treatment relative to the control was striking—1.8 times for height, 2.4 times for diameter, and 3.6 times for foliar cover.

The ratio of Douglas-fir height to diameter reinforces the differences among treatments. For instance, the Garlon 3A and Garlon 4 treatments resulted in height-diameter ratios that were generally lowest in the study, suggesting that stem diameter expanded faster than stem height. Manual release two times and control plots generally had the highest ratios, suggesting that stem diameter expanded slower than stem height.

Plant Moisture Stress

Of the five treatments tested, postdawn minimum moisture stress of tanoak was lowest (4.3 atmospheres) in the manual release two times treatment, intermediate (4.8 atmospheres) in the Garlon 4 treatment, and highest (7.3 atmospheres) in the control *(fig. 2).* Maximum moisture stress was greatest in the control (18.5 atmospheres) and least in 2,4-D (11.0 atmospheres) and Garlon 4 (11.7 atmospheres) treatments. Maximum stress was first noted in the third round of sampling (12:10-1:00 p.m. PST) for all treatments except the control in which it occurred in the fourth round at 2:46 p.m. PST. Tanoak sprouts in the control had the highest internal moisture stress of all treatments in every round of sampling.

For the seven treatments tested, postdawn minimum moisture stress of Douglas-fir seedlings was lowest (6.0 atmospheres) in the cut surface treatment with Garlon 3A, intermediate (8.3 atmospheres) where radii were manually

Table 3—*Stem diameter, height, and foliar cover of Douglas–fir seedlings, by treatment, Six Rivers National Forest, 1982–1992*

Treatment	1982	1984	1987	1992
Diameter			*inches*	
Manual				
5–ft radius two times	–	0.59 a[1]	1.47 ab	3.02 ab
5–ft radius three times	–	0.52 a	1.49 ab	2.95 ab
Chemical				
2,4–D	–	0.72 a	1.87 ab	3.55 ab
2,4–D + Garlon 4	–	0.82 a	2.11 a	4.50 a
Garlon 4	–	0.61 a	1.64 ab	4.05 a
Manual and chemical				
Cut and spray (Garlon 3A)	–	0.80 a	2.17 a	4.64 a
Control	0.24	0.52 a	1.08 b	1.96 b
Standard error	–	0.08	0.19	0.36
Height			*feet*	
Manual				
5–ft radius two times	–	2.95 a	6.99 ab	15.64 ab
5–ft radius three times	–	2.81 a	7.05 ab	14.65 ab
Chemical				
2,4–D	–	3.29 a	8.60 ab	18.18 ab
2,4–D + Garlon 4	–	3.81 a	9.16 ab	19.91 ab
Garlon 4	–	2.81 a	7.11 ab	17.94 ab
Manual and chemical				
Cut and spray (Garlon 3A)	–	3.32 a	9.90 a	21.55 a
Control	1.50	3.07 a	6.06 b	12.08 b
Standard error		0.34	0.83	1.68
Cover			*ft²/acre*	
Manual				
5–ft radius two times	–	1,130 a	3,770 b	16,552 bc
5–ft radius three times	–	1,275 a	4,325 b	12,504 bc
Chemical				
2,4–D	–	1,850 ab	10,900 ab	26,400 ab
2,4–D + Garlon 4	–	2,850 b	13,850 a	35,895 a
Garlon 4	–	1,950 ab	8,050 b	37,750 a
Manual and chemical				
Cut and spray (Garlon 3A)	–	2,550 ab	16,400 a	39,850 a
Control	700	1,900 ab	4,500 b	10,950 c
Standard error		309	1,647	1,422

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

released twice, and highest (15.8 atmospheres) where manually released three times *(fig. 2)*. Maximum moisture stress was generally lowest in treatments where herbicides were used (15 to 18 atmospheres) and highest in manual release three times and the control (23 to 24 atmospheres). From 8:35 a.m. to 4:57 p.m. PST, Douglas-fir seedlings in the control endured higher stress than counterparts in any other treatment.

Internal moisture stress of snowbrush sprouts was quantified only in the control, and registered 13.5 atmospheres of stress at 5:48 a.m., reached 23.3 atmospheres at maximum (12:52 p.m.), and tapered off at 21.8 atmospheres at 5:31 p.m. PST *(fig. 2)*.


A
B
D
E

Figure 1—Relative development of Douglas-fir seedlings and other vegetation by treatment in fall 1987: (A) cut and spray entire plot with Garlon 3A, (B) manually release a 5-foot radius around Douglas-fir seedlings two times, (C) manually release a 5-foot radius around Douglas-fir seedlings three times, (D) apply 2,4-D to entire plot, (E) apply 2,4-D plus Garlon 4 to entire plot, (F) apply Garlon 4 to entire plot, and (G) untreated control.

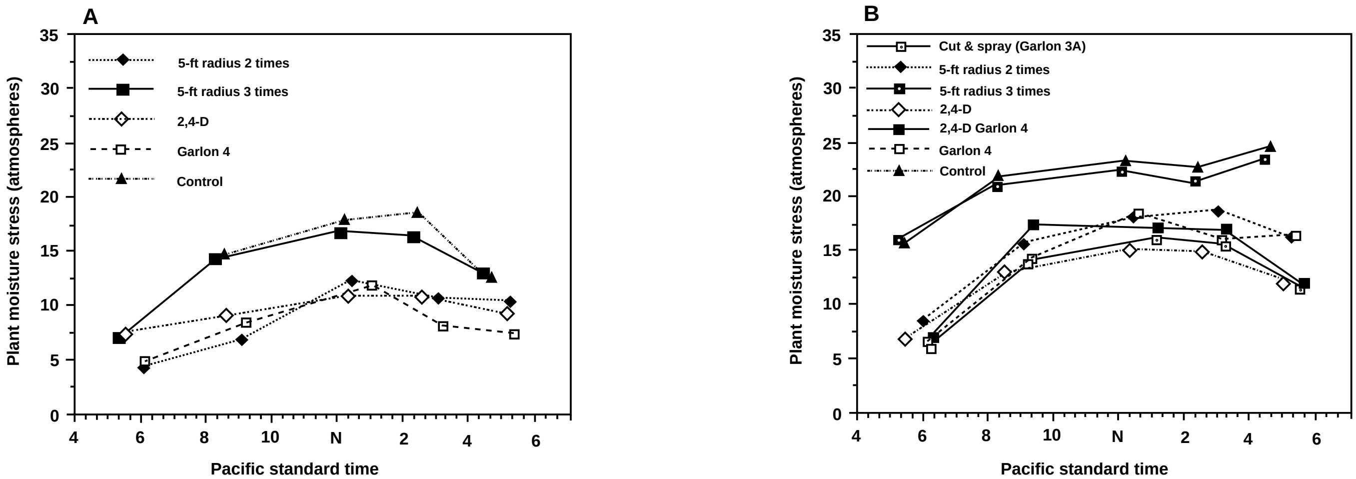

Figure 2—Diurnal trend of internal moisture stress by treatment on August 25, 1984 in (A) tanoak sprouts, and (B) Douglas-fir seedlings. Standard errors applicable to differences between treatments could not be estimated.

Production and Cost

Chainsawing hardwood and shrub sprouts and treating the freshly cut surfaces with Garlon 3A twice, and manually releasing 5-foot radii around Douglas-fir seedlings two times were expensive. Manually releasing 5-foot radii around seedlings 3 times was even more expensive. Directed foliar sprays with chemicals was the least expensive:

Treatment	*Production rate*	*Cost*
	Laborer hours/acre	*Dollars/acre*
Manual release (pull and chainsaw)		
5-foot radius, 2 times	23	201
5-foot radius, 3 times	34	297
Manual and chemical release		
Cut + Garlon 3A, 2 times, entire plot	26	227
Chemical release		
2,4-D, 2 times, entire plot	9	79
2,4-D plus Garlon 4, 2 times, entire plot	9	79
Garlon 4, 2 times, entire plot	9	79

Cost is for labor only and does not include overhead or chemicals. If the cost of the chemicals was included, $10 should be added to the cost per acre for 2,4-D, $70 for Garlon 3A, $40 for 2,4-D + Garlon 4, and $75 per acre for Garlon 4.

Discussion and Conclusions

With an annual precipitation average of 110 inches and mild temperatures, revegetation of the disturbed study area was dynamic. Stimulated by cutting and broadcast burning, dormant buds on root crowns of tanoak, snowbrush, and greenleaf manzanita quickly produced numerous sprouts. These grew rapidly, fueled by energy stored in the root crown and root system. Bull thistle, woolly mullein, willow herb, and groundsel became locally abundant in pockets, but in general never became dense throughout the study area. The grass species invaded in midstudy and were too late to expand their population beyond scattered plants. By the end of the study 20 plant species had been noted. This number is low relative to that found in other studies (17 to 41 species) in our National Administrative Study in young conifer plantations (McDonald and Fiddler 1993).

As noted by Sousa (1984), large individual size just after disturbance is advantageous to a plant for procuring available resources. Certainly, having direct vascular connection to part of a huge parent root system, such as found in root crown sprouts, qualifies as "large." Plant species that germinate from seeds have little chance of competing for long with such individuals. It is soil moisture that they cannot compete for—the limiting environmental factor in most of California. Consequently, forbs, grasses, slower-growing shrubs, and shrubs from seeds in this study never had the opportunity to become abundant. Their presence was relegated to relatively small areas where tanoak and snowbrush were less frequent. Here they persisted.

Analysis of the first full data set in 1982 showed that tanoak and snowbrush constituted more than 92 percent of total competing plant density and 99 percent of foliar cover in the control. Both were the tallest vegetation in the plantation. Density of both species was remarkably stable, each declining by only about 5 percent at the end of the study in 1992. Foliar cover of tanoak and snowbrush followed a steadily increasing trend, with both species over 11,700 ft^2 per acre in 1992. Height of both species was similar in trend and final amount—more than 11 feet tall. Greenleaf manzanita density and foliar cover, however, were low throughout the study.

Development of Douglas-fir seedlings in the control was governed by heavy competition and lower available soil moisture. The likelihood of being overtopped by the burgeoning tanoak and snowbrush sprouts was high. In this situation, Douglas-fir seedlings typically sacrifice crown and needle development for height growth. Consequently, their form tended to be tall and thin with narrow crowns. Many seedlings were so thin that they needed support from nearby shrubs and hardwood trees. By the study's end, Douglas-fir seedlings in the control averaged about 2 inches in diameter, 12 feet in height, and had more than 10,900 ft^2 of foliar cover per acre. These values denote a 7 percent advantage in height over combined tanoak and shrubs, but a 116 percent disadvantage in foliar cover. The sacrifice of support and photosynthetic surface area cannot continue, and at some point the rate of height growth will decline (Wagner 1994). If the height growth rate of competing plants does not decline, most of the Douglas-fir seedlings will eventually die.

In contrast to Douglas-fir seedlings in the control, growth of Douglas-fir in the most effective treatment (cut and spray with Garlon 3A) was characterized by robust diameter (4.64 inches), well developed crowns (39,859 ft^2), and tall trees (21.55 feet). The odds for their survival and continued growth are high.

At the end of the study in fall 1992, the various treatments had all reduced the hardwood tree and shrub components of the plant community to some degree. Average density, cover, and height of combined tree and shrubs were less in all treatments relative to the control. With the exception of 2,4-D, treatments that involved chemicals were more effective than chain sawing vegetation in a 5-foot radius. From previous studies, we found that the minimum effective radius was 5 feet—any lesser radius did 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). Because the 5-foot treated radius in this study was only moderately effective at best, a wider radius seems logical. Jaramillo (1988) found that 8-foot and even 12-foot treated radii significantly improved height and diameter growth of Douglas-fir seedlings growing with sprouting trees and shrubs in southwestern Oregon. For this plant community, however, the tradeoff between effectiveness of an expanded radius and its cost is unknown.

For just the chemical treatments in this study, none differed statistically from the other. Differences were not significant among treatments for combined vegetation or for Douglas-fir seedlings. Thus, the decision to apply a given chemical should be decided on other than biological reasons.

The cost and production data gathered in this study reflect the aggressive nature of the hardwood tree and shrub sprouts. Their hardiness and ability to withstand natural and human-caused perturbations mandated that at least two treatment applications be applied. For manual release, the tanoak and shrub sprouts were only cut off, not severed below the root crown. They and new sprouts from formerly dormant buds on the burl sprouted after site preparation and after each retreatment. The amount of vegetation in the prescribed radius decreased a little with each successive treatment, but the amount of vegetation that was leaning into the radius also increased. Thus the total amount of vegetation that was removed probably did not differ much after each treatment. This total is reflected in the large number of hours expended and the highest cost in the study. For chemical release, the retreatment cost was about half that of the initial cost because much less vegetation had to be treated the second time.

The timing of treatments in this study was adequate, but could have been improved to maximize effectiveness. Competing vegetation is best controlled when the interval between disturbance and becoming established is short (McDonald and Oliver 1984, McDonald and Fiddler 1989). The first 3 years are important; the first year is critical. Seedlings need freedom to vigorously expand their root systems in an ever-increasing volume of soil. In a southern Oregon study, for example, roots of Douglas-fir 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, the initial treatments were applied soon after site preparation and the interval between manually retreating the 5-foot radii was correct. For the chemical treatments, the 2-year interval between the initial treatment and retreatment could have been shortened by 1 year.

A continuing objective of the National Administrative Study on vegetation management is to determine the timing of treatment effectiveness. In general, the faster the occurrence of a statistically significant difference between a treatment and the control, the more effective the treatment. When competition is controlled, stem diameter usually is the conifer parameter that differs significantly first. In this study, however, foliar cover of Douglas-fir seedlings became significant first. Achieving significance in fall 1984, or four growing seasons after planting, probably is about as fast as can be expected, given the aggressive nature of the competing vegetation in this study.

Doing a good job of site preparation and then believing that sufficient conifer seedling growth will result is not realistic. As noted earlier, shrub density and development in the control were such that Douglas-fir seedlings there were tall and thin with little girth or crown development. Although almost all seedlings are alive, their future is uncertain and probably precarious.

A primary goal of vegetation management is to manipulate the after-site preparation plant community to alter the trajectory of its succession. More specifically, it focuses on restoring dominant species, usually one or more conifers, to their natural place in the community. This means having the desired number of conifer seedlings present and developing well. But as they are developing, at least until the crowns close, many other species of plants usually become present. In this study, however, only two other species developed well—tanoak and snowbrush. Other species were not abundant initially, or became established too late to garner enough site resources to grow well. Because Douglas-fir seedlings are present in all treatments, another influence on secondary succession has been introduced. Where the Douglas-fir seedlings grow well, the competing vegetation will develop poorly; where the competing vegetation develops well, the Douglas-fir seedlings will grow poorly. Thus, secondary succession in this study is manifest in different proportions of the same species, each with a different developmental potential.

In the future, ecosystem managers will need to create specific plant communities at specific times in the landscape. Having a choice of species proportions, growth potentials, and costs, as well as a range of treatments to attain them, should prove valuable.

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