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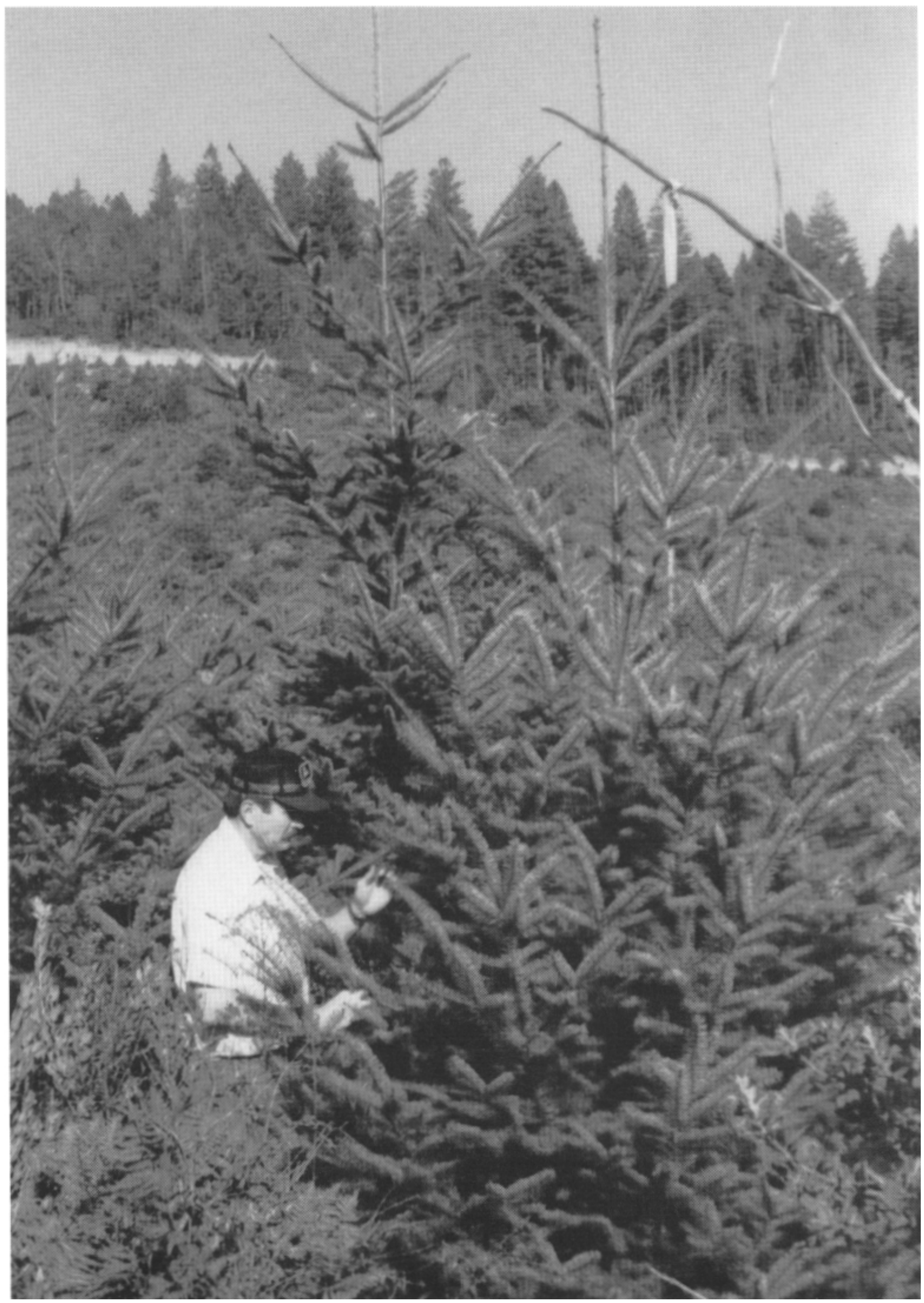
PSW-RP-243

Ecology and Development of Douglas-fir Seedlings and Associated Plant Species in a Coast Range Plantation

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



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Abstract

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On an average site in northern coastal California, a tanoak-mixed shrub community was given several treatments (manual release one, two, and three times; a combination chainsaw and cut surface chemical treatment; two foliar chemicals; and a tank mix of the two chemicals) to study its development over an 11-year period in both a broadcast-burned (untreated control) and released (treated) condition. The chemicals were 2,4-D, Garlon 3A, and Garlon 4, each applied two times. In addition to Douglas-fir, data are presented individually for the four most abundant and well distributed species (tanoak, hairy manzanita, huckleberries, and rhododendron), and for these plus two more of the tallest and most abundant (but poorly distributed) species (snowbrush, elderberry) combined. At the study's end in 1991, combined shrubs in the control had a mean density of 4,733 plants per acre, foliar cover of 16,800 ft^2 per acre, and height of 9.5 feet. In contrast, combined shrubs in one of the most effective treatments for controlling them-2,4-D-had a mean density of 2,000 plants per acre, foliar cover of 2,600 ft^2 per acre and height of 5.5 feet at the end of the study. Here, mean Douglas-fir diameter was 4.0 inches at 12 inches above mean ground line, height averaged 18.7 feet, and mean foliar cover was 34,800 ft^2 per acre. The cost (including chemical) was $77 per acre. The biological and economical data in this paper provide the ecosystem manager, wildlife biologist, and fuels manager with knowledge on how to attain plant communities with different density and development potentials, and the cost of creating them.

Retrieval Terms: Douglas-fir seedlings, ecology, growth, manual and chemical release, northern California, plant community

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In Brief...

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As ecosystem management increasingly becomes the operational paradigm for managing federal forest land, the art and science of vegetation management will have an increased role. Especially needed is information on currently uneconomic species and their interrelationships in the plant community. In ecosystem management, every combination of species could have value at some place in the landscape at some time. In a young conifer plantation, for example, the worth of the small trees and the wood products that eventually come from them has long been recognized. And, with ecosystem management, the seed from a common herbaceous species in the plantation that is critical to a threatened species of wildlife could also be regarded as being equally worthwhile.

Most conifer plantations in California are located in areas that were 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 management goal often is 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 has proved to be a practical technique for preparing the site for planting. Site preparation often gives the planted conifer seedlings at least temporary relief from competing vegetation.

But not in this 11-year study in northern coastal California. Competition from such rapidly growing species as tanoak, snowbrush, rhododendron, huckleberries, and hairy manzanita, was both rapid and heavy. Plainly, release of the plantation was needed if the Douglas-fir seedlings were to grow at the potential of the site. Consequently, three manual treatments (chain saws and shears), three chemical treatments, and a combination manual and chemical treatment were installed to evaluate their effect on the species composition, density, and development of the ensuing plant community. In general, the chemical treatments and manual release three times were the most effective treatments; manual release one and two times, and the uncut control were the least effective. The chemical treatments cost roughly one-sixth that of the manual release treatments.

At the end of the study in 1991, the plant community in the various treatments was comprised almost entirely of vegetatively propagated hardwood trees and shrubs with only a few forbs and no grasses. All were present in all treatments, with fewer and smaller plants in the most effective treatments, and more and larger ones in the least effective treatments. Thus, the resulting plant communities can be characterized as having different proportions of the same species. Douglas-fir was present in all communities as well. However, in the most effective treatments, it had a statistically larger mean foliar cover than in the least effective treatments, and in one of them it had a statistically larger stem diameter at 12 inches above mean groundline. Results from this study should be useful to several disciplines in natural resource management. Ecologists now have data on the early species composition, density, and development of the plants in this community, wildlife biologists can infer browse and seed production, and fuel managers can quickly multiply the foliar cover and height values to arrive at cubic volume estimates by species.

Introduction

Significant public sentiment, expressed through recent polls, newspaper articles, and proposed legislation, seems to favor maintaining the inherent productivity of the forest so that it can provide a full range of amenities and commodities for future generations. Emphasis is being placed on ecosystems and especially on ecosystem components and processes. Sometimes, ecosystems need to be nudged a bit. Large burned areas that once were forest, for example, may have no tree seed source, and centuries can pass before a forest becomes established. And areas where tree seeds fall on land already occupied by vigorous plant species constitute another example where scores of years can elapse before the traditional tree species again clothe the land. In these instances, ecosystem processes can be speeded up by manipulating a key component like plant species. Manipulation could be for a variety of reasons: to create a future forest, to provide an economic crop, to grow plants critical to wildlife along with trees, or simply to provide a broad base of species and structures that provide values and commodities that will be needed in the future. In forestry, much knowledge has been generated on economic species such as conifer trees, but little is available on the currently uneconomic hardwoods, shrubs, forbs, and grasses.

What is known is that the growth of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) seedlings can be reduced to a fraction of its potential by competing vegetation, and that dramatic increases have occurred when this vegetation was removed. Results from a "sister" study about 15 miles southeast of this one on a similar site, but with no fog and a less complex plant community, indicated major gains from reducing the amount and size of competing vegetation. Average diameter of Douglas-fir seedlings at 12 inches above mean ground line in the most effective treatment (cut and spray with Garlon 3A) was 137 percent greater relative to the least effective treatment (the control), stem height was 78 percent larger, and foliar cover was 264 percent greater (McDonald and Fiddler 1996).

Results from a more widespread area show a similar trend. 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; 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 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).

To increase knowledge on the ecology of several plant species in a shrub-rich community in a somewhat unique environment characterized by long, hot, dry summers, and morning fog, information was collected on the species composition and developmental potential of vegetation reoccupying a clearcut-harvested and broadcast-burned area in northern coastal California. Data were gathered for vegetation developing naturally after broadcast burning (control) and for vegetation that was manipulated deliberately by several manual and chemical treatments. Planted Douglas-fir seedlings were part of both plant communities.

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 treatments, plant numbers, growth potentials, and costs, provide ecosystem managers with informed 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 northeast of Crescent City, California, and about 9 miles due east of the Pacific Ocean. Before clearcut-harvesting in 1977, the area supported a patchy stand of mature Douglas-fir trees with scattered Port-Orford-cedar (*Chamaecyparis lawsoniana* [A. Murr.] Parl.), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), and western redcedar (*Thuja plicata* Donn ex D.Don). Hardwood species, scattered in a lower stratum as single trees or as small aggregations, were tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.) and a few Pacific madrone (Arbutus menziesii Pursh), and giant chinquapin (*Castanopsis chrysophylla* [Dougl.] A. DC.). Scientific names of tree species are from Little (1979), and for all other vegetation from Hickman (1993). Shade-tolerant shrubs, common in the understory, were California huckleberry (*Vaccinium ovatum* Pursh), red huckleberry (*Vaccinium parvifolium* Smith) and rododendron (*Rhododendron macrophyllum* D.Don). Salal (*Gaultheria shallon* Pursh) and bracken fern (*Pteridium aquilinum* [L.] Kuhn var. *pubescens* L. Underw.) were widely scattered throughout the area. This vegetation assemblage best fits the tanoak series and the tanoak/evergreen huckleberry-Pacific rhododendron association (U.S. Department of Agriculture 1996).

Merchantable conifers and hardwoods larger than 12 inches in breast-height diameter were harvested in summer 1977. Site preparation began in fall 1977 with the felling of all remaining hardwood and conifer stems. These, plus the logging slash, were broadcast-burned in April 1978. The burn was effective, and almost all small material was consumed, leaving a soil surface of mostly mineral soil and scattered burned logs.

The area was planted at an 8- by 8-foot spacing in March 1979 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 tall vexar leader protector. Although a good job of planting was done, survival in the fall of 1980 was 62 percent.

When the study began in 1981, the plant community consisted mostly of species that originated from root crowns and rhizomes in the soil *(fig. 1).* Also

Figure 1

Rapidly growing clumps of hardwoods and shrubs are visible throughout this part of the study area in fall 1983, six growing seasons after site preparation.

Figure 2
Components of the plant community in the study area in fall 1983 included tanoak and hairy manzanita (left side of photo), rhododendron (center) and huckleberries and manzanita (right side).

present were numerous seedlings of hairy manzanita (*Arctostaphylos columbiana* Piper) *(fig. 2)* from dormant seed in the soil, and forbs from windblown seeds such as fireweed (*Epilobium* spp.), *sow* thistle (*Sonchus* spp.), and ragwort (*Senecio* spp.). The most abundant residual forbs were bear-grass (*Xenophyllum tenax* [Pursh] Nutt.) (family Liliaceae) and a tall lily (*Lilium* spp.) No grasses were recorded. In addition to the two species of huckleberries, rhododendron, and salal, other shrub species of lesser size or abundance were Oregon grape (*Berberis* spp.), blue elderberry (*Sambucus mexicana* C. Presl), blackcap raspberry (*Rubus leucodermis* Torrey & A. Gray), thimbleberry (*Rubus parviflorus* Nutt.), cascara (*Rhamnus purshiana* DC.), snowbrush (*Ceanothus velutinus* Hook. var. *hookeri* M. Johnston), and blue blossom (*Ceanothus thyrsiflorus* Eschsch.). Based on the height-age relationship of Douglas-fir, site quality of the study area is medium (McCardle and others 1961). The geology of the area consists of Jurassic sediments with some marine sedimentary deposits. The soil is complex and best described as being deep (2 to 10 feet), reddish in color beneath a dark brown surface layer, and contains only a small percent of rock. Soil texture varies from loam to clay-loam. The suggested soil association is described as Aiken-Skalan-Goldridge. The average elevation of the study is 1,500 feet, slopes vary from 10 to 50 percent, and aspect includes north, south, and east. Precipitation averages at least 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. A temperature-ameliorating influence is fog, which occurs at night and in the morning of 30 to 40 days during the summer of each year.

Study and Design

This study presents data on Douglas-fir seedlings, hardwoods, and shrubs that were collected during 1981-1991. It includes information gathered on plant species developing in the control and after receiving a range of release treatments.

The experimental design was randomized block with four blocks and eight treatments per block. Thus, each treatment was replicated four times. A treatment (plot), which was about one-seventh acre in size, consisted of approximately 14 Douglas-fir seedlings surrounded by two or three rows of buffer (seedlings receiving similar treatment). Treatments and installation dates were:

Manual release (chainsaw and shears)

5-foot radius one time, July 1981,
5-foot radius two times, July 1981, October 1982
5-foot radius three times, July 1981, October 1982, March 1984

Chemical release

2, 4-D, two times, entire plot, April 1981, April 1984

2, 4-D plus Garlon 4, two times, entire plot, April 1981, April 1984

Garlon 4, two times, entire plot, April 1981, April 1984

Manual and chemical release

Chainsaw & 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 one, two and three times from a fixed radius around crop trees.

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 also was mixed with water and diesel oil. Because the chemicals were aimed directly at the competing vegetation, the likelihood of chemical drift was minimal. The Douglas-fir seedlings were not covered during treatment.

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. For all treatments, vegetation was sheared if leaning into the 5-foot radius or designated measurement area.

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.

Sampling

In each plot, 8 to 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 at 12 inches above mean groundline, and total height were measured. The seedlings were checked for injury from chemicals, animals, and insects. Sampling took place in fall 1981, 1984, 1987, and 1991.

Sampling intensity for evaluating other vegetation in all treatments and foliar cover of Douglas-fir 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 (chemical, manual plus chemical, and control), a square 1 milacre (0.001 acre) frame was used. For manually released plots, sampling took place only in the treated radius. 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 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 equaled zero. Statistical significance in all tests was at $\alpha = 0.05$. Data were gathered from

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

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.

Soil moisture tension was measured using a single junction, screen-cage thermocouple psychrometer by a cooperator[2] during early summer-fall of 1982. Data (in atmospheres) were recorded on the 15th of each month from May through October in four treatments (manual release one time, 2,4-D, Garlon 4, and control) in one replication at the 24-inch soil depth.

Internal moisture stress of planted Douglas-fir seedlings, tanoak sprouts, and hairy manzanita seedlings was determined to help explain growth differences that became apparent among treatments early in the study. Internal moisture stress also was denoted for huckleberry, but only in the control. Xylem sap tension was measured with a Scholander pressure chamber (Scholander and others 1965) on August 23, 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 per treatment 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 change while enroute 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 is familiar to foresters and biologists.

Results

In this study, we wished to portray developmental relationships and treatment effects for all species possible. These included tanoak, hairy manzanita, the two huckleberries, rhododendron, and planted Douglas-fir. Information on these species, as well as that on soil moisture and internal plant moisture stress, help explain why the Douglas-fir seedlings survived and developed as they did.

Soil Moisture Tension

To gain insight into the amount of moisture available during the growing season relative to use by shrubs, hardwoods, and Douglas-fir seedlings, soil moisture was quantified.

At the 24-inch depth, soil moisture tension in May was less than one atmosphere in all treatments. In general, it increased through August, peaked in September, and declined in October. Peak tension was highest (7.4 atmospheres) in the control, followed by Garlon 4 (6.2 atmospheres) and 2,4-D (4.1 atmospheres), and was lowest in plots released manually one time (2.1 atmospheres).

Plant Moisture Stress

To gain insight into the potentially ameliorating effect of summer fog on internal water relationships in various plant species during the typical long dry Mediterranean summer, plant moisture stress was quantified in the same replication as soil moisture.

[2] Data from Daniel R. Sendek, Humboldt State University, Arcata, CA. May 1983, on file, Pacific Southwest Research Station, Redding, Calif.

Plant moisture stress of tanoak sprouts was quantified in six of the eight treatments, with manual release three times and cut and spray with Garlon 3A excepted. Of the six treatments, predawn minimums ranged from a low of 4.2 atmospheres in plots manually released two times to 6.5 atmospheres in the manual-release-one-time treatment and control *(fig. 3)*. Internal moisture stress then increased in all treatments (except manual release two times) through the 11:30 a.m. to 1:00 p.m. PST period, peaked at this time with values of 8.3 to 16.5 atmospheres, and then declined to values of 7.0 to 11.8 atmospheres in the 4:20 to 5:00 p.m. period. For the five timespans sampled, plant moisture stress was lowest for tanoak in plots treated by manual release two times and 2,4-D plus Garlon 4, and highest in treatments that were manually released one time and in the control.

Of the seven treatments tested (manual release three times was the exception), predawn minimum moisture stress of hairy manzanita seedlings was lowest in plots treated with Garlon 4 and cut and spray (Garlon 3A) at 3.5 atmospheres and highest in plots that were manually released one time at 7.5 atmospheres *(fig. 3)*. Plant moisture stress then increased in all treatments, peaked between 10:25 a.m. and 3:40 p.m. PST with values that ranged from 11.8 to 21.5 atmospheres, and then declined to values of 6.5 to 17.2 atmospheres in late afternoon. For the five timespans sampled, plant moisture stress was lowest most often for hairy manzanita in plots treated with 2,4-D, and consistently highest in those that were manually released one time.

Plant moisture stress of Douglas-fir also was evaluated in seven of the eight treatments with manual release three times being the exception. Predawn minimum moisture stress of this conifer was lowest in plots treated by cut and spray (Garlon 3A) at 4.5 atmospheres, and highest in counterparts in the control at 12.8 atmospheres *(fig. 3)*. Plant moisture stress then increased in all treatments, peaked between 10:00 a.m. and 3:45 p.m. PST with values that ranged from 16.7 to 23.2 atmospheres, and then declined to values of 12.5 to 19.5 atmospheres in late afternoon. For the five timespans sampled, plant moisture stress was lowest most often for Douglas-fir in plots treated by cut and spray (Garlon 3A), and highest most often for this conifer in the control.

Internal moisture stress of the huckleberries was quantified only in the control, where it registered 4.8 atmospheres of stress at 6:00 a.m. PST, reached 17.0 atmospheres at peak (12:01 p.m.), and declined to 14.8 atmospheres at 4:40 p.m. PST.

Plant Diversity

In addition to the planted Douglas-fir seedlings, the natural plant community near the beginning of the study consisted of 2 species of conifers, 3 species of hardwoods, 12 shrubs, 10 forbs, 1 fern, and no grasses for a total of 28 species *(table 1)*. After 10 years, the community consisted of no naturally established conifer seedlings, the same 3 species of hardwoods, 3 more species of shrubs, 6, less species of forbs, and no grass for a total of 23 species. Two hardwood species (Pacific madrone, giant chinquapin), 2 forb species (vetch, unknown), and 8 species of shrubs (blackcap raspberry, blue blossom, cascara, coyotebrush, deerbrush, Oregon grape, rose, and thimbleberry) were scarce in the study area.

Tanoak

Although harvesting and site preparation removed many above-ground tanoak stems, a host of root crowns remained at or just below the soil surface. After cutting and burning, many stumps or burned root crowns sprouted, and by 1981 tanoak clumps in the control averaged 950 per acre with foliar cover of 2,500 ft^2 per acre and an average height of 3.8 feet *(table 2). By* the end of the study in 1991, tanoak clump density had increased by 5 percent to 1,000 per acre, mean foliar cover increased by 191 percent to 7,267 ft^2 per acre, and average height had increased by 197 percent to 11.3 feet.

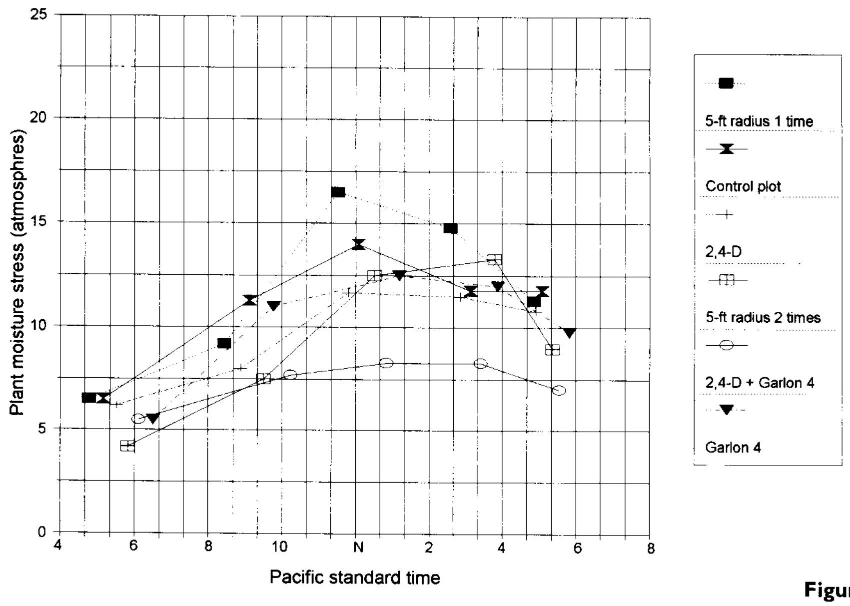

Figure 3
Diurnal trend of internal moisture stress by treatment on August 25, 1984 in (A) tanoak sprouts, (B) hairy manzanita seedlings, and (C) planted Douglas-fir seedlings. Standard errors applicable to differences between treatments could not be estimated.

Figure 3 A

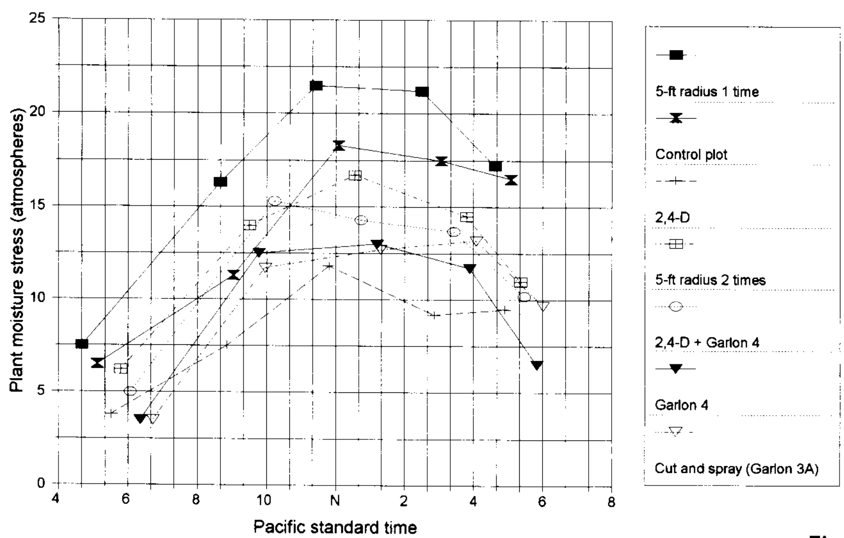

Figure 3 B

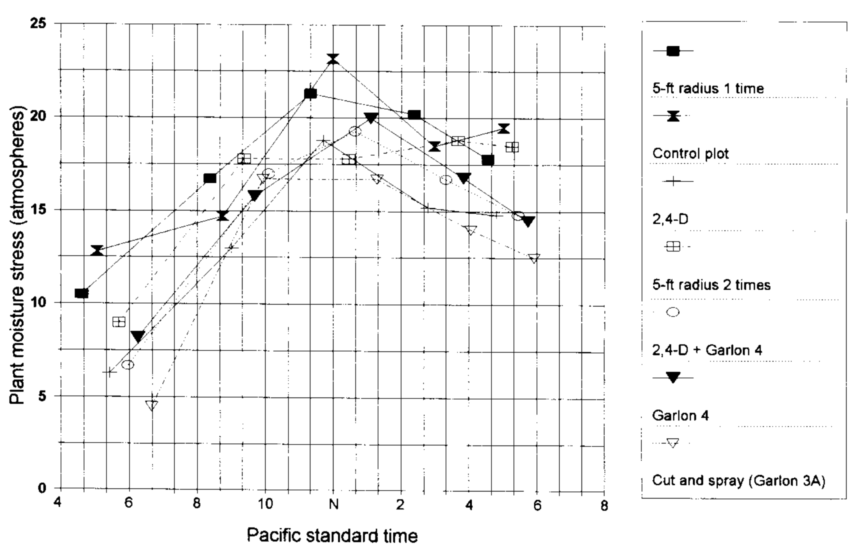

Figure 3 C

On treated plots in 1991, tanoak density ranged from 148 to 1,146 plants per acre, foliar cover from 800 to 7,267 ft^2 per acre, and height from 6.5 to 11.3 feet *(table 3)*. Although tanoak clumps were taller and wider in the control, no statistical differences were found.

Hairy Manzanita

Typical of disturbance-enhanced *Arctostaphylos* species, hairy manzanita produced thousands of seedlings from dormant seeds in the soil. In fall 1981, density of this manzanita in the control averaged 8,350 plants per acre with 6,100 ft^2 of foliar cover and 2.7 feet of height *(table 2)*. By fall 1991, average plant density in the control had decreased 66 percent to 2,800 plants per acre and mean foliar cover had decreased by 6 percent, to 5,733 ft^2 per acre, but mean height had increased 167 percent to 7.2 feet.

On treated plots in fall 1991, density of hairy manzanita ranged from 333 plants per acre in plots treated by 2,4-D and cut and spray (Garlon 3A) to over 5,600 plants per acre in plots that were manually released one and two times *(table 3)*. However, these differences were not statistically significant at the 5 percent level. In terms of foliar cover, plants in plots treated with 2,4-D, 2,4-D +

***Table 1**-Natural vegetation in study plots, Signal Plantation, Six Rivers National Forest, California, 1982-1991*

Common name	1982	1991
Conifers		
Douglas-fir	X	-
Western hemlock	X	-
Hardwoods		
Tanoak	X	X
Pacific madrone	X	X
Giant chinquapin	X	X
Shrubs		
Elderberry	X	X
Rhododendron	X	X
Salal	X	X
California huckleberry	X	X
Red huckleberry	X	X
Blackcap raspberry	X	X
Thimbleberry	X	X
Cascara	X	X
Deerbrush		X
Coyotebrush	-	X
Oregon grape	X	X
Snowbrush	X	X
Blue blossom	X	X
Rose	-	X
Hairy manzanita	X	X
Forbs		
Beargrass	X	X
Fireweed	X	-
Vetch	X	X
Groundsel	X	-
Ragwort	X	-
Lily	X	X
Sow thistle	X	-
Hawkweed	X	-
Unknown	X	X
Unknown	X	-
Fern		
Bracken fern	X	X
Total	28	23

Garlon 4, and cut and spray with Garlon 3A averaged significantly less cover than counterparts on plots that were manually released one and two times. Foliar cover of plants treated with the ester form of Garlon (Garlon 4) or manually cut three times did not differ significantly from plants in the control. Manzanita height ranged from 4.2 feet in plots treated with 2,4-D to 7.2 feet in the control, but did not differ significantly among treatments.

Huckleberries

These shade-enduring species were well distributed throughout the study area, had relatively low density and cover values, and indicated no statistical differences among treatments. Originating mostly from below-ground organs,

***Table 2**-Average density, cover, and height, with standard errors (SE), of tanoak, hairy manzanita, huckleberries, rhododendron, and combined shrubs in the control, 1981-1991*

Year	Density	SE	Cover	SE	Height	SE
	Plants/acre		*Ft^2/acre*		*Ft*	
Tanoak						
1981	950	320	2,500	1,323	3.8	0.5
1984	1,050	395	5,150	1,731	6.3	1.0
1987	1,100	404	4,600	1,169	7.8	1.1
1991	1,000	503	7,267	1,967	11.3	1.6
Difference[1] (pct)	+5		+191		+197	
Hairy Manzanita						
1981	8,350	1,323	6,100	2,255	2.7	0.5
1984	7,400	1,556	9,800	2,895	4.3	0.6
1987	5,700	1,601	14,050	3,198	6.0	0.8
1991	2,800	1,039	5,733	3,291	7.2	1.0
Difference[1] (pct)	-66		-6		+167	
Huckleberries						
1981	450	96	750	150	2.7	0.2
1984	950	492	1,350	568	3.6	0.1
1987	750	419	1,550	457	4.3	0.6
1991	933	353	933	481	5.0	0.3
Difference[1] (pct)	+107		+24		+85	
Rhododendron						
1981	300	173	800	408	2.4	0.3
1984	450	320	1,400	683	3.0	0.1
1987	400	271	1,250	585	3.9	0.3
1991	600	416	1,800	1,102	5.2	0.8
Difference[1] (pct)	+100		+122		+116	
Combined Shrubs						
1981	9,300	1,248	8,000	2,020	2.8	0.5
1984	9,050	1,791	12,850	1,773	4.3	0.4
1987	7,100	1,865	19,150	3,113	5.9	0.9
1991	4,733	1,618	16,800	4,084	9.5	2.4
Difference[1] (pct)	-49		+110		+239	

[1]Difference between 1981 and 1991 values expressed as a percent increase or decrease.

they increased in number and size in the control, however. From 1981 to 1991, mean density increased by 107 percent from 450 to 933 plants per acre, foliar cover by 24 percent from 750 to 933 ft2 per acre, and height by 85 percent from 2.7 to 5.0 feet *(table 2)*.

On treated plots, huckleberry density ranged from 133 to 1,333 plants per acre, foliar cover from 0 to 1,733 ft^2 per acre, and height from 1.3 to 5.3 feet *(table 3)*.

Rhododendron

Density and development of this evergreen, shade-enduring species was much like that of the huckleberries. It also originated from belowground organs. In the control, mean plant density, foliar cover, and height all increased during the study: density by 100 percent from 300 to 600 plants per acre, foliar cover by 122 percent from 800 to 1,800 ft^2 per acre, and height by 116 percent from 2.4 to 5.2 feet *(table 2)*.

In the various treatments, low density was characteristic of rhododendron. Mean density varied from 111 to 702 plants per acre *(table 3),* foliar cover from 111 to 2,366 ft^2 per acre, and mean height from 3.3 to 5.6 feet. No significant differences were found among treatments for this species.

Combined Shrubs

This category includes species that had the tallest and most numerous plants. It consisted of the two species of huckleberries, hairy manzanita and rhododendron, plus two others (snowbrush and elderberry), that were so poorly distributed that they could not be presented individually.

In fall 1981, density of combined shrubs in the control averaged 9,300 plants per acre with 8,000 ft^2 of foliar cover and 2.8 feet of height *(table 2).* By fall 1991, density had decreased 49 percent, but cover and height had increased 110 and 239 percent, respectively.

Among treatments in 1991, the highest density of combined shrubs was recorded on plots that were manually released one and two times (7,172 and 7,578 plants per acre) and the lowest was on plots treated with herbicides and those manually released three times (867 to 3,400 plants per acre) *(table 3).* However, no differences were statistically significant. For foliar cover, the highest values occurred on plots manually released one and two times (20,701 and 24,176 ft^2 per acre), and the lowest on plots treated with 2,4-D and the Garlon compounds (2,133 to 7,000 ft^2 per acre). Some of these relationships were statistically significant *(table 3)*. Average height of combined shrubs ranged from 9.5 feet in the control to 2.8 feet in plots treated with 2,4-D + Garlon 4, but no differences were statistically significant.

Salal

The relatively small plants of salal were inconspicuous relative to the other much taller shrubs, and were not sampled until 1991. In this study, salal was relegated to the lowermost stratum of the understory. Here it persisted with slender upright stems and large leaves in almost total shade. Among the various treatments, average density ranged from more than 6,000 to 17,700 stems per acre *(table 4)*, foliar cover from 0 to more than 1,180 ft^2 per acre, and height from 0.4 to 2.6 feet. No significant differences among treatments were found.

Douglas-fir

As noted earlier, survival of Douglas-fir seedlings in fall 1980 was 62 percent. Mortality had occurred in all treatments with slightly more in the control and in plots manually released one time. After we began the study, mortality continued with 1 seedling noted as dead in 1982, 1 in 1983, 5 in 1987, and 27 in 1991. Mortality appeared to be unrelated to treatment, with death attributed to the general effects of competition.

***Table 3**-Average density, cover, and height of tanoak, hairy manzanita, huckleberries, rhododendron, and combined shrubs in treated and control plots, Six Rivers National Forest, 1991*

Treatment	Density	Cover	Height
	Plants/acre	*Ft^2/acre*	*Ft*
Tanoak			
Manual			
5-ft radius one time	148 a[1]	1,109 a	7.2 a
5-ft radius two times	739 ab	4,547 a	8.6 a
5-ft radius three time	1,146 b	5,286 a	8.9 a
Chemical			
2,4-D	267 ab	2,200 a	6.5 a
2,4-D + Garlon 4	600 ab	800 a	7.5 a
Garlon 4	533 ab	1,133 a	6.5 a
Manual and chemical			
Cut and spray (Garlon 3A)	400 ab	1,533 a	8.3 a
Control	1,000 ab	7,267 a	11.3 a
Standard error	199	1,348	1.5
Hairy Manzanita			
Manual			
5-ft radius one time	5,915 a	17,892 b	6.5 a
5-ft radius two times	5,619 a	16,931 b	7.0 a
5-ft radius three times	1,553 a	5,804 ab	6.4 a
Chemical			
2,4-D	333 a	600 a	4.2 a
2,4-D + Garlon 4	733 a	1,333 a	4.6 a
Garlon 4	1,933 a	5,933 ab	6.1 a
Manual and chemical			
Cut and spray (Garlon 3A)	333 a	800 a	4.3 a
Control	2,800 a	5,733 ab	7.2 a
Standard error	1,290	2,785	0.9
Huckleberries			
Manual			
5-ft radius one time	628 a	444 a	3.3 a
5-ft radius two times	1,035 a	518 a	3.5 a
5-ft radius three times	739 a	111 a	2.9 a
Chemical			
2,4-D	1,333 a	1,733 a	5.3 a
2,4-D + Garlon 4	1,000 a	267 a	1.3 a
Garlon 4	1,200 a	733 a	3.2 a
Manual and chemical			
Cut and spray (Garlon 3A)	133 a	0 a	2.2 a
Control	933 a	933 a	5.0 a
Standard error	442	607	0.8
Rhododendron			
Manual			
5-ft radius one time	628 a	2,366 a	4.8 a
5-ft radius two times	702 a	1,183 a	5.0 a
5-ft radius three times	111 a	111 a	5.6 a
Chemical			
2,4-D	333 a	267 a	3.4 a
2,4-D + Garlon 4	267 a	533 a	3.3 a
Garlon 4	267 a	333 a	4.2 a
Manual and chemical			
Cut and spray (Garlon 3A)	200 a	400 a	3.8 a
Control	600 a	1,800 a	5.2 a
Standard error	179	680	0.3
Combined Shrubs			
Manual			
5-ft radius one time	7,172 a	20,701 c	5.6 a
5-ft radius two times	7,578 a	24,176 c	6.5 a
5-ft radius three times	2,403 a	6,026 ab	5.2 a
Chemical			
2,4-D	2,000 a	2,600 a	5.5 a
2,4-D + Garlon 4	2,000 a	2,133 a	2.8 a
Garlon 4	3,400 a	7,000 ab	5.5 a
Manual and chemical			
Cut and spray (Garlon 3A)	867 a	2,533 a	6.4 a
Control	4,733 a	16,800 bc	9.5 a
Standard error	1,468	3,135	2.7

[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.

Damage to Douglas-fir seedlings was noted only if the terminal shoot and bud were killed. It occurred throughout the study period and consisted of 3 seedlings that had been browsed and 23 seedlings whose tops had died for unknown reasons. Damage appeared to be independent of treatment or year of occurrence. However, in almost every instance, the seedlings developed a new top and were alive at the end of the study.

By 1984, horizontal and vertical development of Douglas-fir seedlings was beginning to differ among treatments, especially on plots treated with chemicals versus those manually released one time and in the control *(fig. 4).* Statistically

Table 4-*Average density, cover, and height of salal in treated and control plots, Six Rivers National Forest, 1991*

Treatment	Density	Cover	Height
	Plants/acre	*Ft^2/acre*	*Ft*
Manual			
5-ft radius one time	14,694 a[1]	333 a	0.8 a
5-ft radius two times	11,497 a	1,183 a	1.9 a
5-ft radius three times	6,155 a	1,054 a	2.6 a
Chemical			
2,4-D	11,867 a	333 a	1.6 a
2,4-D + Garlon 4	17,700 a	400 a	0.5 a
Garlon 4	15,000 a	0 a	1.0 a
Manual and chemical			
Cut and spray (Garlon 3A)	6,400 a	0 a	0.4 a
Control	8,133 a	400 a	2.6 a
Standard error	9,867	375	0.9

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

Figure 4

A difference in growth between Douglas-fir seedlings in the Garlon 4 treatment (A) and the manual-release, one-time treatment (B) was visible in fall 1983.

Figure 4A

Figure 4B

significant differences among treatments for Douglas-fir were first realized in 1987 when mean foliar cover of seedlings in plots treated with 2,4-D was significantly greater than for counterparts in plots manually released one time *(table 5).* By 1991, seedlings in all chemical treatments had significantly more foliar cover than in plots released one time and in the control. The difference was striking--29,133 to 37,750 ft^2 per acre vs 10,831 to 11,467 ft^2 per acre, or two to three times more cover. Significant differences in stem diameter of Douglas-fir were not found until 1991 when seedlings in plots treated by cut and spray (Garlon 3A) had a significantly larger average diameter at one foot of height than counterparts in the control (4.2 vs 2.4 inches) *(table 5).* No significant difference among treatments was found for stem height during the study. Overall, the consistently poorest treatments for enhancing Douglas-fir development were manual release one time and the control.

Production and Cost

Manually cutting vegetation in a 5-foot radius around Douglas-fir seedlings was expensive, even if done only once. And manually cutting a 5-foot radii around Douglas-fir seedlings two and three times was even more expensive. Chain-sawing hardwood and shrub sprouts and treating the freshly cut surfaces with Garlon 3A twice, also was costly. Applying foliar sprays with chemicals was the least expensive:

Treatment	*Production rate*	*Cost*
	Laborer hours/acre	*Dollars/acre*
Manual release (chainsaw and shears)		
5-foot radius, 1 time	36.0	315
5-foot radius, 2 times	51.0	446
5-foot radius, 3 times	59.6	521
Chemical release		
2,4-D, 2 times, entire plot	6.5	67
2,4-D plus Garlon 4, 2 times, entire plot	6.5	67
Garlon 4, 2 times, entire plot	6.5	67
Manual and chemical release		
Cut + Garlon 3A, 2 times, entire plot	39.6	346

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

Soil moisture tension in the four treatments tested, especially at the 24-inch depth, was low through June 15 and then increased rapidly through August 15 as plant roots and evaporation depleted the moisture in the soil. Tension peaked September 15, and then declined through October 15, probably because of a combination of upward moving water in the soil, fall rain, and less transpirational and evaporative demand.

For internal plant moisture stress and its precursor--soil moisture--the limiting environmental factor in most of California, predawn minimum values and peak maximum values are useful for indicating differences among treatments and species (tanoak, hairy manzanita, and Douglas-fir). Treatments with a large amount of vegetation (control and 5-foot radius one time, for example) had the highest predawn and peak moisture stress, and those treatments with the least vegetation (chemicals) in general had the lowest predawn and peak moisture stress. For the three species tested, the highest predawn value was for Douglas-fir,

***Table 5**—Average stem diameter, height, and foliar cover of Douglas fir seedlings, by treatment, Six Rivers National Forest, 1981-1991*

Treatment	1981	1984	1987	1991
			Diameter *(inches)*	
Manual				
5-ft radius one time	0.45 a[1]	0.99 a	1.85 a	2.89 ab
5-ft radius two times	0.41 a	1.00 a	2.00 a	3.33 ab
5-ft radius three times	0.49 a	1.14 a	2.29 a	3.88 at
Chemical				
2,4-D	0.40 a	0.96 a	2.10 a	4.00 at
2,4-D + Garlon 4	0.39 a	0.80 a	1.90 a	3.46 ab
Garlon 4	0.43 a	1.00 a	2.11 a	3.74 ab
Manual and chemical				
Cut and spray (Garlon 3A)	0.34 a	0.90 a	2.17 a	4.18 b
Control	0.47 a	0.93 a	1.50 a	2.38 a
Standard error	0.04	0.10	0.21	0.34
			Height *(feet)*	
Manual				
5-ft radius one time	2.21 a	4.51 a	8.61 a	14.34 a
5-ft radius two times	1.50 a	4.74 a	9.51 a	16.96 a
5-ft radius three times	2.25 a	5.11 a	10.72 a	19.07 a
Chemical				
2,4-D	1.80 a	4.89 a	9.86 a	18.66 a
2,4-D +Garlon 4	1.77 a	3.79 a	8.25 a	14.70 a
Garlon 4	2.14 a	4.82 a	9.68 a	17.30 a
Manual and chemical				
Cut and spray (Garlon 3A)	1.82 a	3.88 a	8.96 a	17.24 a
Control	2.52 a	5.30 a	9.00 a	14.42 a
Standard error	0.35	0.71	0.97	2.04
			Cover *(ft^2 / acre)*	
Manual				
5-ft radius one time	111 a	1,747 a	5,295 a	10,831 a
5-ft radius two times	305 a	2,911 a	8,012 ab	12,790 ac
5-ft radius three times	111 a	2,967 a	9,482 ab	28,132 bc
Chemical				
2,4-D	200 a	3,500 a	18,950 b	34,800 b
2,4-D + Garlon 4	150 a	3,050 a	14,000 ab	29,133 b
Garlon 4	1,300 a	4,950 a	16,000 ab	37,750 b
Manual and chemical				
Cut and spray (Garlon 3A)	-	2,650 a	15,600 ab	33,867 b
Control	750 a	3,950 a	8,450 ab	11,467 a
Standard error	447	872	2,383	3,123

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

followed by tanoak, and hairy manzanita. For maximum moisture stress, the highest value was for Douglas-fir, hairy manzanita, and tanoak.

The diameter growth values in *table 5* and the plant moisture stress curves in *figure 3* show that the most-- and least--effective treatments for Douglas-fir seedlings were cut and spray with Garlon 3A, and control, respectively. Given that photosynthesis begins to decrease in Douglas-fir seedlings at 8 atmospheres (Cleary 1971), seedlings treated by cut and spray with Garlon 3A maintained a positive carbon balance for at least an hour early in the morning, but seedlings in the control were unable to do so. This one-hour difference could be important as it constituted an energy input rather than a drain. Furthermore, seedlings in the control had to endure many more hours at a higher level of moisture stress than were counterparts in the cut and spray plots.

Fertile soil, mild temperatures, and copious precipitation combined to make the vegetation in this study the most dynamic that we have encountered in the 42 studies in our vegetation management research program. Altogether, the 18 species of hardwoods and shrubs formed a dense mass of developing vegetation that so occupied the site and so captured the available resources, that little opportunity existed for additional species, especially forbs and grasses, to become established. The few forbs that did invade the area were present only as individuals and in small aggregations for a short time. The two most abundant forbs, present at the end of the study, were bear-grass and a tall lily. Bear-grass, which is not a grass at all, but a vigorous forb that arises from woody, tuber-like rhizomes, produces a tall flowering stalk every 3 to 7 years. Like most lilies, the one in this study also originates from a large bulb. These forbs persisted because of their ability to develop from large below-ground structures that had sufficient energy to produce stems that were tall enough to compete with the shrubs. Opportunistic bracken fern developed well in scattered areas, particularly where the shrubs had been reduced in density and size by chemicals.

When the study began, we noted 28 species; when it ended, we found only 23 species. This number is low relative to that found in other studies (17 to 46 species) in our National Administrative Study Program in young conifer plantations (McDonald and Fiddler 1993, 1997).

The developmental trajectories of the vegetation in this study indicated the critical need to grow as tall as possible, as fast as possible. Fueled by the energy stored in the root crowns and root systems of parent plants, and stimulated by cutting and broadcast burning, dormant buds quickly produced numerous sprouts. These grew rapidly in height and width. Vertical development of hardwoods, shrubs, ferns, and forbs was more than 2 feet when the study began, with large and consistent increases thereafter. By the end of the study, no species was less than 5 feet tall, and blue blossom and snowbrush were over 30 feet tall. In places, bracken fern reached 5 feet in height, and even vetch adopted a tall and skinny form.

By the end of the study, much of the soil surface was covered with vegetation. In fall 1981 or after the first year of study, horizontal development of the shrubs and tanoak in the control totaled 10,500 ft^2 per acre and that of Douglas-fir 750 ft^2 per acre. At the end of the study, the foliar cover of tanoak averaged 2,293 ft^2 per acre, the shrubs 16,800 ft^2, and Douglas-fir 11,467 ft^2 per acre. Foliar cover of salal added another 400 ft^2 per acre, for a combined total of 30,960 ft^2 per acre. This equates to 71 percent of each acre being cast in solid shadow, independent of the additional cover provided by the rare and poorly distributed species.

Unlike the developmental pattern of the hardwoods and shrubs in the control of the "sister" study 15 miles away, where just two species (tanoak and snowbrush) dominated the plant community at the end of the study, the pattern in this study was one of no clear dominance pattern, but excellence in density, or cover, or height by several species. Competition to Douglas-fir seedlings was not by one or two species, but by most of them together.

Although Douglas-fir seedlings in the control were impacted by heavy competition and lower available soil moisture, their development was still 20 percent taller than their tallest rival (tanoak). Thus, the consequence of the competing vegetation was not so much the danger of overtopping Douglas-fir, but more a slowdown in its total development, especially of foliar cover. When foliar cover of Douglas-fir at the end of the study in each treatment was compared to that in the most effective treatment (Garlon 4), the relative proportion (in percent) was:

5-ft radius one time	29
5-ft radius two times	34
5-ft radius three times	75
2,4-D	92
2,4-D + Garlon 4	77
Cut and spray (Garlon 3A)	90
Control	30

Plainly, foliar cover of Douglas-fir seedlings was much poorer in the less-frequent radius treatments and in the control.

In contrast to these ineffective treatments, the growth of Douglas-fir seedlings in 1991 in the most effective treatments (for diameter, cut and spray with Garlon 3A; for height, 5-ft radius 3 times; and foliar cover, Garlon 4) was characterized by robust diameter (4.18 inches), tall trees (19.07 feet), and well developed crowns (37,750 ft^2 per acre). The odds are for continued rapid growth in these treatments.

The cost and production data reflect the capability of the many fast-growing sprout stems of the hardwoods and shrubs in this study, Their dynamic nature mandated that they be treated at least two times. 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 below-ground structures developed rapidly after the first release, but less rapidly after successive treatments because of competition from Douglas-fir. However with time, more vegetation leaned into the plots and had to be clipped. 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 for treatments with manual release and the highest costs in the study. For chemical release, the retreatment cost was about equal to that of the initial cost because the amount and size of vegetation was about the same.

A continuing objective of the National Administrative Study Program on vegetation management is to determine the timing of treatment effectiveness. Based on results from the many studies in this program, some trends are emerging. In general, the faster the occurrence of a statistically significant difference in conifer seedling growth between a treatment and the control, the more effective the treatment. Lack of an early statistical difference occurs when the vegetation in an ineffective treatment slows the growth of the conifer seedlings relative to their counterparts in the control. When competition is controlled, stem diameter usually is the first conifer variable to differ significantly. In this study, however, foliar cover of Douglas-fir seedlings in the most effective treatment in 1987 (2,4-D) versus the least significant treatment (5-foot radius, one time) became significant first. Achieving significance in fall 1987, or nine growing seasons after planting, is late relative to other studies in our vegetation management study program. This was because of the effective competition present even in the best treatment.

Doing a good job of site preparation and then believing that sufficient conifer seedling growth will result is not realistic. Release is needed. Site preparation also is needed. Stein (1995) noted that certain site preparation treatments, particularly those involving broadcast burning and herbicides, significantly enhanced Douglas-fir seedling growth for the first 10 years in Oregon Coast Range plantations. The early survival of Douglas-fir seedlings in this study, including that in the control, was probably due to site preparation.

A primary goal of vegetation management is to manipulate the plant community to alter the trajectory of its succession. 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 *(fig. 5)*, usually when competing species are absent or developing poorly. In this study, however, almost all species that were present at the end of the study were developing well. Where the Douglas-fir seedlings were growing well, the competing vegetation was growing well, albeit with lesser numbers and perhaps with a bias toward the most shade-tolerant species. Where the Douglas-fir seedlings were growing poorly, the competing vegetation was also growing well, albeit with a slight bias toward higher numbers of slightly larger plants. Thus for the next several decades, the composition of the plant community is not likely to change very much. Regardless of treatment, secondary succession during this period will be manifest in different numbers and sizes of the same species.

With time, however, the increasing size of the Douglas-fir trees and their capability to capture light, soil moisture, and nutrients, will influence the plant

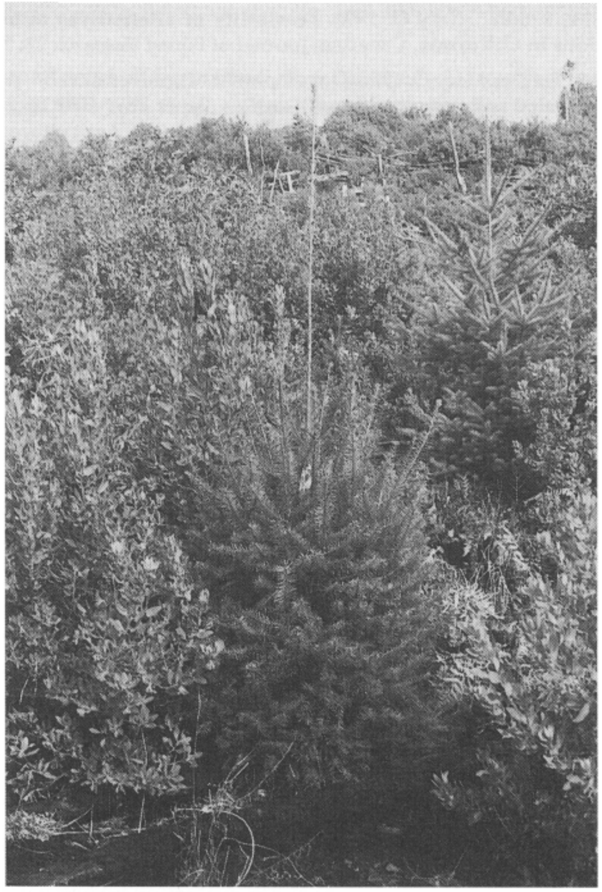

Figure 5
Reducing competition in the highly competitive plant community of this study allowed Douglas-fir seedlings to establish their root systems and begin to grow rapidly.

community. Certainly the larger firs will negatively affect the development and eventually the species composition of plants in the understory before their slower-growing counterparts.

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

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