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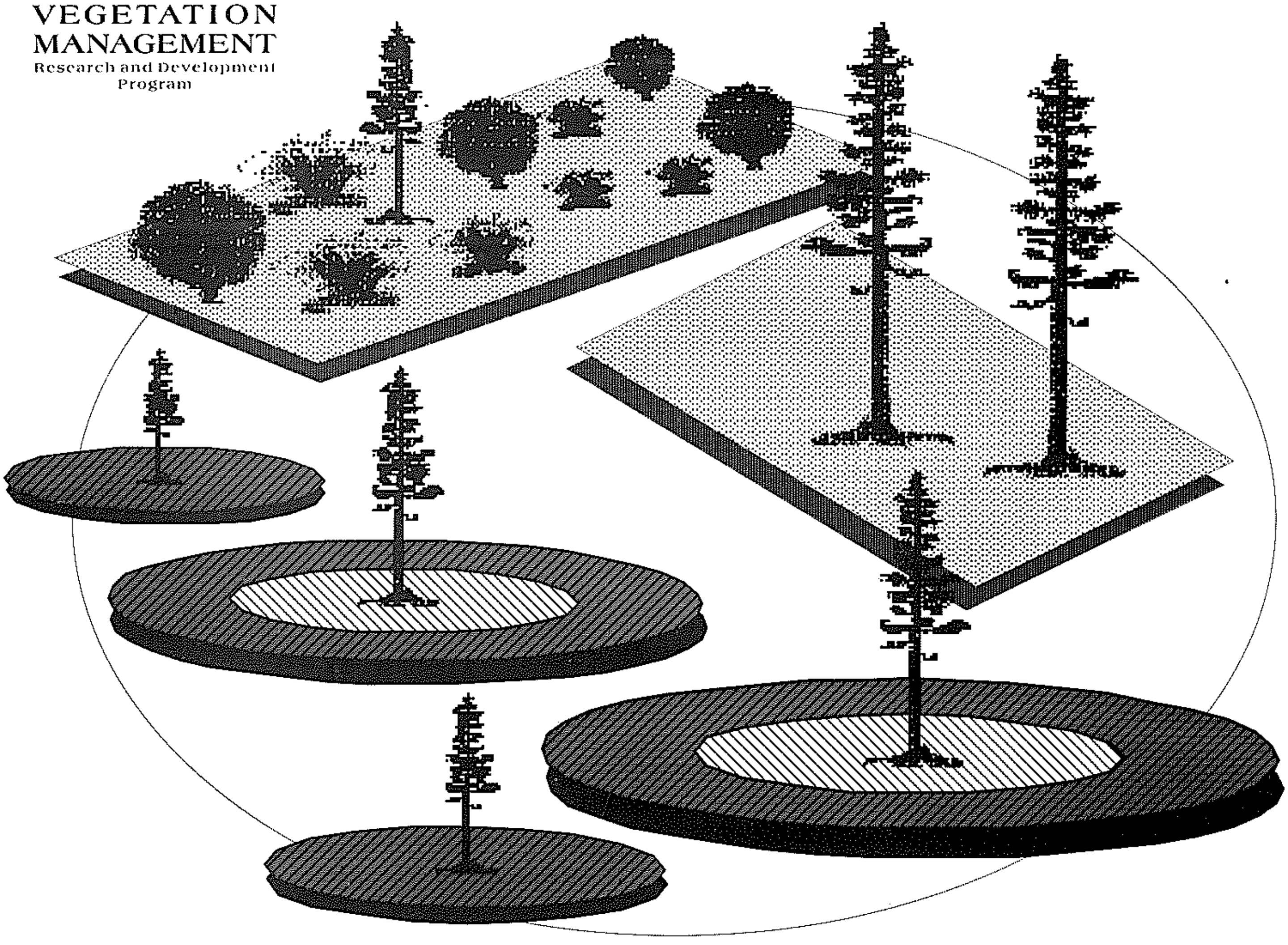
# Ponderosa Pine Seedlings and Competing Vegetation: Ecology, Growth, and Cost

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



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Foresters often need information on the cost effectiveness of manual and chemical release treatments for individual and combined species in young mixed-shrub communities. A study in northern California evaluated five manual and chemical treatments and their effect on several shrubs and grasses. Treatments were grubbing at age 1 to 2- and 4-ft (0.6- and 1.2-m) radii, regrubbing and expanding the 2-ft radii to 4 ft, regrubbing and expanding the 4-ft radii to 6 ft (1.8 m) at age 4, and applying Velpar herbicide to the entire plot at age 2. Five years after initial manual release and 4 years after chemical release, ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) stem caliper at 12 in. (30 cm) above mean ground line differed significantly between Velpar and the untreated control, 2-ft radius, 4-ft radius, and 2-ft radius expanded to 4 ft. Expanding the radius from 4 to 6 feet provided a pine stem caliper that differed significantly from that in the control, and the 2-ft and 4-ft radii treatments. Additional analyses with ponderosa pine seedling height also indicated significant differences among treatments that were generally similar to those above. Differences among the six treatments, which are presented in 15 comparisons of stem caliper and treatment production rates, provide forest managers with growth and cost comparisons, and should aid them in selecting the release treatment best suited to their particular situation.

*Retrieval Terms*: vegetation management, regeneration, manzanita, ponderosa pine, manual and chemical treatments, Shasta-Trinity National Forests, California

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# IN BRIEF . . .

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When foresters contemplate releasing young conifer plantations, they often ask: What is the most effective treatment and how cost effective is it? A related question usually follows: When is the best time to apply the treatment? The central theme of the study reported here, which is one of many in a National Forest Service Administrative Study on vegetation management, addresses these questions.

A 1-year-old ponderosa pine plantation on the Shasta-Trinity National Forests in northern California was released from mixed shrubs and grasses by several manual and chemical techniques. Around selected seedlings a 2-ft (0.6-m) radius was grubbed, and around others a 4-ft (1.2-m) radius. At age 4, half of the 2-ft radii were regrubbed and expanded to 4-ft radii, and half of the 4-ft radii were regrubbed and expanded to 6-ft (1.8-m) radii. Other areas were treated with Velpar herbicide at age 2.

Two years after Velpar was applied, stem caliper and height of ponderosa pines in this treatment differed at the 5 percent level from counterparts in the least intensive treatments (control, 2-ft, 4-ft, and 2-ft expanded radii)—the first time that a significant difference among treatments was noted. Five years after initial manual release and 4 years after chemical release, ponderosa pine stem caliper at 12 in. (30 cm) above mean ground line differed significantly between the Velpar treatment (1.70 in. or 4.32 cm) and the untreated control (0.88 in. or 2.23 cm), 2-ft radius (0.90 in. or 2.29 cm), 4-ft radius (0.90 in. or 2.29 cm), and 2-ft radius expanded to 4-ft (1.10 in. or 2.79 cm). The 4-ft radius expanded to 6 ft (1.43 in. or 3.63 cm) differed significantly from the control, 2-ft, and 4-ft radii. Additional analyses, which compared internal plant moisture stress and needle length among treatments, showed similar results and reinforced the finding that the two most intensive treatments (4-ft radius expanded to 6 ft, Velpar) were the most effective. Comparing ratios of pine height to pine caliper showed that stem caliper in the Velpar treatment was expanding faster relative to height than in other treatments.

The cost of applying the treatments ranged from $38 to $578 per acre ($94 to $1428/ha). Expanding a 4-ft radius to 6 ft was the most expensive treatment; spraying with Velpar was the least expensive. Velpar was the most cost-effective treatment. Grubbing small radii (4.0 ft or 1.2 m or less) around ponderosa pine seedlings did not appear to be effective biologically and was expensive. New plants, sprouts, and "edge" plants apparently usurped critical resources in the cleared area, and lowered the productivity of pine seedlings. Applying treatments at an early age led to statistically significant differences among treatments earlier than in other studies, and suggested the worth of treating competing vegetation as soon as possible.

# INTRODUCTION

Harvesting a timber stand sets in motion a sequence of events that greatly influences subsequent vegetation and, therefore, establishment of a productive forest of desired species. On an area in northern California where a natural stand of ponderosa pine *(Pinus ponderosa* Dougl. ex Laws. var. *ponderosa)* was seared by wildfire and then harvested by clearcutting, mixed shrubs and grasses were treated by manual and chemical methods. The mixed-shrub stand consisted of greenleaf manzanita *(Arctostaphylos patula* Greene), Sierra chinkapin *(Castanopsis sempervirens* [Kell.] Dudl.), and snowbrush *(Ceanothus velutinus* Dougl. ex Hook.), and native perennial grasses rescuegrass *(Bromus catharticus* Vahl.) and California needlegrass *(Stipa californica* Merr. & Davy).

To increase existing knowledge on the ecology of this large and increasing plant community, information was collected on growth dynamics and competitive relationships of these shrubs and grasses, as well as on young pine seedlings. The study was part of a National Forest Service Administrative Study on alternative release methods begun in 1980 in northern California (Fiddler and McDonald 1984). Total study length is planned for 10 years.

This paper reports results on the effectiveness, timing, and cost of various manual and chemical release treatments on the Shasta-Trinity National Forests in northern California, from 1981 to 1985. It suggests that managers can match the growth response of conifer seedlings to the treatment best suited to their particular goals and budget.

# STUDY LOCATION AND ENVIRONMENT

The study area, located on the McCloud Ranger District of the Shasta-Trinity National Forests, is about 6 miles (9.7 km) northeast of McCloud, California. Before harvest, the study site supported a young-mature forest of several species and age classes. The most abundant species was California white fir *(Abies concolor* var. *lowiana* [Gord.] Lemm.) with scattered ponderosa pines, Jeffrey pines *(Pinus jeffreyi* Grev. & Balf.), and incense-cedars *(Libocedrus decurrens* Torr.) in the overstory, which numbered about 25 trees per acre (62/ha). Groups of trees and single trees of intermediate and immature ages were scattered throughout. The understory consisted of a dense stand of mature shrubs of mostly greenleaf manzanita, followed by Sierra chinkapin, and snowbrush. Bitter cherry *(Prunus emarginata* [Dougl.] Walp.) and snowberry *(Symphoricarpos* spp.) were occasional shrubs. Forbs and grasses were few, small, and scattered in the dense stand of trees and shrubs.

Observations of blackened bark, firescars, and burned stumps in stands adjacent to the study area suggested numerous wildfires in the past, although with decreasing frequency in recent decades. Frequent wildfire often leads to stands of sprouting shrubs, rapid sprout growth, and a tendency for high seed production (Gratkowski 1961, Keeley 1977). Viable seeds of *Arctostaphylos* and *Ceanothus* species would likely be present in the upper soil layers in large numbers.

After harvest in 1978, slash and woody shrubs were pushed into windrows with a brushrake-equipped bulldozer and burned in fall 1979. Almost no shrub root crowns remained and soil disturbance was minor. By 1981, the windrows could scarcely be seen.

Ponderosa pine seedlings from a local seed source were raised in a Medford, Oregon, nursery and hand planted as 1-year-old bare-root stock in auger-prepared holes in May 1980. Spacing was 8 by 12 ft (2.4 by 3.7 m) with a density of about 400 seedlings per acre (988/ha). The planting job was judged as good, and the area was virtually free of competing vegetation. Survival at the end of the first growing season in 1980 was 90 percent—a reflection of the successful site preparation and regeneration effort.

After site preparation, dormant seeds of greenleaf manzanita—which germinated by the thousands—and root sprouts of Sierra chinkapin formed a dense stand of new shrubs. Greenleaf manzanita was by far the most abundant shrub species. Sprouts of chinkapin and a few seedlings and sprouts of snowbrush also were present, but distribution was clumpy. In fall 1980, or 1 year after site preparation, density of manzanita seedlings was about 14,000 per acre (34,594/ha), chinkapin about 10,000 per acre (24,710/ha), and snowbrush about 500 per acre (1236/ha).

Density of rescuegrass seedlings was about 4500 plants per acre (11,120/ha) and needlegrass about 3000 per acre (7413/ha). These were evenly distributed throughout the study area and showed promise of increasing greatly in number. Forbs, all early pioneers, generally were few and scattered. The most prominent were bigflower groundsmoke *(Gayophytum diffusum)*, lettuce wirelettuce *(Stephanomeria lactucina)*, prickly hawkweed *(Hieracium horridum)*, stickseed *(Hackelia californica)*, and small woolly eriophyllum *(Eriophyllum lanatum* var. *integrifolium)*.

Numerous mammals and rodents were present in the study area, but only two species were considered a threat to the plantation. In fall 1980, the pocket gopher *(Thomomys* spp.) population was observed to be increasing rapidly. Because it constituted a threat to pine seedling survival, the study area and a large buffer were treated with strychnine bait (0.3 percent active ingredient) on November 14 and December 1, 1980, and again on April 29, 1981. Mule deer *(Odocoileus hemionus)* were common in the study area but no browsing damage was noted on year-old seedlings.

The environment of the study area is best described as being harsh for young conifer seedlings. Summers are warm and dry, the soil retains little moisture, and the wind blows incessantly. The average January temperature is about 31 °F (-1 °C); the average July temperature is about 66 °F (19 °C); the mean annual temperature is about 47 °F (8 °C); and the frost-free season is 80 to 110 days (Soil Conservation Service 1983). Annual precipitation averages between 40 and 50 in. (1016 and 1270 mm) with most falling as snow. The cold spring winds are so pervasive, especially around Mt. Shasta 6 miles (9.7 km) to the northwest, that planting is not even attempted in some places until after April 15, when the winds diminish somewhat. Elevation of the study area is 4800 ft (1464 m) with slopes of 5 to 15 pct on a southeast aspect.

The soil, which is of the Shasta Series, is excessively drained, has moderately rapid permeability, and little runoff. It is deep (65 in. or 1.6 m), with about half the profile being loamy sand at upper levels and extremely gravelly loamy sand grading to sand below.

Based on the height-age relationship of California white fir, site quality of the study area before harvesting was 75 ft (23 m) in 50 years (Dolph 1987). Harvesting and site preparation are estimated to have changed the inherent productivity of the site little, if any. As a whole, the study area is remarkably uniform in terms of aspect, slope, and site quality.

# TREATMENT AND STUDY METHODS

## Experimental Design

The experimental design was completely randomized with one-way treatment structure. Confidence intervals for the difference between any two treatments—designated as ($\bar{D}\pm w$), where $\bar{D}$ equals the sample difference between treatment means, and w equals the half-width of the confidence interval—were calculated by the Tukey method based on an analysis of variance model. Significance in all tests was at $\alpha = 0.05$. The confidence interval can be used to present the best information available on the range of values within which the expected difference is estimated (with 95 percent confidence) to lie. Because information was gathered from permanent plots measured each year, the data are not truly independent from year to year. The $\alpha$ levels or type I errors given for various tests apply to each measurement and year separately. The overall error rate could increase by as much as the given amount for each measured variable each year.

Treatments, each replicated four times, included four manual, two chemical, and an untreated control. A replicate consisted of about one-seventh acre (0.06 ha) on which were 30 to 35 ponderosa pine seedlings surrounded by two to three rows of buffer (seedlings receiving similar treatment). In all treatments, the equivalent of 200 to 250 "crop trees" per acre (494 to 618/ha) were flagged. As their name implies, these were thrifty seedlings that had good potential of becoming merchantable trees. Small, misshapen and discolored seedlings were not part of the study—their chance of being alive after 10 years was remote, given the large population of woody shrubs.

## Manual Treatments

The manual treatments were designed to test the effect of removing competing vegetation from different radii around crop trees and consisted of grubbing shrub and herbaceous seedlings with Finnley hoes (shovel head with a hoedad handle), and severing chinkapin sprouts deep in the ground. The manual treatments were these:

- Grub 2-ft (0.6 m) radius one time
- Grub 2-ft radius one time, regrub the original radius and expand to 4-ft (1.2 m) radius the second time (hereafter referred to as expanded 2-ft radius)
- Grub 4-ft radius one time
- Grub 4-ft radius one time, regrub the original radius and expand to 6-ft (1.8 m) radius the second time (hereafter referred to as expanded 4-ft radius).

Although part of the ground was treated twice in some treatments, each of the manual operations is described as a separate treatment in the rest of the paper. The expanded radii treatments were not judged as applied until the second application was completed. The ponderosa pine seedlings were initially released in late August 1980, with the second application being completed in late May 1984, before shoot growth began. A second treatment often is used in this area, particularly when older shrub seedlings encroach into cleared growing space and new manzanita and snowbrush seedlings and chinkapin sprouts appear.

## Chemical Treatments

Chemical treatments were the herbicides 2,4-D and Velpar, which for various reasons were not applied until 1982 and not until May 20, the time of earliest accessibility to the study area.[1] When the study began, 2,4-D was the foliage-active herbicide most often applied to forest plantations in California, and Velpar was a soil-active herbicide (possibly with some foliage activity) just beginning to be used in conifer plantations in California.

The 2,4-D was applied directly in ester form from a backpack apparatus and a carbon-dioxide pressurized boom, which simulated helicopter application, at the rate of 3 pounds (1.4 kg) acid equivalent in a total of 10 gallons of solution per acre (18 L/ha). Nozzles on the boom were the same as those used in helicopter application, hence rate of application and droplet size were similar. The boom, which covered a 9-ft (2.8 m) swath, was held about 12 in. (30 cm) above the shrubs and the spray was directed downward. Trial runs with water determined the proper walking speed needed to apply the correct amount of herbicide to each

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

replicate. The entire seventh-acre replicate and half the buffer were sprayed. Personnel were used as guides at each side of the swath to ensure even coverage and no overlap. Cool temperatures insured that terminal buds on pine seedlings were hard and that growth had not begun. The seedlings were not covered as the hard buds were assumed to protect the seedlings from spray damage. Spraying took place in clear, calm weather at about 10 a.m. P.s.t.

Velpar was applied at the rate of 2 pounds (0.9 kg) acid equivalent per acre. Standard backpack hand-operated sprayers were used to apply the chemical to the entire replicate. Care was taken to insure that spray coverage was uniform without skips or overlaps. Substantial rain fell on May 22, which helped get the herbicide into the soil.

## Production Rates

Production data were gathered for each treatment. The basis for production was hourly records; the basis for cost was $7.50 per hour—the rate for a WG-1 laborer, U.S. Department of Labor, as of June 1984.

## Sampling

Sampling intensity was five randomly selected plots in each replication. Plots were centered around seedlings and were circular with 2-, 4-, or 6-ft radius, and 1 milacre (4 $m^2$) for entire area treated (Velpar, 2,4-D) and control. A representative current-year needle from each of these pine seedlings was measured for length each year. In addition, 20 to 25 ponderosa pine seedlings having potential as crop trees in each replicate were measured annually for height, stem caliper at 12 in. (30 cm) above mean ground line, and checked for insect depredation and damage from 2,4-D and Velpar.

Vegetation was measured annually 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), and average dominant height (average of the three tallest stems measured from mean ground line to bud). Treatment means were calculated each year and plotted graphically. Data were statistically analyzed each year.

Internal moisture stress of ponderosa pine seedlings was determined to help explain growth differences among treatments that became apparent early in the study. Xylem sap tension was measured with a Scholander pressure chamber (Scholander and others 1965) on August 8, 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 well before 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 in each treatment. Consequently, three twigs were tested in the pressure chamber at five measurement times throughout the day. Each twig was placed in a sealed plastic bag. The elapsed time between cutting and placement in the chamber did not exceed 3 minutes. Every third sample was measured twice in the chamber as a check on technique and working order of the equipment. "Plant moisture stress" in atmospheres is used in this paper to express pressure chamber values (Waring and Cleary 1967) because it is positive, direct reading, and most familiar to foresters and biologists.

# RESULTS

## Ponderosa Pine

Although the buds of ponderosa pine seedlings were hard, spray damage from 2,4-D was extensive. Most pine seedlings were killed, and those that remained died back to the whorl closest to the ground. In many instances a new terminal shoot formed, but it took 2 years to do so. Needles and buds on the new shoot were not distorted, as often is the case from herbicide damage, but growth was much reduced, probably because the amount of photosynthetic area remaining was small. Because the spring application of this herbicide and its effect on pine survival and growth was atypical, this treatment was not considered further.

Mortality of ponderosa pine seedlings was less than one per replication, during the study period. Consequently, survival ranged from 94 to 98 percent, with no statistically significant differences among treatments occurring at any time ($p > 0.05$). Despite the presence of numerous deer, occasional infestation of grasshoppers, and a small but increasing population of pocket gophers, no damage to ponderosa pine seedlings was recorded.

Statistically significant differences among treatments for ponderosa pine stem caliper, measured at 12 in. above mean ground line, first showed up in fall 1983, or two growing seasons after treatment. Mean stem caliper of pines in the Velpar treatment was significantly larger than that in two manual treatments (2-ft and 4-ft radii) and the control. In spring 1984, pine caliper in areas having treated 2- and 4-ft radii were indistinguishable from counterparts in the to-be-expanded treatments. This similarity was true of height as well. In fall 1984, pine caliper in the Velpar treatment was significantly larger than in the 2-ft radius, expanded 2-ft radius, 4-ft radius, and control—a finding that continued through 1985. Also, in 1985 pines in the expanded 4-ft radius treatment were significantly larger than pines in the 2-ft radius, 4-ft radius, and the control, indicating the efficacy of additional grubbing to a larger area *(table 1)*.

Statistically significant differences among treatments for ponderosa pine seedling height were first noted in fall 1983. Average height of pines in the Velpar treatment was significantly larger than for counterparts in the 2-ft and 4-ft manual treatments in 1983, and differed significantly from them and the control in 1984 and 1985. Also in 1985, or two growing seasons after the second treatment was applied, ponderosa pines in the expanded 4-ft radius treatment were significantly larger than those in the 4-ft radius treatment or in the control *(table 1)*.

Bringing height and diameter together in the form of a ratio helps explain the effect of treatment. In the Velpar treatment, for example, the height-diameter ratio steadily decreased throughout the study period; in the control, the ratio was constant; and in the manual treatments the ratio increased and then declined. The treatment with the lowest value at the end of the study period was Velpar—suggesting that stem caliper was expanding fastest relative to stem height in this treatment.

Analysis of needle length showed trends that were similar to those of stem caliper and height. In 1982, needle length of pines was shortest in the control *(fig. 1)*. In 1984 and 1985, needles in the Velpar and expanded 4-ft radius treatments were longer than those in the other radius treatments and the control.

Predawn minimum moisture stress of ponderosa pine seedlings was lowest (5.7 atmospheres) in the Velpar treatment, highest in the control (12.7 atmospheres), and intermediate in the other treatments *(fig. 2)*. Maximum moisture stress of pine seedlings also was lowest in the Velpar treatment (16.5 atmospheres) and highest in the control (19.3 atmospheres). Maximum stress in the Velpar treatment occurred in late afternoon, but in the control took place at 10:10 a.m., meaning that seedlings in the Velpar treatment had to endure a much shorter period of high stress. Indeed, by being under 15 atmospheres of moisture stress (Cleary 1970), these seedlings probably achieved positive net photosynthesis for over 5 hours, while seedlings in the control did so for about 1 1/2 hours.

**Table 1**—*Stem caliper and height of ponderosa pine seedlings, by treatment, Shasta-Trinity National Forests, 1982-1985*

| Treatment | 1982 | 1983 | 1984 | 1985 |
|---|---|---|---|---|
| | | **Caliper** *(inches)* | | |
| Manual | | | | |
| 2-ft radius | 0.30 a[1] | 0.48 a | 0.75 a | 0.90 a |
| Expanded 2-ft radius | | | 0.80 a | 1.10 ac |
| 4-ft radius | 0.23 a | 0.45 a | 0.70 a | 0.90 a |
| Expanded 4-ft radius | | | 1.05 ab | 1.43 bc |
| Chemical | | | | |
| Velpar | 0.42 a | 0.70 b | 1.20 b | 1.70 b |
| Control | 0.23 a | 0.45 a | 0.68 a | 0.88 a |
| Standard error | 0.02 | 0.04 | 0.07 | 0.11 |
| | | **Height** *(feet)* | | |
| Manual | | | | |
| 2-ft radius | 1.10 a | 1.73 a | 2.43 a | 2.98 ac |
| Expanded 2-ft radius | | | 2.28 a | 3.18 ac |
| 4-ft radius | 1.10 a | 1.68 a | 2.30 a | 2.90 a |
| Expanded 4-ft radius | | | 2.95 ab | 4.03 bc |
| Chemical | | | | |
| Velpar | 1.28 a | 2.20 b | 3.25 b | 4.45 b |
| Control | 1.08 a | 1.75 ab | 2.33 a | 2.90 a |
| Standard error | 0.07 | 0.10 | 0.17 | 0.25 |

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

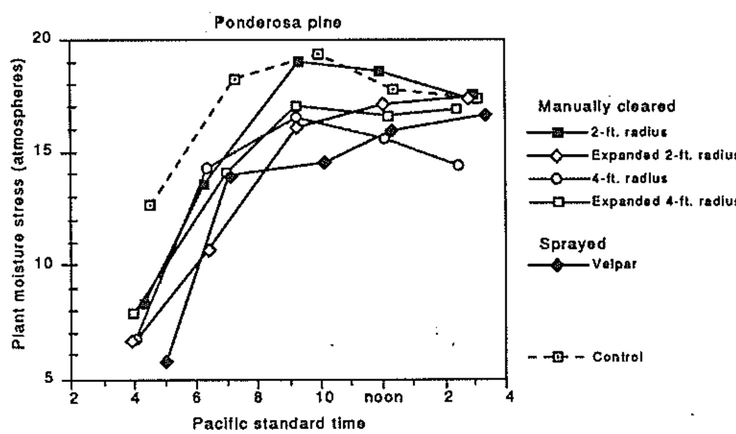


**Figure 2**—Diurnal trend of moisture stress in ponderosa pine on August 8, 1984. Standard errors applicable to differences between treatments could not be estimated.

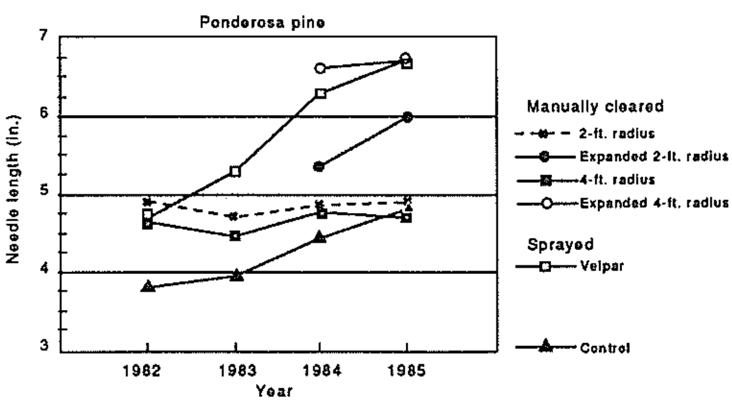


**Figure 1**—Relationship of ponderosa pine needle length to treatment, 1981-1985. Standard errors, most too small to graph, ranged from 0.1 to 0.5 inches.

## Greenleaf Manzanita

Greenleaf manzanita, a hardy, vigorous, sclerophyllous shrub, was the most abundant woody species in the plantation. After site preparation, viable seeds in the soil germinated by the thousands. Because greenleaf manzanita is a widespread and commonplace competitor in many pine plantations in California and southern Oregon, several relationships are presented for it. To show its dynamics as a seedling, density, foliar cover, and height are presented in the control for 1981-1985 *(table 2)*. To show its response to the various treatments, density, cover, and height are presented for 1985 or after six growing seasons *(table 3)*. Density of greenleaf manzanita peaked in 1982 at about 38,000 plants per acre (93,898/ha) and declined thereafter. Cover and height steadily increased. After four additional growing seasons, manzanita plants had increased an average of 1 percent, cover 3900 percent, and height 350 percent.

Amount and timing of regrowth was of particular interest. Manzanita density did not differ significantly until 1984, when the number of seedlings in the Velpar treatment were reduced significantly relative to the 2- and 4-ft manually released treatments. Manzanita seedlings in the expanded 2-ft radius also differed significantly from counterparts in the 4-ft radius. Nearly the same relationships continued in 1985 *(table 3)*. Foliar cover of manzanita also did not differ significantly until 1984. In 1984, cover in the expanded radii treatments differed significantly from that in the control, a relationship that continued through 1985. Height of manzanita differed significantly each year of the study. Differences generally were between the least intensive treatments (2-ft radius, 4-ft radius, expanded 2-ft radius, control) and most intensive treatments (expanded 4-ft radius, Velpar).

**Table 2**—*Density, cover, and height, with standard errors (SE), of greenleaf manzanita, Sierra chinkapin, snowbrush, and grass in the control, and overall difference, 1981-1985*

| Year | Density | SE | Cover | SE | Height | SE |
|---|---|---|---|---|---|---|
| | *Plants/acre* | | *Ft²/acre* | | *Ft* | |
| | | | **Greenleaf manzanita** | | | |
| 1981 | 29,500 | 11,181 | 300 | 129 | 0.4 | 0.1 |
| 1982 | 38,050 | 17,624 | 2,650 | 1,182 | 0.6 | 0.1 |
| 1983 | 36,650 | 15,708 | 6,550 | 2,865 | 1.2 | 0.1 |
| 1984 | 33,800 | 13,356 | 8,750 | 3,181 | 1.4 | 0.2 |
| 1985 | 29,750 | 10,658 | 12,000 | 4,444 | 1.8 | 0.2 |
| Difference (pct) | +1 | | +3900 | | +350 | |
| | | | **Sierra chinkapin** | | | |
| 1981 | 10,800 | 5,026 | 1,500 | 843 | 1.1 | 0.2 |
| 1982 | 9,350 | 5,827 | 2,200 | 1,679 | 0.9 | 0.3 |
| 1983 | 7,450 | 3,939 | 3,400 | 2,435 | 1.3 | 0.4 |
| 1984 | 9,850 | 4,914 | 4,000 | 2,843 | 1.5 | 0.5 |
| 1985 | 9,650 | 4,850 | 4,850 | 3,557 | 1.7 | 0.5 |
| Difference (pct) | -11 | | +223 | | +64 | |
| | | | **Snowbrush** | | | |
| 1981 | 600 | 163 | 0 | — | 0.2 | 0.01 |
| 1982 | 1,700 | 465 | T[1] | — | 0.2 | 0.04 |
| 1983 | 2,000 | 606 | T | — | 0.4 | 0.10 |
| 1984 | 1,350 | 640 | T | — | 0.4 | 0.10 |
| 1985 | 1,000 | 497 | T | — | 0.5 | 0.22 |
| Difference (pct) | +67 | | — | | +150 | |
| | | | **Grass** | | | |
| 1981 | 18,100 | 6,164 | 1,200 | 510 | 0.5 | 0.05 |
| 1982 | 38,550 | 4,659 | 1,850 | 596 | 0.5 | 0.04 |
| 1983 | 39,400 | 4,175 | 4,100 | 412 | 1.2 | 0.30 |
| 1984 | 48,850 | 6,878 | 3,750 | 624 | 0.6 | 0.05 |
| 1985 | 46,500 | 4,235 | 4,050 | 1,021 | 0.5 | 0.05 |
| Difference (pct) | +157 | | +238 | | 0 | |

[1]Trace.

**Table 3**—*Density, cover, and height of greenleaf manzanita, Sierra chinkapin, snowbrush, combined shrubs, and grass, by treatment, Shasta-Trinity National Forests, 1985*

| Treatment | Density | Cover | Height |
|---|---|---|---|
| | *Plants/acre* | *Ft²/acre* | *Ft* |
| | **Greenleaf manzanita** | | |
| Manual | | | |
| 2-ft radius | 31,371 bc[1] | 7,453 ab | 1.4 a |
| Expanded 2-ft radius | 3,466 ac | 347 b | 0.5 b |
| 4-ft radius | 32,151 b | 8,146 ab | 1.5 a |
| Expanded 4-ft radius | 6,413 ab | 385 b | 0.5 b |
| Chemical | | | |
| Velpar | 2,600 a | 900 ab | 0.8 b |
| Control | 29,750 ab | 12,000 a | 1.8 a |
| Standard error | 6,376 | 2,523 | 0.2 |
| | **Sierra chinkapin** | | |
| Manual | | | |
| 2-ft radius | 2,773 a[1] | 2,426 a | 1.4 bd |
| Expanded 2-ft radius | 2,556 a | 1,083 a | 0.7 c |
| 4-ft radius | 780 a | 1,343 a | 1.6 ad |
| Expanded 4-ft radius | 3,100 a | 1,194 a | 0.5 c |
| Chemical | | | |
| Velpar | 1,550 a | 1,750 a | 1.1 b |
| Control | 9,650 a | 4,850 a | 1.7 a |
| Standard error | 2,148 | 1,582 | 0.2 |
| | **Snowbrush** | | |
| Manual | | | |
| 2-ft radius | 3,293 a[1] | 0 a | 0.5 a |
| Expanded 2-ft radius | 389 a | 0 a | 0.2 a |
| 4-ft radius | 1,430 a | 0 a | 0.5 a |
| Expanded 4-ft radius | 366 a | 0 a | 0.2 a |
| Chemical | | | |
| Velpar[2] | — | — | — |
| Control | 1,000 a | 0 a | 0.5 a |
| Standard error | 1,209 | — | 0.1 |
| | **Combined shrubs** | | |
| Manual | | | |
| 2-ft radius | 37,437 a[1] | 9,879 ab | 1.2 ab |
| Expanded 2-ft radius | 6,413 b | 1,430 b | 0.6 bc |
| 4-ft radius | 34,360 ab | 9,576 ab | 1.1 ac |
| Expanded 4-ft radius | 9,879 ab | 1,579 b | 0.4 c |
| Chemical | | | |
| Velpar | 4,150 b | 2,650 b | 0.8 ac |
| Control | 40,400 a | 17,000 a | 1.4 a |
| Standard error | 7,082 | 2,898 | 0.1 |
| | **Grass** | | |
| Manual | | | |
| 2-ft radius | 75,221 c[1] | 4,160 ab | 0.4 a |
| Expanded 2-ft radius | 19,498 b | 1,690 ab | 0.4 a |
| 4-ft radius | 44,760 ad | 6,586 b | 0.5 a |
| Expanded 4-ft radius | 21,492 bd | 3,043 ab | 0.5 a |
| Chemical | | | |
| Velpar | 14,200 b | 1,150 a | 0.5 a |
| Control | 46,500 a | 4,050 ab | 0.5 a |
| Standard error | 5,080 | 1,201 | 0.06 |

[1]For each shrub, combined shrubs, and grass, and within each column, treatment means followed by the same letter do not differ statistically at the 0.05 level.

[2]No snowbrush plants present before or after treatment.

## Sierra Chinkapin

Sierra chinkapin is widespread and commonplace in conifer plantations in California and southern Oregon where it is considered to be a strong competitor to young ponderosa pine seedlings. Little is known about its ecology and dominance potential. Consequently, its dynamics as a sprout in an untreated condition and its response to the various treatments are presented.

After site preparation, sprouts from this sclerophyllous shrub originated from viable rootstocks that remained in the soil. Several shoots often come from one root system. And even though seed from mature shrubs nearby was abundant and disseminators (birds, rodents) were plentiful, no new chinkapin seedlings were noted. Consequently, the density of chinkapin in the study area is best described as being only moderately dynamic with relatively minor increases and decreases occurring. Changes in foliar cover also tended to be moderate with a steady increase taking place.

Peak density in fall 1981 was followed by a general but erratic decline *(table 2)*. Cover increased steadily and height also increased—although erratically. In 1985 the number of chinkapin plants had decreased an average of 11 percent, cover increased an average of 223 percent, and height increased by 64 percent. Overall, the developmental trend for this species is for slightly fewer plants but with increased width and height.

Analyses of chinkapin density and cover showed that neither parameter differed significantly among treatments at any time during the study. Differences in chinkapin height first occurred in 1984. Differences among treatments were numerous, the exceptions being that sprouts in the 4-ft radius and control did not differ, nor did sprouts in the expanded radii differ from each other. The differences among treatments that were present in 1984 continued to be significant in 1985 *(table 3)*.

## Snowbrush

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

In fall 1981, density of snowbrush plants in the control was low, with only a small amount of foliar cover, and little height *(table 2)*. Density more than doubled in 1982, peaked in 1983, and declined in 1984 and 1985. Foliar cover and height increased slowly. From fall 1981 through fall 1985, number of snowbrush plants increased an average of 67 percent and height 150 percent. At no time did snowbrush density, cover, or height differ significantly among treatments *(table 3).*

## Combined Shrubs

Although greenleaf manzanita was fairly evenly distributed in all replicates, Sierra chinkapin and snowbrush were not. The best way to show the relationship of shrubs to the various treatments is to portray the density, foliar cover, and height of the three shrub species combined.

Number of seedlings did not differ significantly until 1984, when differences became numerous. Number of plants in the Velpar and expanded radius treatments differed significantly from number of plants in the control and 2-ft radius treatment. In 1985, number of plants in the control and 2-ft radius treatment differed significantly from the Velpar and expanded 2-ft radius treatments *(table 3).* Foliar cover of combined shrubs did not differ significantly until 1984. In 1984, combined shrub cover of expanded radii treatments and those sprayed with Velpar resulted in significantly fewer seedlings than in the control—a relationship that continued through 1985. Height of shrubs when combined first differed significantly in 1984 when those in the control were much taller than those in the expanded radii treatments, and shrubs in the 2-ft radii treatment were taller than those in the expanded 4-ft radii treatment. This relationship continued through 1985. Differences among treatments and confidence intervals (95 percent) are shown for combined shrub density, cover, and height *(table 4).*

Table 4—*Differences between treatment means plus or minus half-width of 95 pct confidence interval* ($\bar{D}\pm w$) *for combined shrub density, cover, and height, 1985*

| Treatments compared | Density | | | Cover | | | Height | | |
|---|---|---|---|---|---|---|---|---|---|
| | *No./acre* | | | *Ft²/acre* | | | *Ft* | | |
| Velpar, control | 36,250 | ± | 31,796 | 14,350 | ± | 13,015 | 0.61 | ± | 0.68 |
| 2-ft man., control | 2,963 | | 31,796 | 7,121 | | 13,015 | 0.26 | | 0.68 |
| Expanded 2-ft man., control | 33,987 | | 31,796 | 15,570 | | 13,015 | 0.86 | | 0.68 |
| 4-ft man., control | 6,040 | | 31,796 | 7,424 | | 13,015 | 0.28 | | 0.68 |
| Expanded 4-ft man., control | 30,521 | | 31,796 | 15,421 | | 13,015 | 1.00 | | 0.68 |
| Velpar, 2-ft man. | 33,287 | | 31,796 | 7,229 | | 13,015 | 0.35 | | 0.68 |
| Velpar, expanded 2-ft man. | 2,263 | | 31,796 | 1,220 | | 13,015 | 0.25 | | 0.68 |
| Velpar, 4-ft man. | 30,210 | | 31,796 | 6,926 | | 13,015 | 0.32 | | 0.68 |
| Velpar, expanded 4-ft man. | 5,729 | | 31,796 | 1,071 | | 13,015 | 0.39 | | 0.68 |
| Expanded 4-ft man., 2-ft man. | 27,558 | | 31,796 | 8,300 | | 13,015 | 0.74 | | 0.68 |
| Expanded 4-ft man., expanded 2-ft man. | 3,466 | | 31,796 | 149 | | 13,015 | 0.14 | | 0.68 |
| Expanded 4-ft man., 4-ft man. | 24,481 | | 31,796 | 7,997 | | 13,015 | 0.68 | | 0.68 |
| 4-ft man., 2-ft man. | 3,077 | | 31,796 | 303 | | 13,015 | 0.06 | | 0.68 |
| 4-ft man., expanded 2-ft man. | 27,947 | | 31,796 | 8,146 | | 13,015 | 0.54 | | 0.68 |
| 2-ft man., expanded 2-ft man. | 31,024 | | 31,796 | 8,449 | | 13,015 | 0.60 | | 0.68 |

## Grass

As noted earlier, grasses were virtually absent under the canopy of the uncut forest. However, where the canopy was more open and the shrub community more extensive, a few grass plants became established between shrubs and under shrub crowns. Each year the grasses produced at least a little seed, which probably was stored in the upper layers of the forest floor. Soon after site preparation, several thousand plants of rescuegrass and needlegrass were present. These in turn produced seed, and together with more seeds from the soil and perhaps some disseminated into the study area from nearby areas, resulted in an explosion of grass plants.

Density of rescuegrass and needlegrass increased through 1983, peaked in 1984, and decreased slightly in 1985 *(table 2).* Foliar cover peaked in 1983 and remained virtually unchanged through 1985. Grass height peaked in 1983 and declined rapidly through 1985. Overall, grass density and cover increased greatly over initial values. Height was the same in 1985 as it was in 1981.

Grass seedlings first differed significantly among treatments in 1982, when number of seedlings in the control was greater than in those grubbed to 2-ft and 4-ft radii, or sprayed with Velpar. By fall 1985 the average number of grass plants in the various treatments had sorted themselves into a general pattern: control, 2-ft, and 4-ft radii treatments differed significantly from Velpar and the expanded 2-ft radii treatment *(table 3).* In some treatments, the number of grass plants was extensive, numbering the equivalent of 44,000 to 75,000 per acre (108,724 to 185,325/ha). Differences in foliar cover became apparent in 1983 when cover of grasses in the Velpar treatment was significantly lower than that of grasses in the control. In 1984 and 1985, grasses in the Velpar treatment had significantly lower cover than counterparts in the 4-ft radius treatment. Average height of grasses first differed significantly among treatments in 1982 when those in the control were markedly taller than those in the 2-ft radius treatment, and in the 4-ft radius treatment in 1983 as well. Grass height did not differ significantly among treatments after 1983.

## Production and Cost

The cost and production data gathered in this study were found to be similar to average costs from contracts awarded on several National Forests in northern California, even though production rates in this study were from small areas and those from the National Forests were from large. The data were similar, probably because both the contracts and study involved equally experienced and motivated crews, and similar terrain, species of woody shrub, age of plantation, and type of treatment.

Grubbing a 4-ft radius and then regrubbing and expanding it to a 6-ft radius took the most time and was the most expensive treatment. Applying Velpar was the least expensive:

| Treatment | Production rate | Cost |
|---|---|---|
| | *Laborer hours/acre* | *Dollars/acre* |
| Manual | | |
| 2-ft radius | 12 | 90 |
| 2- to 4-ft radius | 51 | 382 |
| 4-ft radius | 25 | 188 |
| 4- to 6-ft radius | 77 | 578 |
| Chemical | | |
| Velpar | 5 | 38 |

Costs are for labor only and do not include overhead or the cost of the chemical.

Cost information can be matched to pine seedling growth data, and together with a measure of confidence, lead to an economical and biological comparison of treatments. Differences between any two treatments are presented for ponderosa pine stem caliper and production rates in 1985 *(table 5)*. Confidence intervals for stem caliper, which are also presented, are useful to the forest manager. They show, in the example of the compared treatments (Velpar and control), that one could expect with 95 percent confidence that the average stem caliper due to treatment in an environment similar to that in the study area will be somewhere between 0.37 and 1.27 in. (0.94 and 3.23 cm) at age 6.

Assume that a manager requires an increase of at least 0.3 in. (0.8 cm) in stem caliper before declaring a treatment worth applying. Further assume that a tight budget mandates that release costs be no more than $50 per acre ($124/ha), excluding the cost of the chemical. On the basis of these results, one can be reasonably certain that this standard can be obtained because the average stem caliper increase will be no lower than 0.37 in. (0.94 cm), and the treatment should be within budget (5 hours times $7.50 per hour, or $38). If a manager could not apply an herbicide but wanted some temporary release, say from manually grubbing a 4-ft radius at age 1, the prospect would be discouraging. The manager would be virtually certain that the increase in stem diameter at age 6 would be very small even though the release cost would be $188 per acre ($465/ha).

Table 5—*Treatment means and differences between treatments for stem caliper, and production rate, ponderosa pine, 1985*

| Treatments compared | Stem caliper: Treatment means | Stem caliper: $\bar{D} \pm w$[1] | Production rate |
|---|---|---|---|
| | *Inches* | | *Man hours/acre* |
| Velpar, control | 1.70 - 0.88 | 0.82±0.45 | 5 |
| 2-ft man., control | 0.90 - 0.88 | 0.02 0.45 | 12 |
| Expanded 2-ft man., control | 1.10 - 0.88 | 0.22 0.45 | 51 |
| 4-ft man., control | 0.90 - 0.88 | 0.02 0.45 | 25 |
| Expanded 4-ft man., control | 1.43 - 0.88 | 0.55 0.45 | 77 |
| Velpar, 2-ft man. | 1.70 - 0.90 | 0.80 0.45 | 7 |
| Velpar, expanded 2-ft man. | 1.70 - 1.10 | 0.60 0.45 | 46 |
| Velpar, 4-ft man. | 1.70 - 0.90 | 0.80 0.45 | 20 |
| Velpar, expanded 4-ft man. | 1.70 - 1.43 | 0.27 0.45 | 72 |
| Expanded 4-ft man., 2-ft man. | 1.43 - 0.90 | 0.50 0.45 | 65 |
| Expanded 4-ft man., expanded 2-ft man. | 1.43 - 1.10 | 0.33 0.45 | 26 |
| Expanded 4-ft man., 4-ft man. | 1.43 - 0.90 | 0.53 0.45 | 52 |
| 4-ft man., 2-ft man. | 0.90 - 0.90 | 0.00 0.45 | 13 |
| Expanded 2-ft man., 4-ft man. | 1.10 - 0.90 | 0.20 0.45 | 26 |
| Expanded 2-ft man., 2-ft man. | 1.10 - 0.90 | 0.20 0.45 | 39 |

[1]Difference between means plus or minus half-width of the confidence interval.

## DISCUSSION

A good job of site preparation created an opportunity for buried seeds of snowbrush and greenleaf manzanita to germinate, and for sprouts of chinkapin to develop. These shrub species have many morphological and physiological adaptations that allow them to capture resources and grow rapidly. A rapidly developing, downward-thrusting root system, exploitative resource use, and physiological tolerance of stress during establishment are among the major adaptations that allow shrubs to dominate after severe disturbance. The worth of these adaptations is shown by an example from the brushfields of Mt. Shasta where greenleaf manzanita seedlings had a visually deleterious effect on ponderosa pine seedling vigor and growth after only three growing seasons (Bentley and others 1971).

What is remarkable is the disparity between the planted pines and the naturally developing manzanita seedlings in terms of age, and size of roots and shoots when competition began, and the capability of the manzanita to overcome this disparity and dominate. The manzanita plants began from seeds, while the pines were bare-root seedlings, grown in a nursery for 2 years and then outplanted when 7 in. (18 cm) tall, with roots that were 11 in. (28 cm) long. Lack of vigor and growth at age 3 became more manifest at age 5 when "reduced growth of pines became more apparent each year" (Bentley and others 1971).

In the study reported here, the dynamics of greenleaf manzanita, Sierra chinkapin, snowbrush, and grass in the control give insight into individual species development in a young mixed-species community. Manzanita clearly was the most abundant shrub, with over 2.5 times as many plants as the second most abundant shrub, chinkapin, and nearly 50 times that of the third shrub, snowbrush, after two growing seasons. This surfeit in numbers, however, did not result in an additional numerical advantage in subsequent years, because after six growing seasons, ranking of shrubs and proportion of total shrub plants per acre remained almost identical.

Where a gain did accrue was in foliar cover. In fall 1985, manzanita had 2.4 times as much cover as chinkapin and fully 70 percent of total shrub cover. And manzanita had caught up with chinkapin in terms of average height. This height growth was quite an accomplishment when one considers that the manzanita plants originated from seeds and chinkapin from established root systems, even though chinkapin roots probably were damaged during site preparation. Although the shrub population was large, there was room for grasses—over 46,500 plants per acre (114,902/ha) after six growing seasons. But with little gain in cover the last three growing seasons and better than a 58 percent decrease in height, grass appears to be falling behind, probably as a result of increased competition for scarce resources by the burgeoning shrubs.

The effect of the various treatments on individual shrub species and combined shrubs ranged from almost none to large. In general, grubbing a 2-ft or 4-ft radius around a pine seedling at the end of the first growing season reduced the cover and height of all brush and grass species by the end of the fifth growing season, but not the density of the species that originated from seed. Actual increases occurred in manzanita, snowbrush, and grass density relative to the control. The net effect was that at least 34,000 shrubs per acre (84,014/ha) and 44,000 grass plants (108,724/ha) remained, and grubbing to a 2-ft and a 4-ft radius produced levels of competition that did not differ significantly from the control.

Expanding the radius 3 years later was much more effective for reducing vegetative competition. In general, using an expanded radius and manually grubbing at least part of the area twice decreased combined shrub density to one-fourth of that in the control. Foliar cover was reduced significantly—to one-eleventh of that in the control and height to at least one-half of the control value in 1985 or two growing seasons after the second application. The expanded radius treatments signficantly reduced grass density to about one-half of that in the control but with only small differences in cover or height.

Applying Velpar after two growing seasons significantly reduced the density of the three shrub species combined to one-tenth of that in the control, and shrub cover to one-fifth of that in the control by fall 1985. Although not significant, height of combined shrubs in the Velpar treatment was reduced by almost half that of shrubs in the control. The question of how long the mostly soil-active Velpar is effective in excluding competing vegetation is often asked. Close examination of the combined shrub and grass data showed that combined shrub density was constant at about 9 percent of control density for four growing seasons after application. Grass density was constant at about 23 percent of control density for the first 3 years and then jumped to 31 percent the fourth year. Thus, the effective timespan of Velpar in the study environment probably is 3 years, at least for grass. The effective timespan for shrubs cannot be determined until data for additional years accumulate.

The various amounts of shrubs and grasses in a given area are a product of the kind and number of treatments. In turn, the amount of growth by ponderosa pine seedlings is a function of the amount of competing vegetation that remains and its rate of recovery. Amount of new vegetation also is important. Consequently, the treatment that best controls competing vegetation almost always is best for ponderosa pine seedling growth. An additional factor, however, is timing. The best treatment is one that not only effectively controls competing vegetation, but does so when the conifer seedlings are becoming established (McDonald and Oliver 1984), probably their first 3 years. The first year is particularly critical. In this study, manual release began just after the first growing season and chemical release just before the second season—well within the timespan when treatments are most effective. But even with effective and timely treatments, a statistical difference among treatments was not realized until fall 1983 when the pine seedlings in the Velpar treatment became statistically larger in stem caliper than seedlings in the least intensive treatments (2-ft and 4-ft radii, control).

Similar results also became manifest for pine seedling height in 1983 in the 2-ft and 4-ft radii treatments. Attaining a statistically significant difference after two growing seasons probably is about the fastest that such a difference can be realized. In an earlier study of 7-year-old Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) seedlings, treated at ages 3 and 5, differences in stem caliper among treatments became significant before differences in height (McDonald and Fiddler 1986). Perhaps when treatments are applied early, as in the study reported here, both diameter and height are indicators of treatment effectiveness. This could prove true only for ponderosa pine. Such relationships will be studied in the near future.

The need to treat the vegetation that emerges after site preparation is critical. Without such treatment, the entire study area probably would have resembled the control in 1985: 40,400 shrub seedlings and sprouts per acre (99,828/ha), 1.4 feet (0.4 m) tall, with crowns that covered almost 40 percent of the area so closely that they cast a solid shadow. In this environment, most of the ponderosa pine seedlings were still alive, but many were hard to find. Although ponderosa pine seedlings are noted for their capability to survive, at least for a decade or two in such an environment, the odds for decreased growth and survival are high.

Even though pines were substantially taller than the competing vegetation, both initially and every year for 6 years, their productivity was far below that attainable from the best available treatments. In the control in 1981, for example, pine seedling height was 20 percent greater than height of combined shrubs, and in 1985 was 107 percent greater. Yet pine height in 1985 in the most intensive treatments was 53 percent greater (Velpar) and 40 percent greater (expanded 4-ft radius), than pine height in the control. Likewise, pine stem caliper 12 inches above mean ground line in the Velpar treatment was 93 percent greater than pine caliper in the control, and pine caliper in the expanded 4-ft radius treatment was 62 percent greater than in the control.

The many differences among treatments that were present in 1985 suggest that few additional differences will occur. Existing differences, however, probably will accelerate. Significant differences in ponderosa pine stem caliper and height between Velpar and least intensive treatments (including control) began in 1983 and, together with the expanded 4-ft radius treatment, strengthened in 1985. This trend should continue. Large differences among treatments in terms of competing vegetation should mean differential response by the conifer seedlings. And, because no more retreatments are planned, differences between most intensive and least intensive treatments should widen as the pines in the most intensive treatment outstrip their counterparts encumbered by burgeoning shrubs. On a nearby area, McDonald and Oliver (1984) quantified the growth of ponderosa pine relative to various densities of the same woody shrubs as those in this study. After 18 years, stem diameter and height of pines differed significantly among light, medium, and heavy shrub density classes. And for pines free of shrubs (intensive treatment), growth was accelerating away from those growing with a medium or heavy amount of shrubs (less intensive treatments).

## CONCLUSIONS

Comparing overall treatment effectiveness for manual release once, manual release twice, and applying Velpar once shows the efficacy of these treatments in the environment of the study area. Grubbing one time to a 2-ft and a 4-ft radius, even when the plantation was very young, nevertheless proved ineffective. Expanding the radius from 2 ft to 4 ft did not significantly improve ponderosa pine seedling diameter or height either. Competition from new shrub seedlings in the cleared radius and competition from plants around the cleared area reduced pine diameter and height to a level that did not differ significantly from the control. Applying Velpar when ponderosa pine seedlings were 2 years old gave statistically significant results earlier than other treatments, effectively controlled competing vegetation for at least 3 years, and cost less than other treatments. Grubbing a 4-ft radius at an early age and then regrubbing and expanding it to 6 ft 3 years later also was effective.

In this study, mortality of ponderosa pine seedlings was almost nonexistent. The primary effect of competing vegetation was reflected in stem caliper and height. Pine seedlings growing for 6 years with many rapidly expanding shrubs had smaller and shorter stems, and seedlings that had at least some growing space with fewer competing shrubs had thicker and taller stems. After dividing mean height by mean diameter, values for pine seedlings by treatment were 38 for control, 34 to 38 for manual treatments, and 32 for Velpar. Stem caliper was expanding faster relative to stem height in the Velpar treatment. Also, Velpar was the only treatment that showed a steady trend of decreasing height-diameter ratios during the study period, suggesting that future growth will be best in this treatment.

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