

United States  
Department of  
Agriculture

Forest Service

Pacific Southwest  
Forest and Range  
Experiment Station

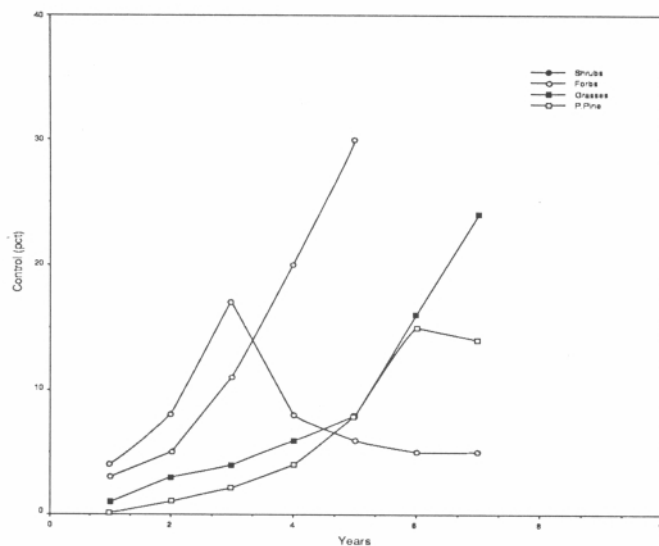
General Technical  
Report PSW-113

# Competing Vegetation in Ponderosa Pine Plantations: Ecology and Control



Philip M. McDonald

Gary O. Fiddler



McDonald, Philip M.; Fiddler, Gary O. 1989. **Competing vegetation in ponderosa pine plantations: ecology and control**. Gen. Tech. Rep. PSW-1 13. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 26 p.

Planted ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) seedlings in young plantations in California are at a disadvantage compared with competing shrubs, forbs, and grasses. In many instances, roots of competing plants begin expanding and exploiting the soil earlier and in greater numbers, thereby capturing the majority of available resources and lowering pine survival and growth. Competition thresholds or "how much is too much?" are: for treatments where a cleared radius is prescribed, no weeds are acceptable within the space needed for maximum growth of pine seedlings during the establishment period; for treatments involving the entire area, crown cover values of 10 to 30 percent seem to be the level beyond which shrub competition significantly affects pine growth.

Methods for preparing the site, which include mechanical and chemical methods, use of fire, and combinations of treatments, show the interaction of site and ensuing vegetation. Techniques for controlling competing vegetation from seed include preventing such plants from getting started by use of preemergent herbicides or mats (collars). To prevent sprouting, hardwood trees and large shrubs can be pushed over, thereby getting the root crown out of the ground, or if still in the soil, grinding it out with a machine. Once present, the effect of weeds from seed can be minimized by grubbing or spraying when young, by grazing plants with cattle or sheep, or by introducing plants of low competitive ability. Once sprouting weeds are present, their effect can be minimized by spraying with chemicals, or if palatable, by grazing with cattle or sheep. Costs range from as low as \$10 per acre (\$25/ha) for aerially applying herbicides to \$711 per acre (\$1757/ha) for grinding out tanoak stumps.

*Retrieval Terms:* seedling growth, competition, weeds, control, ponderosa pine, *Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*

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## The Authors:

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**PHILIP M. MCDONALD** is a research forester assigned to the Station's Vegetation Management Research Unit, with headquarters at Redding, Calif. **GARY O. FIDDLER** is a silviculturist assigned to the Timber Resource Planning and Silviculture Development Unit, Pacific Southwest Region, with headquarters in San Francisco, and stationed at Redding, Calif.

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## Publisher:

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**Pacific Southwest Forest and Range Experiment Station**  
**P.O. Box 245, Berkeley, California 94701**

**July 1989**

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## INTRODUCTION

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Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) is the conifer species most planted on National Forest land in California. From 1982 through 1986, new plantations of ponderosa and Jeffrey pines (*Pinus jeffreyi* Grev. & Balf.) averaged 14,875 acres (6,020 ha) annually, or 53 percent of all the acres planted. Only a small proportion of this acreage was Jeffrey pine. This annual plantation establishment rate is expected to double by 1998 as new forest plans and reforestation from the 1987 fires are implemented (Fiske 1987). Ponderosa pines are being counted on to survive and grow well to meet future needs.

In *plantations*, where a decision already has been made to grow trees and spend money to prepare the site, plant seedlings, and do whatever else is necessary to establish a new forest, survival of the seedlings is not enough—fully stocked acres *growing at the potential of the site* is the goal. A major way to provide such growth is to have vigorous seedlings, those with virtually no competition for site resources during the first few years. It is during this time, and certainly the critical first year, that the basis for rapid growth—the number and amount of fine roots—develops. Vigorous seedlings at the start often mean vigorous trees later. Weeds in the form of woody shrubs, forbs, and grasses (*fig. 1*) can seriously limit the establishment and growth of young pines. Too often, weeds are better adapted than pine seedlings, especially belowground,



A



B



C

**Figure 1—** (A) After a good job of site preparation, manzanita and other shrubs have almost taken over this 15-year-old ponderosa pine plantation. (B) Forbs also have high potential to excel in pine plantations as seen in this large population of thistles. (C) A month before this photo, pines were easily seen, now grass dominates the area.

for becoming established on the disturbed ground of new plantations (*fig. 2*).

This paper describes the general environment that affects pine seedlings and the ecological capabilities of competing vegetation—or weeds, as they are often called. It brings together published and unpublished data on the morphological characteristics of young pines, especially with regard to root development. When root development of pines is compared with that of shrubs and grasses, it is not surprising that pine seedlings are at a disadvantage.

Because the environment in which pine seedlings begin to grow has major impact not only on their performance, but also on the kind and amount of competing vegetation that ensues, this paper discusses the major forms of site preparation (mechanical, chemical, fire). Their effect on mycorrhizal and nutritional relationships is emphasized. The literature is then reviewed for the effect of competition on pine survival and growth, with special emphasis on defining how much competition is too much. For releasing conifer seedlings, both from seeds and sprouts, numerous techniques are presented in the

framework of both preventing competition and minimizing its effect. The cost of applying these treatments is presented throughout. Finally, pines, weeds, treatments, and costs are brought together in terms of recommendations that managers should find useful.

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## OPERATIONAL ENVIRONMENT OF NEW PINE PLANTATIONS

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Ponderosa pine is a major timber species in northern and central California. This region includes the east-facing slopes of the Coast Range, the Klamath Mountains, the west-facing slopes of the southern Cascade and the Sierra Nevada ranges, and the area east of the Cascade-Sierra Nevada crest known as the eastside pine type. Here this pine grows vigorously and

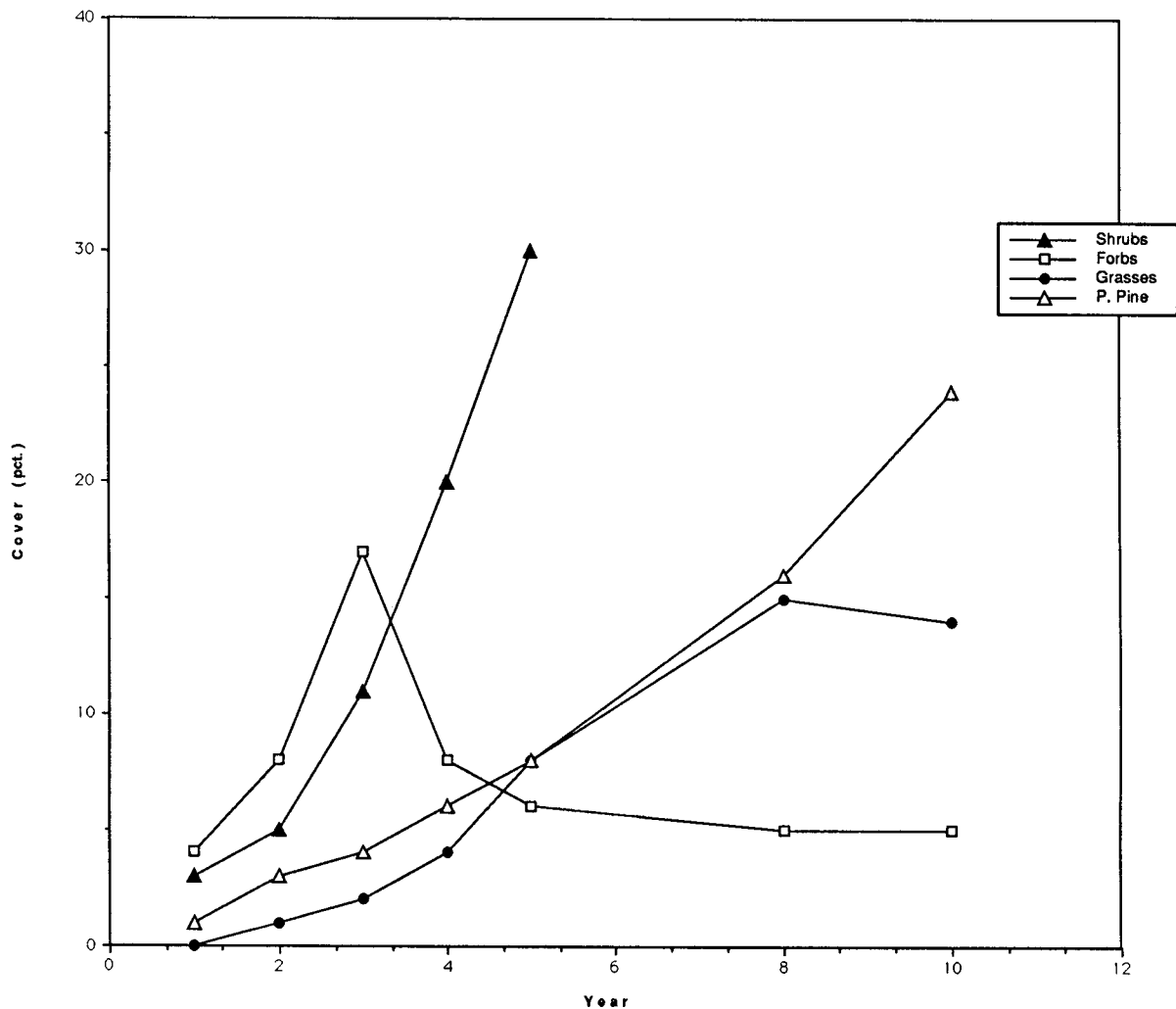


**Figure 2**—Schematic of grass, forb, and shrub cover relative to that of ponderosa pine seedlings in northern California shows the advantage of the shrubs and forbs during the first 5 years.

achieves best development in an elevational range from about 1,000 to 4,000 feet (305 to 1219 m) in the north to 2,000 to 6,000 feet (610 to 1829 m) in the south (Eyre 1980).

Broadly defined, the operational environment of ponderosa pine seedlings in new plantations includes those factors that directly affect them at some time during their life (Mason and Langenheim 1957). These include topography and soils, climate, history of land use, and characteristic vegetation and animals.

## ***Topography and Soils***

Ponderosa pine prospers on a wide range of soil textures, except heavy clays. In general, this pine grows best on medium to coarse textured, deep, and well-drained soils. In the Coast Range and Klamath Mountains, ponderosa pine stands are found on deep, slightly acid loamy and gravelly clay loams derived from sandstone and shale. In the southern Cascade Range and northern Sierra Nevada, this pine grows best on deep loams and clay loamy derived from metavolcanic rock. In the Sierra Nevada ponderosa pine grows best on deep, acid to moderately acid sandy loam soils derived from granitic rock. The species is found on thin soils, rocky slopes, and old mine spoils; some so poor that establishment is amazing. Rarely is this pine found on soils originating from serpentine.

In the central part of ponderosa pine's natural range, where it grows best, the most common soil series has a loamy texture in surface horizons grading to a clay loam with depth. The soil is deep—at least to 30 feet (9 m) as observed in road cuts. The mean soil temperature at 20 inches (0.5 m) is 47 to 55 °F (8 to 13 °C) (Laacke 1979). Above 12 inches the soil is dry from June through September, and moist in other months. Soil surface temperatures commonly reach 150 °F (65 °C) but seldom exceed 160 °F (71 °C).<sup>1</sup>

## ***Climate***

In the area where ponderosa pine is considered to be an important timber species, the climate is characterized by warm dry summers and cool moist winters. While the dryness of summers is assured, the wetness of winters is not, and droughts occur every 10 to 15 years and generally last 2 years (Major 1977). In general, the supply of water and the need for water are out of phase. The growing season is limited by the cool temperatures of winter and the lack of moisture in summer. May and June are the months when temperatures and available moisture best coincide, and when most growth takes place.

At a location in the central part of ponderosa pine's natural range in the Sierra Nevada where it grows best, the average midsummer maximum temperature (based on a 43-year record) was 90 °F (32 °C), the midwinter minimum was 30 °F (-1 °C).<sup>1</sup> The growing season was about 200 days. Annual

precipitation, also based on 43 years of record, averaged 68 inches (1727 mm) with about 98 percent falling between October and May. January (averaging 13.11 inches [333 mm]) was the wettest month followed in order by December (11.86 inches [301 mm]), February (10.77 inches [274 mm]), and March (9.48 inches) [241 mm].

## ***History of Land Use***

In the low- to mid-elevation forest zone where ponderosa pine is abundant, disturbance in the form of cutting, grazing, and fire has been severe. In some instances, the structure and species composition of the forest has been affected, in others the very forest itself has given way to brushfields and grasslands, often in combination. These forces took place in different parts of the ponderosa pine forest at different times. They are a major reason for the present-day vegetation being what it is. Knowledge of the general trends of disturbance, the species reduced, and the species favored, gives the forest manager invaluable information on past vegetation and when it might be present again. Overall trends in forest land use in California follow.

Fire has been frequent and widespread in the ponderosa pine forest. Scarcely a foot of ground has not burned in the last 150 years. Fire scars, historical accounts, and interviews with oldtimers substantiate this fact. Lightning and possible burning by Indians were the major causes of fire.

Once the white man arrived, the frequency and magnitude of burning increased greatly. Mining for gold began in December 1848 and was the impetus for a large influx of people throughout the pine region. Lumber was needed at first for the sluice boxes, rockers, flumes, and cabins of miners and later for their bridges, barns, and towns. The forests were an impediment to mining and gotten rid of as expeditiously as possible, usually by burning. In addition, lumbering was carelessly performed and if a fire started, seldom was much energy expended to put it out. Large accumulations of slash built up and added to the size and intensity of fires in many instances.

After the Civil War, gold mining and the demand for wood products declined locally, but was more than made up for by the needs of the burgeoning cities and the export market (McDonald and Lahore 1984). The advent of timber-transporting, water-filled flumes, a well developed rail system, and fleets of ocean-going schooners insured that lumber and other wood products were marketed throughout the world. By the turn of the century, the seemingly inexhaustable pine forests of the Coast Ranges and the Sierra Nevada were becoming depleted. In the eastside pine type of northeastern California, overgrazing and fire had taken their toll.

Sometime in the early 1900's public sentiment changed from regarding the forest as an impediment to mining and agriculture to regarding it as a resource that would be needed in the future. Furthermore, it was decided that steps should be taken to protect this resource and even to restore it in former locales. Many people came to believe that the use of fire must be regulated by the government to protect natural resources as

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<sup>1</sup>Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Redding, California.

well as life and property. Still others advocated that fire be excluded in timbered areas (Show and Kotok 1923). California trended toward a State policy of fire exclusion during the dry months (Phillips 1976). To this end, State and federal agencies became proficient at exhorting the public from starting fires and in controlling them once started.

In the late 1960's sentiment shifted again; this time to recognizing that excluding fire had led to the elimination of an important ecological factor in much of the pine range. Fire exclusion had increased the density of forest stands with shrubs and trees, packed stands with small trees, created a continuous vertical arrangement of fuels, shifted to more shade-tolerant species, and altered successional patterns. Controlling fire had created numerous overstocked stands with high fuel loadings. It had increased the risk of severe insect epidemics and more destructive fires. Successionally, in places it had decreased the proportion of pines and increased that of the more tolerant Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), California white fir (*Abies concolor* var. *lowiana* [Gord.] Lemm.), and incense-cedar (*libocedrus decurrens* Torr.) (Dickman 1978, Parsons and DeBenedetti 1979, Weaver 1967).

After World War II, the crawler tractor and logging truck became prevalent on forest land. The amount of timber harvested increased inexorably until the mid 1960's, particularly on federal land, and with it came an ever stronger need to reestablish the forest. Currently, State and federal policies on forest land emphasize eliminating slash, thinning overstocked plantations, regenerating pines, and wisely using fire. Since the 1950's, the management system most often used in California is even-aged with mostly clearcutting and hand planting of pines.

## Characteristic Vegetation and Animals

Plant communities within the ponderosa pine region of California have been described by several authors, but the communities have yet to be actually mapped. At the present time the Forest Cover Types listed by the Society of American Foresters (Eyre 1980) give a good overview of the vegetation. Included in each type description is a section on associated conifer, hardwood, and shrub species. Because the pine region is large and diverse in climate and soils, the vegetation is diverse as well—too diverse to describe in detail here. In most places where ponderosa pine is found, a number of woody and herbaceous species will be present. For example, in the central part of ponderosa pine's natural range where it grows best, 156 plant species were present 5 years after clearcutting. These included 4 conifers, 6 hardwoods, 30 woody shrubs, 17 grasses, and 99 forbs.<sup>1</sup>

Although many animals occasionally damage young pine plantations in California, the one with the highest potential for

extensive damage is the pocket gopher (*Thomomys* spp.). This pest is noted as being the "most serious animal hazard to reforestation in the western states" (Crouch 1986, p. 196). The porcupine (*Erethizon dorsatum*) probably is the second most destructive animal, but generally its damage is confined to small areas.

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## ECOLOGY OF COMPETING VEGETATION

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### *Distribution and Development*

Mother Nature almost always places some weeds on the land. Dormant seeds in the soil, sprouts, and seeds distributed by wind, water, and animals practically guarantee this. Through natural selection over millions of years, many weeds are superbly adapted to dominate in newly disturbed areas. And land recently prepared for planting is nearly ideal: soil moisture levels are high and nutrients generally are plentiful. Sprouting species, although damaged aboveground, quickly produce new stems and foliage. Dormant seeds, already in the soil, often germinate by the thousands. Wind-borne seeds and those dislodged from the fur, feet, and feathers of animals and birds germinate quickly and produce new offspring.

Many grass and forb seeds germinate in the fall and overwinter as small plants. After emergence, shoot growth is sporadic and generally slow because of falling temperatures. Root growth, however, probably is not slowed as much. Between the 1000- and 3500-foot (305- and 1067-m) elevations in the central Sierra Nevada, roots of resident annual grasses (*Bromus mollis* L., *B. rubens* L., *B. rigidus* Roth., *Festuca megalura* Nutt., and *Avena barbata* Brot.) showed continuous elongation even though little or no foliar growth took place. Depth of roots averaged 6.0 inches (15 cm) in January and 8.5 inches (22 cm) in March (Schultz and others 1955).

Early in spring, root growth of many grasses and some forbs accelerates, often at soil temperatures too cold for conifer root growth. Consequently, many grasses and forbs have developed fairly deep and extensive root systems by the time conifer seedling roots become physiologically active. The amount of roots that develop on grasses is large. A single wild oat plant, excavated after 80 days of growth, had developed a total root system that measured over 50 miles (Radosevich and Holt 1984). The combined roots and root hairs of a single 4-month-old cereal rye plant grown in the laboratory had a total root surface area of 2554 square feet (237 m<sup>2</sup>) and a total length of 387 miles (623 km) (Robbins and Weier 1950). Although rye grass plants develop much faster than most perennial grass seedlings, the magnitude of root and root hair development demonstrates the strong competitive nature of grasses. Furthermore, the amount of biomass on grasses is deceptive—most is not seen. Nearly 85 percent of the total standing crop of

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<sup>1</sup>Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Redding, California.

live plants in North American grasslands is below ground (Trappe 1981). A double advantage accrues to plants that first occupy an area—they capture the bulk of available resources, and they deny resources to the conifer seedlings, which have to endure not only with less resources but also with a more vigorous competitor. Once the grass and forb root systems are established, aboveground plant parts increase rapidly in size and height.

Broad-sclerophyll shrubs also emphasize early and vigorous root development. In central California, seedlings of several species of *Arctostaphylos* and *Ceanothus* emerged between March 1 and April 15 (Schultz and others 1955), suggesting that root growth of established seedlings would occur during these dates. After seed dormancy is broken, usually after a strong input of heat and light, a slender taproot is formed which grows straight down in an effort to stay in a zone of adequate soil moisture. Cooper (1922) stated "every seedling (of chamise [*Adenostoma fasciculatum* H. & A.]) possesses a well developed taproot." Seedlings of bigpod ceanothus (*Ceanothus megacarpus* Nutt.) "show a strong, early allocation of fixed carbon to the development of roots" (Schlesinger and others 1982). Dealy (1978) noted that "a pronounced specialization was demonstrated for rapid root growth in relation to top growth of curlleaf mountain-mahogany (*Cercocarpus ledifolius* Nutt.) seedlings, indicating a high potential for natural establishment in the face of severe competition."

After at least some vertical root development, lateral roots of shrubs begin to increase. Shoot growth usually is slow the first year and sometimes the second, but accelerates thereafter. Root development, and to a lesser extent shoot development, depends on species, texture of soil, depth to a hard soil layer, and other factors. At mid elevations in the central Sierra

Nevada, seedlings of wedgeleaf ceanothus (*Ceanothus cuneatus* [Hook.] Nutt.) and chaparral whitethorn (*C. leucodermis* Greene) grew unchecked throughout the summer, both above and below ground. After 9 months, wedgeleaf *Ceanothus* seedlings were 18 to 20 inches (46 to 51 cm) tall and those of chaparral whitethorn reached 9 inches. Root systems of both species extended 5 to 6 inches (13 to 15 cm) after 2 weeks, 14 to 15 inches (36 to 38 cm) after 1 month, and up to 4.5 feet (137 cm) within 3 months (Schultz and others 1955). On sites of good quality in the southern Klamath Mountains, deerbrush (*Ceanothus integerrimus* H. & A.) seedlings were 28 inches (71 cm) tall with roots at least 20 inches (51 cm) long after one growing season. On a similar site in the northern Sierra Nevada, height of the three tallest year-old deerbrush plants in a small clearcutting averaged 46 inches (117 cm) with roots of 22 inches (56 cm) (fig. 3). Roots were longer than this, but not excavated.<sup>2</sup> In the Oregon Cascades, roots of snowbrush (*Ceanothus velutinus* Dougl. ex Hook.) extended 18 to 24 inches (46 to 51 cm) after one growing season (Newton 1987). Once the root system of sclerophyllous shrubs and others like deerbrush is well in place, large increases in shoot, and presumably root, biomass occur annually for at least a decade.

Not only are mycorrhizae important on conifer seedlings, but also on many competing plant species. In general, most forage plants of arid and semi-arid rangelands are mycorrhizal (Trappe 1981), as are many woody shrubs. For example, Largent and others (1980) found a large majority of the heath and fire-adapted plants of northern California to have one or more types

<sup>2</sup>Walsh, Robert. Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Redding, California.



**Figure 3**—Shoot and root development of a 1-year-old deerbrush seedling in the northern Sierra Nevada of California. Large ruler is 48 inches (120 cm) long.

of mycorrhizae. Early seral species, however, were mostly nonmycorrhizal, at least in semi-arid Colorado (Reeves and others 1979).

Capability to capture resources intended for conifer-growth enhancement also is characteristic of some weed species. On a site of poor quality in the Sierra Nevada of California, whiteleaf manzanita (*Arctostaphylos viscida* Parry) captured most of the nitrogen added to stimulate ponderosa pine growth (Powers and Jackson 1978). Based on this example, adding nitrogen does little more than aid competing vegetation on poor sites deficient in nutrients. Reduced competition appears to be essential before fertilization can enhance conifer growth.

Another characteristic that gives vegetation a competitive "edge" is allelopathy, that is, the emission of toxic substances by one species that interferes with the life cycle of other species. Several broad-sclerophyll shrubs and grasses have been found to produce such toxic substances (Del Moral and Cates 1971, Rietveld 1975). Water-wasting has also been noted as a competitive process of broad sclerophylls (Miller and Poole 1979). Apparently these plants have the capability to use all available water and then reduce respiration to nonlethal levels. Plants not capable of reducing respiration are not able to survive once the water is gone.

Woody shrubs from sprouts have the outstanding competitive advantage of an already-established root system. This and a host of other morphological and physiological adaptations allow shrubs to prosper in a broad range of microsites, some of which are environmentally harsh for establishing conifer species (McDonald 1982). And, the harsher the site, the better adapted are the shrubs relative to the conifers. Indeed, "shrubs exemplify, more than any other kinds of plants, the great plasticity that has been largely responsible for the outstanding evolutionary success achieved by flowering plants" (Stebbins 1972, p. 120).

## **Mechanism of Competition**

Given the many attributes that give weeds an "edge," it is likely that vegetative competition inhibits early growth of conifer seedlings. For example, the relative size each year of planted ponderosa pine and seeded manzanita, and the visually negative effects of competition exhibited by pines at age 3 (Bentley and others 1971), suggests that early competition is belowground and probably at the fine root level.

The root-shoot acceleration theory (McDonald and Fiddler 1986) could explain why the absence of competing vegetation early in the life of a conifer seedling is important. Although scientific verification of the theory is weak, it is supported by much empirical evidence. In the absence of competition, conifer seedling roots extend both vertically and horizontally—but especially vertically—at the maximum rate possible. They increase in size and length, number of root tips, and in absorption capacity. By increasing the volume of soil exploited, they increase the amount of water and nutrients available for rapid growth. The resources stored in or acquired by the root system lead to production of more aboveground biomass and more

carbohydrates. This in turn fuels additional growth above and below ground in an accelerating process, which continues each year.

But competing plants (grasses and shrubs, for example), if present, begin soil exploitation and root expansion earlier and in greater numbers than conifers, thereby capturing the bulk of the resources. Conifer seedling roots consequently encounter conditions unfavorable for rapid expansion. Although the precise nature of these conditions is unknown, several causes are suspected, including moisture-depleted soil and suppression of mycorrhizal development by competing vegetation or its fungal associates.

Whatever the mechanism of competition—and it probably varies by environment and species of competing vegetation—the result is likely to be the same. Lack of initial resources available to the conifer seedling causes stress, low food production, decreased exploitation of soil, less resource collection, poor growth, and in many instances death. The likely result is a seedling that is slow to establish dominance, if ever, and frequently one that is susceptible to attack from insects and diseases. And even if the seedling survives, losses in growth are seldom made up.

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## **CHARACTERISTICS OF PONDEROSA PINE SEEDLINGS**

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Most ponderosa pine seedlings planted in California are grown in the nursery for 1 or 2 years and then outplanted in the spring. To grow millions of conifer seedlings on a production basis and to produce seedlings that will perform well in the field, the nursery manager pampers the typical bare-root seedling. It is grown in a near-optimal environment in terms of temperature, light, nutrients, and water. Within practical limits, care is taken to condition the seedling to the intended field environment. Particular care is given to ensure that roots have the potential for new growth soon after planting. Timing of root growth is critical. And the more stressful the environment, the more urgent the need to establish functional contact between the root system of the seedling and the soil. Ideal timing on a harsh site, for example, is when most conifer roots produce new growth the day after planting. Nevertheless, in just about all plantations, it probably is safe to say that the conifer seedling is placed in an environment that is more inhospitable than the nursery environment from which it came.

Needles and shoots of planted seedlings usually are those that develop in the nursery and are not altered before or during planting in the field. Root systems, however, are anything but natural, being altered by undercutting, lifting, and pruning. Roots generally are undercut at least once, in midseason, and again when lifted—the purpose being to enlarge root mass and number of small feeder roots. Length of taproot is reduced drastically in this operation, and a number of mycorrhiza-

infected roots, if present, are removed as well.

Mycorrhizae aid the host pine by increasing the efficiency of the root system for gathering nutrients and water and by protecting the roots against infection by pathogenic fungi. They also help trees to grow in soils that have high levels of organic and inorganic toxins, high temperatures, or extreme pH. The major gain to young pine seedlings is the increased absorptive surface area provided by the hyphal network, and lengthening of the timespan for root activity.

Before planting, ponderosa pine seedlings should meet certain specifications of size and expected growth performance. Although these can vary depending on the site, they usually include specifics of stem caliper, shoot length, root length, and length of new roots attained after several weeks in a standard growth medium. Based on measurements of several thousand seedlings from federal, state, and private nurseries, characteristics of typical 1-0 and 2-0 ponderosa pine seedlings were determined (*table 1*). Total root length of 1-0 seedlings averaged about 78 inches (198 cm); of 2-0 seedlings, about 250 inches (635 cm)—values much less than those presented earlier for grasses.

Expected growth performance pertains to the physiological state of the seedling, and the expression most accepted is root growth capacity. The minimum amount usually specified is 27.5 inches (70 cm) of new white roots present 4 to 6 weeks after planting. The seedlings in *table 1* exceeded this amount.

Once in the ground, the root pattern of pine seedlings is to emphasize vertical elongation. Consequently, for the 1st year or 2, a taproot develops, with only minimal growth of lateral

roots. In a study with 1-0 ponderosa pines on a wide range of sites in northern California, length of the deepest root ranged from 15.1 to 18.0 inches (38 to 46 cm) after 1 year<sup>3</sup>. On the equivalent of at least a moderate site in Arizona, the deepest root on 2-0 ponderosa pines penetrated to 29 inches (74 cm) after two growing seasons (Larson and Schubert 1969). After the roots reach a zone of available soil moisture, lateral roots develop. After one full growing season, total length of new roots of 1-0 ponderosa pine seedlings on a site of high quality in northern California averaged 101 inches (257 cm)<sup>4</sup>. Total length of new roots of 2-0 ponderosa pine seedlings on a site of medium quality in north central California averaged 59 inches (150 cm), and for Jeffrey pine, 94 inches (239 cm) after one season (Kirk 1937).

These data form the morphological and physiological base upon which a pine seedling must build to become established and to outgrow competing vegetation.

## EFFECT OF COMPETITION ON SURVIVAL AND GROWTH

The competitive effects of grasses, forbs, and woody shrubs on ponderosa pine seedlings are presented in relation to two plantation regimes: (1) eastside pine—the generally poorer, drier, sites of eastern California and Oregon, and (2) westside pine habitat—the generally better sites in the southern Cascade, Sierra Nevada, and Coast Range, which have deeper soils and more precipitation.

### Eastside Pine Habitat

In southcentral Oregon, Crouch (1979) applied atrazine<sup>5</sup> to a grass and forb community to decrease damage to ponderosa pine seedlings by lessening preferred herbage of pocket gophers (*Thomomys mazama*). After 10 years, pine survival increased by 55 percent and height by 32 percent relative to the untreated control. Atrazine reduced grasses and forbs the year after fall application and the effects persisted through the 10th year. Number of gopher mounds decreased eightfold relative to untreated controls—indicating that controlling herbage effectively lessened the competitive impact of both the plant cover and the gophers dependent on it.

In northeastern California, survival of planted pines varied

**Table 1**—Characteristics of 1-0 and 2-0 ponderosa pine seedlings before planting<sup>1</sup>

| Characteristic | 1-0                       |                       | 2-0                       |                       |
|----------------|---------------------------|-----------------------|---------------------------|-----------------------|
| Top Length     | <i>inches</i>             | <i>cm</i>             | <i>inches</i>             | <i>cm</i>             |
| Mean           | 4.9                       | 12.5                  | 7.2                       | 18.2                  |
| Range          | 3.2-7.2                   | 8.0-18.2              | 2.0-14.6                  | 5.0-37.0              |
| Stem Diameter  | <i>inches</i>             | <i>mm</i>             | <i>inches</i>             | <i>mm</i>             |
| Mean           | 0.13                      | 3.3                   | 0.20                      | 5.0                   |
| Range          | 0.08-0.22                 | 2.0-5.5               | 0.10-0.33                 | 2.6-8.3               |
| Root Length    | <i>inches</i>             | <i>cm</i>             | <i>inches</i>             | <i>cm</i>             |
| Mean           | 9.0                       | 22.5                  | 10.9                      | 27.7                  |
| Range          | 7.5-9.4                   | 19.0-24.0             | 9.1-14.6                  | 23.0-37.1             |
| Root Weight    | <i>oz</i>                 | <i>g</i>              | <i>oz</i>                 | <i>g</i>              |
| Mean           | 0.021                     | 0.6                   | 0.062                     | 1.9                   |
| Range          | 0.011-0.035               | 0.30-1.02             | 0.021-0.102               | 0.6-2.9               |
| Root Volume    | <i>inches<sup>3</sup></i> | <i>cm<sup>3</sup></i> | <i>inches<sup>3</sup></i> | <i>cm<sup>3</sup></i> |
| Mean           | 0.13                      | 2.1                   | -                         | -                     |
| Range          | 0.05-0.34                 | 0.9-5.5               | -                         | -                     |

<sup>1</sup>Data of G. A. Walters and P. M. McDonald on file at Pacific Southwest Forest and Range Experiment Station, Redding, CA.

<sup>3</sup>Lanspa, Kenneth. Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Redding, California.

<sup>4</sup>Walters, Gerald. Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Redding, California.

<sup>5</sup>This paper neither recommends the pesticide uses reported nor implies that they have been registered by the appropriate governmental agencies.

with ground cover of shrubs and grasses (Roy 1953). After 2 years, survival ranged in order from best to worst as follows: bare ground with no stones, slash, open stony ground, shrub cover, and grass cover. Also in northeastern California, 80 percent of ponderosa pine seedlings died when planted in a sown mixture of 1-year-old grasses (Baron 1962). Only 30 percent died when no grasses were present—an early indication of the value of keeping out competing vegetation when pines are becoming established.

In eastern Oregon, manzanita (*Arctostaphylos* sp.) and snowbrush seedlings did not significantly affect survival of ponderosa pine seedlings but significantly reduced their growth. Moreover, manzanita was "more severe in its competitive effect on height growth of pine reproduction than is snowbrush" (Dahms 1950, p. 2). Pine survival in the Burney Spring plantation of northeastern California improved significantly when woody shrubs were treated by burning and stripping (alternately leaving and clearing strips 30-40 feet or 10-12 m wide). Four years after this treatment, height growth of pines doubled from burning alone and tripled from stripping alone (California Forest and Range Experiment Station 1940).

The capability of grass to decrease growth of pines (up to 30 feet or 9 m tall) was demonstrated in northeastern California (Gordon 1962). Different combinations of shrubs and grasses were created beneath a stand of pine poles. After 5 years, basal area growth of pines increased 28 percent over the control when grasses were removed and 6 percent when broad-leaved shrubs were eliminated.

Near Bend, Oregon, Barrett (1979) evaluated diameter growth of trees 19 to 36 years old, half of which grew in an environment maintained free of such understory vegetation as Parry manzanita (*Arctostaphylos parryana* Lemmon var. *pinetorum* [Roll.] Wies. & Schreib.), antelope bitterbrush (*Purshia tridentata* [Pursh] DC.), snowbrush and grasses, and half with uncontrolled understory vegetation. Trees with no competitive ground cover averaged 6.5 inches (17 cm) of diameter growth per decade; those completely surrounded by understory vegetation grew only 3 inches (8 cm).

## Westside Pine Habitat

Not only do grasses lower ponderosa pine seedling survival and growth in the eastside habitat, but also in the westside habitat. On sites with heavier-textured soils in central Washington, survival of pine seedlings was increased 700 percent by spraying atrazine or dalapon before planting in a seeded grass mix containing orchardgrass (*Dactylis glomerata* L.), hard fescue (*Festuca ovina* var. *duriscula*), and pinegrass (*Calamagrostis rubescens* Buckl.) (Stewart and Beebe 1974).

Although forbs are suspected of being as troublesome as grasses during the first few years of a conifer seedling's life, few documented examples of plantation failure or growth loss are available. On the Sequoia National Forest in the Sierra Nevada, big deervetch (*Lotus crassifolius* [Benth.] Greene) caused failure of about 400 acres (162 ha) of ponderosa pine plantations. This tall perennial legume forms dense stands

after site disturbance. It also forms prime habitat for pocket gophers. The combination of overtopping, excessive moisture use, and gopher damage often causes almost total plantation failure in the first year after planting (Hipp 1985).

Vetch (*Lotus* sp.) also is a problem in ponderosa pine plantations on the Shasta-Trinity National Forest in northern California. After clearcutting and site preparation, this species can form dense stands about 18 inches (46 cm) tall. Roots are rhizominous, with each segment capable of producing a new plant. Overtopping and strong competition for moisture decreased ponderosa pine seedling survival by as much as 35 percent after 3 years (Ratledge 1985).

Several species of lupine, notably the short *Lupinus breweri* Gray, and the tall *Lupinus andersonii* Wats., negatively impact the establishment of ponderosa and Jeffrey pine seedlings in plantations on the Sequoia National Forest. If lupine is present in a significant amount immediately after planting, the plantation generally fails. Both species possess extensive root systems and both attract pocket gophers (Rogers 1985).

While the effect of shrub seedlings on the growth of conifer seedlings of the same age is usually not apparent for several years, the effect of shrub sprouts on conifer seedling growth usually is observable after 1 or 2 years. In southwest Oregon, Douglas-fir seedlings were planted in treated and untreated areas where competing vegetation was primarily sprouts of canyon live oak (*Quercus chrysolepis* Liebm.) and greenleaf manzanita (*Arctostaphylos patula* Greene). After just one growing season, the negative effect of the resprouting shrubs could be seen. After five growing seasons, excavation showed that seedlings in the control and lightly treated areas had produced virtually no new roots and had retained the same shape of root system as that when planted. And root biomass of essentially free-to-grow seedlings was 9 times that of seedlings planted immediately after slashing and 22 times that of seedlings planted among 3.3-foot (1.0 m) tall sprouts in the untreated areas (Tesch 1988). In northern California, biomass accumulation of 1-year-old greenleaf manzanita sprouts on a good site was approximately 60 times that of ponderosa pine seedlings (Radosevich 1984). After the third growing season, reductions of 80 to 90 percent in pine growth were noted from shrub proportions of 50 percent or more.

As long ago as the turn of the century, brushfields in western National Forests were regarded as furnishing competition to conifer seedlings. On the Crater National Forest in the Cascade Mountains of southern Oregon, Foster (1912, p. 221) reported "there is more danger that brush may hinder rather than aid reproduction. It is often so dense as either to preclude it, or retard its growth." On a medium site in the Shasta-Trinity National Forest of northern California, Bentley and others (1971, p. 4) first noticed a decline in vigor of ponderosa pine seedlings because of shrub competition after the third growing season. After 5 years, "the data clearly show that brush control promoted growth of ponderosa pine seedlings planted on a cleanly bulldozed area." The data also showed that more brush control during the first 5 years might have promoted early growth of pines. On a good site in the northern Sierra Nevada, reducing greenleaf manzanita density by 75 percent did not

free pine seedlings for adequate growth (Radosevich 1984). Rapid regrowth by the remaining 25 percent soon equaled the competitive effect of that removed.

Based on a somewhat limited sample of 4- to 10-year-old ponderosa and Jeffrey pine plantations in central California, Kirchner and others (1978) showed that with a shrub crown cover of 10 percent or less, diameter growth of pines would equal or exceed that expected from intensive forestry. When shrub crown cover exceeded 60 percent, diameter growth was below that needed to meet intensive forestry growth objectives.

Five long-term studies in northern and central California evaluated the effect of woody shrubs on ponderosa pine seedling growth. In the first study in El Dorado County, Tappeiner and Radosevich (1982) examined the effect of beararm (*Chamaebatia foliolosa* Benth.) on survival and growth of planted ponderosa pine seedlings on a good site. Treatments were free-to-grow beararm, beararm sprayed with a mixture of 2,4-D and 2,4,5-T, and beararm eliminated by a combination of herbicide, clipping of sprouts, and trenching to prevent root and rhizome invasion. After 19 years, tree heights averaged 5.2 feet (1.6 m) with no treatment, 6.2 feet (1.9 m) with the mixture of 2,4-D and 2,4,5-T, and 18.7 feet (5.7 m) with the combination of treatments. If extended to 50 years, net wood production in uncontrolled beararm would have been reduced an estimated 75 percent.

In the second study, which was on a good site in Yuba County, ponderosa pine was planted at five spacings ranging from 6 by 6 to 18 by 18 feet (2 by 2 to 5 by 5 m) with half of each plot maintained in a shrub-free condition and half with naturally occurring shrubs. Over all of the spacings after 15 years, shrub competition reduced periodic annual increment (PAI) diameter at breast height by 31 percent, height by 29 percent, and stem volume by 51 percent (McDonald and Oliver 1984). For the period 14 to 20 years, the PAI volume reduction was 41 percent (Oliver 1988).

The third study also involved tree spacing and understory vegetation, but on a poor site in Colusa County. For the period 5 to 10 years after treatment, PAI basal area per acre was reduced 65 percent by shrub competition. Close spacing of trees did not restrict shrub growth, but increasing shrub density decreased ponderosa pine growth. Apparently, the shrubs were better adapted to utilize site resources than the pines. Also, pine terminal deformation by the gouty pitch midge (*Cecidomyia piniinopis*) and other insects was related to the crown cover of woody shrubs. At age 5 for example, only 10 percent of trees in shrub-free areas suffered deformed tops, but 23 percent of trees in areas with 60 percent shrub crown cover suffered serious damage (Oliver 1988).

Comparing the two spacing studies led to a significant finding. Loss of tree growth was proportionally more on the poor site, but in absolute terms the growth loss was greater on the good site—a finding that extended knowledge on the effect of shrub competition.

The fourth study, located on a medium-to-poor site in Siskiyou County, quantified the growth of ponderosa pine relative to various densities of woody shrubs (McDonald and Oliver 1984). After 18 years, foliar cover, height, and stem

diameter of pine differed significantly among shrub density classes (table 2). Average pine cover, height, and diameter increased significantly as shrub density decreased.

On no-shrub areas, shrubs were removed at age 2 and age 4. Removing shrub competition at an early age is critical because it allows conifer seedlings to capture as much of site resources as possible. This process probably was a key factor in the rapid development of pines in shrubless areas.

**Table 2**—Ponderosa pine values by shrub density class in a plantation near Mt. Shasta, California, 1962-1979

| Density class | Density         | Cover      | Height    | Diameter      |
|---------------|-----------------|------------|-----------|---------------|
|               | <i>no./acre</i> | <i>pct</i> | <i>ft</i> | <i>inches</i> |
| No shrubs     | 1000            | 46         | 16.5      | 5.1           |
| Light shrubs  | 1000            | 29         | 12.0      | 3.9           |
| Medium shrubs | 1000            | 23         | 9.3       | 2.9           |
| Heavy shrubs  | 750             | 8          | 5.8       | 1.4           |

Five years after pine planting, a native needlegrass (*Stipa* sp.) began to invade the area. Two years later, it was well established in the no-shrub and light-shrub plots. After 18 years, needlegrass density was related to shrub density:

|                | Needlegrass density                  |           |
|----------------|--------------------------------------|-----------|
| Shrub density: | <i>plants per acre (per hectare)</i> |           |
| None           | 50,000                               | (123,500) |
| Light          | 17,600                               | (43,472)  |
| Medium         | 8,200                                | (20,254)  |
| Heavy          | 533                                  | (1,312)   |

Plainly, lack of shrubs led to increased densities of needlegrass. More importantly, once the shrubs were eliminated in the no-shrub plots, they did not reestablish in spite of the almost certain presence of seed in the soil and constant dissemination by birds and animals from sources nearby. Interference by needlegrass, whether chemical (allelopathy) or physical (resource capture), prevented germination of shrub seeds (McDonald and Oliver 1984).

Also noteworthy, insect damage tended to increase with increasing shrub density. Damage to terminal buds by the gouty pitch midge and possibly other insects occurred almost annually, occasionally reaching near-epidemic status. In 1973, for example, the proportion of damaged trees was 2 percent in the no-shrub plots, 1 percent in light shrub, 12 percent in medium shrub, and 31 percent in heavy shrub plots.

The fifth long-term study was installed on a poor site in Sierra County, where shrub density classes were light, medium, and heavy (McDonald and Oliver 1984). Because of burgeoning shrubs, the plantation was aerially sprayed 4 years after planting with 2,4,5-T. After 15 years, foliar cover and height of ponderosa pines differed significantly among shrub density classes (table 3). Decreased pine growth was evident as shrub density class changed from light to heavy. In fact, pine height growth in the medium- and heavy-shrub classes was insufficient to meet Forest Service timber growth objectives

**Table 3** —*Ponderosa pine values by shrub density class in a plantation near Downieville, California, 1964-1978*

| Density class | Cover      | Height    |
|---------------|------------|-----------|
|               | <i>pct</i> | <i>ft</i> |
| Light shrubs  | 29         | 8.4       |
| Medium shrubs | 18         | 6.8       |
| Heavy shrubs  | 14         | 5.9       |

(Fiske 1982), corresponding to a similar finding in the fourth long-term study.

In the light-shrub plots, where all or most shrubs were eliminated, the perennial forb woolly nama (*Nama lobbii* Gray) became abundant. Areas with an initially dense cover of woolly nama remained free of woody shrubs for the length of the study. However, on nearby areas with no woolly nama, new greenleaf manzanita seedlings became established.

The herbicide treatment at age 4 reduced total shrub density by 30 to 49 percent, depending on shrub density class; foliar cover decreased by 56 to 71 percent; and shrub height was lowered by 14 to 33 percent. Mortality from the herbicide continued for an additional 2 years and amounted to about 100 plants per acre (247/ha). Had the herbicide been applied earlier—say at age 2 when the shrubs were smaller—treatment likely would have been more effective.

The effect of competing vegetation differs little between eastside and westside habitats. In both habitats, grasses, forbs, and woody shrubs have strong negative effects on survival and growth of conifer seedlings during the establishment period. However in the westside pine habitat, information on grasses affecting conifer growth after establishment is conspicuously absent.

## How Much Competition Is Too Much?

At an April 1985 meeting of industrial, Forest Service, and research professionals concerned with vegetation management in California, the research priority identified was to assess "how much competition is too much?". Quantifying vegetative competition is of particular interest to silviculturists, and such questions as: "beyond what amount of competing vegetation is there going to be a serious impact on pine growth?" and "when should treatment begin and how much treatment will be necessary?" often are asked. Similar questions have been asked in agronomy, with answers like: "one weed per 30 feet (9 m) of row is costly in years to come" and "the weed threshold is zero" (Norris 1986).

As hypothesized in the root-shoot acceleration theory, almost any competing vegetation within the space needed for maximum growth of a pine seedling early in its life is potentially too much. After observing shrub and pine seedling growth relationships for several years, Bentley and others (1971, p. 4) were the first to address the issue of too much:

there is no "benefit in pine growth from reducing the brush volume index below 10,000 ft<sup>3</sup> per acre at age 5 years"—implying that beyond this volume of shrubs, growth of ponderosa pine seedlings would be negatively affected. Barrett (1973) recommended that understory vegetation of mostly shrubs be sprayed at 15 percent ground cover, which implied that this amount was too much. Kirchner and others (1978) showed that too much occurred at a shrub crown cover of 30 percent.

From two long-term spacing studies, "the (regression) equations suggest that any amount of shrubs will restrict diameter growth," and beyond 30 percent crown cover, the shrubs dominate (McDonald and Oliver 1984 p. 85, Oliver 1984). Data from the study in Siskiyou County suggest that shrub cover of 15 to 21 percent caused a marked decline in pine height growth. In the study in Sierra County, total foliar cover was only 28 percent after 15 years. Plotting pine height over shrub cover indicated that between 10 and 15 percent cover markedly reduced pine height. Any amount of shrubs, however, probably reduced pine growth in this harsh environment (McDonald and Oliver 1984). In general, crown cover is too much when it exceeds 10 to 20 percent on poor sites and 20 to 30 percent on good sites.

How much space around each seedling is needed to minimize growth loss? In the foothills of the Sierra Nevada, scalps 3.5 by 4.0 feet (1.0 by 1.2 m) were created around newly planted ponderosa and Jeffrey pine seedlings in the spring. In June, survival was 93 percent, but by August few seedlings were alive. Roots from grass plants bordering the scalps grew into the openings and robbed the pine seedlings of critical soil moisture (Jenkinson 1983). In northern California, openings 2 feet and 4 feet (0.6 and 1.2 m) in radius around newly planted pine seedlings were kept intact on some plots and after three growing seasons were expanded from 2 to 4 feet and from 4 to 6 feet (1.2 to 1.8 m) on others. Data were analyzed after two additional seasons. Results showed that the 4-foot radius was not adequate to prevent woody shrubs from significantly impacting ponderosa pine seedling height and diameter.<sup>1</sup>

Similar data from plots with radii larger than 6 feet are not available for ponderosa pine, but are available for Douglas-fir seedlings. On a good site in the Plumas National Forest, Stone (1984) found that sprouting hardwoods and shrubs negatively impacted Douglas-fir seedling diameter and height growth, with diameter being affected most, and recommended that the release circle be at least 8 feet (2.4 m) in radius. On the Siskiyou National Forest in Oregon, 3-year stem diameter growth of Douglas-fir seedlings differed significantly between clearings of 4- and 8-foot radii (Jaramillo 1986). Growth of seedlings in 12-foot (3.7 m) radius circles was consistently better than in 8-foot circles for both height and diameter, which implied that roots of bordering vegetation were impacting growth.

The question of which shrub parameter best measures competition has not been answered fully. In a test of crown volume

<sup>1</sup>Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Redding, California.

versus crown cover as measures of above-ground shrub competition affecting pine growth, Oliver (1984) found that crown cover percent yielded a higher correlation ( $r = 0.71$ ) than crown volume ( $r = 0.62$ ). Instinctively, total shrub biomass or leaf area index seem best, but these parameters are difficult to measure and interpret. The merit of using crown cover is the ease of estimating and interpreting the effect of relative amounts. Probably no single parameter is best for all species of shrub in all environments; but until more work is done, crown cover remains the most practical estimator of shrub competition.

The amount at which competition becomes excessive needs to be recognized for grasses and forbs. Based on limited studies but much field observation, one grass plant in a 6-foot square (1.8 m) (about a 3-foot or 0.9-m radius) around a new pine seedling early in the season is probably too much (McDonald 1983a). The presence of too much grass *after* pines become established is of concern only on poor sites where pine and grass roots compete throughout the soil profile. On good sites with deep soil, grass roots seldom extend as deeply as those of pines and shrubs. Resources used by grass are less than those used by deeper-rooted shrubs. Consequently, grass on good sites may never reach excessive levels. And, if grass becomes established first and in large numbers, it may keep shrubs from reestablishing (McDonald 1986).

For forbs, too much competition relative to ponderosa pine seedlings is relevant only for relatively large, densely rooted species that become abundant quickly. Within this framework, variation is so large that each species of forb must be evaluated independently.

The question of which parameter provides the best indication of competition to ponderosa pine seedlings also applies to grasses and forbs. The answer is virtually unknown. Because much of total grass biomass is below ground, the best parameter probably should incorporate a measure of below-ground material. But until an easy method for quantifying below-ground biomass is found, perhaps plant density is the most *practical*. The best parameter for forbs depends on species and, at least in part, on how resources are distributed. For species that channel the bulk of resources below ground, density may be best; for those that channel most resources above ground, cover or volume seem the most practical.

Ultimately, the best parameter for quantifying competition is one that expresses the relationship between site occupancy and competition. For a species of native bunchgrass, for example, 10 percent cover (or any other measure such as leaf area) might equal total site occupancy and 100 percent competition to a ponderosa pine seedling. Much bare ground and a few large plants or little bare ground and many small plants could make up this 10 percent. Consequently, for all vegetation—shrubs, forbs, and grasses—the best parameter that expresses competition for an individual species may be an index value. This value would express the relationship between percent cover and site occupancy.

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## SITE PREPARATION

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Site preparation consists of a broad range of activities of varying intensity whose purpose is to accomplish one or more tasks. The primary task is to remove competing vegetation to reserve soil moisture and nutrients for the intended conifer seedlings (Schubert and Adams 1971). Other important tasks are to free the area from logging slash, thereby facilitating access and lessening the amount of organic material that could interfere with the planting process; and to reduce fuel loading, which in turn would lessen the chance of catastrophic fire. Another important goal, often accomplished concomitantly, is to create less desirable habitats for insect and animal pests.

Time, as a factor in site preparation, is receiving increasing attention today. Time that land is idle or not at full production can be viewed as a cost. And the more time that elapses between harvest and site preparation, the more nutrients that will be available for use by an increasing amount of competing vegetation. And the more time between harvest and site preparation, the greater the likelihood of pocket gophers. That site preparation occur immediately after harvest is clear.

If reforestation is needed, site preparation is also needed. This is because a site that was good enough to grow timber is also good enough to grow weeds. Unless a site was recently burned—in effect already prepared—almost all areas intended as plantations require some form of site preparation. Consequently, the manager has no choice. Once the decision has been made to establish a plantation, site preparation must be done. The long term effects of site preparation, which is the first opportunity that the manager has to create an environment beneficial to the intended crop, are not clear. In some instances yield has increased, in others it has not. Results are fragmented by section of the country, method of site preparation, environment, and weed and tree species (Stewart and others 1984). At this point, all the manager can do is to try to be sure that the technique chosen will accomplish the job, not negatively impact the soil or its nutrition, and be cost effective.

The site preparation techniques most used in California are mechanical, chemical, use of prescribed fire, or some combination of all three. Which technique is best applied where is determined by such concerns as the steepness of the slope, the kind and amount of slash or vegetation, the species to be planted, the species to be controlled, sensitivity of the soil to burning, need to improve the physical condition of the soil (ripping for example), and weed species that are likely to ensue. Although site preparation in California has ranged from drastic to gentle, only the techniques listed above will be described here. Each is presented in terms of methodology, cost, and effect on nutrients, subsequent vegetation, and mycorrhizae, where applicable.



**Figure 4**—On level ground, a skilled operator with a brush rake-equipped tractor can do an excellent job of piling slash and preparing the ground for planting.



**Figure 5**—Masticators are useful for "shortening" tall brush and leaving the ground covered with organic material.

## Mechanical Methods

Mechanical site preparation usually involves use of heavy machines such as bulldozers (*fig. 4*) with and without rippers, and chippers and masticators (*fig. 5*) (Roby and Green 1976). The primary machine is usually a crawler-tractor equipped with a toothed blade, but occasionally a straight blade for piling slash. Bulldozers with a toothed blade, or brush rake as it often is called, are especially effective on gentle terrain and on slopes up to 35 percent, provided that soils are stable. Competing vegetation is uprooted or sheared off and placed in piles or in windrows oriented up and down the slope. A skilled operator places little soil in the windrow, and the ridges of soil on the contour created by the tractor serve as erosion catchments. In addition, thousands of little surface dams of twigs, stones, and organic debris slow the movement of water and reduce erosion. Windrows rarely are soaked through by early fall rains and carry fire well after a few days of drying. A single ignition at the downhill end creates a fire that usually travels throughout the windrow. Because the surrounding forest usually is wet, the chance for escape is small and the need for standby crews is low. Consequently, the cost of burning windrows also is low (McDonald 1983b). And the concentrated fuel burns hot and clean—a desirable characteristic in air pollution-prone areas.

In addition to the cost of burning windrows, which ranges from \$25 to \$75 per acre (\$62 to \$185/ha), mechanical scarification averages between \$80 and \$145 per acre (\$198 and \$358/ha). In this paper, cost data are expressed in 1986 dollars

and derived from many published and unpublished sources. Overhead and chemical costs are excluded.

Removing the topsoil by mechanical means can lead to nutrient loss through increased erosion and leaching to ground water. In one study, sediment yields in runoff were increased by over 14 percent on 30 to 50 percent slopes; in another with clearcutting, nitrate concentrations in the soil solution were more than 11 times greater from areas between windrows than from the uncut forest 6 years after harvest. Concentrations of potassium, magnesium and calcium also increased greatly in the soil solution (McColl and Powers 1984). In sapling- and pole-sized ponderosa pine stands in northern California and southern Oregon, Powers and others (1987) tested the soil for mineralizable nitrogen at the 7- to 9-inch (18- to 23-cm) depth. On areas that had been scalped, mineralizable nitrogen averaged 15.5 ppm and on areas that had not been scalped, nitrogen averaged 24.9 ppm.

The species of competing vegetation that are present on an area often differ by type of site preparation. In general, mechanical site preparation often leads to an abundance of manzanita seedlings, as compared with broadcast burning, which results in large numbers of seedlings from *Ceanothus* species. On a good site in the northern Sierra Nevada where the ground was scraped, whiteleaf manzanita was favored throughout the compartment; on the edge of the windrows, deerbrush was abundant; and in the severely heated soil where burning took place, prickly lettuce (*Lactuca serriola* L.) was the only vegetation present. Site preparation with a brush rake can encourage manzanita seedlings, but snowbrush sprouts. Apparently



**Figure 6**—On steep ground, herbicide application by helicopter is an economical and effective method of site preparation.

the burls of snowbrush are either deeper in the soil and not as easily dug out or sheared off, or they are more firmly anchored than manzanita burls. Consequently, manzanita must reproduce from seed to be present, but snowbrush need only resprout.

## Chemical Methods

Chemical preparation of the planting site involves applying herbicides aerially (*fig. 6*), from a boom mounted on wheeled or tracked vehicles, or by hand. Each chemical has a distinct effect on the environment of conifer seedlings. Often several alternative chemicals are available that can be used in establishing conifers on a given site, but cost and need for retreatment or animal control dictate choice (Newton and Roberts 1977). Effectiveness depends on susceptibility of the weed to a particular chemical, suitable environmental conditions for applying the chemical, and proper delivery of the chemical to weed surfaces.

With suitable conditions, most grass and forb populations are killed outright by herbicides, and many times young shrub populations are killed as well. Older shrub populations, however, rarely are killed. Usually at least the top half of the crown is affected, sometimes the entire crown, and occasionally the entire plant. Sometimes patches of vegetation are killed while those nearby are left intact. Such variability is common, even in the best of conditions.

Chemicals best suited for treating grass populations, either as seed or plants, in soon-to-be ponderosa pine plantations, are amitrole, hexazinone, dalapon, simazine, atrazine, and glyphosate (Newton and Roberts 1977, Hamel 1981). Broadleaf herbs are susceptible to 2,4-D, amitrole, glyphosate, and hexazinone. Young shrub plants less than 3 years old generally succumb to hexazinone and glyphosate as well. Because the smaller grasses, forbs, and young shrubs do not impede access, almost any means of chemical application is possible.

Older, larger shrubs of many species are susceptible to 2,4-D, triclopyr, and possibly other herbicides in specific environments. Application at label amounts in stated seasons generally is adequate. The older shrubs often form almost impenetrable brushfields and limit chemical delivery to aerial means.

Because chemical site preparation in older brushfields leaves large amounts of living and dead biomass above ground, planting of conifer seedlings usually is difficult and expensive. Debris tends to fall in the planting hole and obstructs seedling placement. In addition, competing vegetation often sprouts and provides intense competition to young conifers. For this reason, chemicals are most often used alone when competing vegetation is young and small.

Sometimes older woody shrubs are first crushed with heavy machinery, usually a bulldozer, or treated with a chemical such as 2,4-D (Bentley and Graham 1976), or glyphosate to kill enough biomass to carry a fire. The chemical often is applied aerially and mass ignition by helicopter drip torch, or manually applied primacord and jellied gasoline is effective. In this manner, height and biomass of the shrubs are reduced. And the

plants are weakened and susceptible to a second chemical application.

The cost of applying chemicals (excluding the chemical itself) ranges from \$10 to \$150 per acre (\$25 to \$371/ha). In addition to possible costs of preparing fire lines and falling snags, the cost of crushing or spraying and burning shrubs varies widely by the size of vegetation to be treated, number and size of compartments, distance among compartments and to home base, the chemical used, and the method of delivery. In general, large compartments spread costs over more acres and hence are less expensive than small compartments; several compartments, close together, and close to base are less expensive than a few compartments far apart; 2,4-D is less expensive than other chemicals; and aerial application over large acreages is cheapest, other factors being equal.

The cost of walking a bulldozer over the shrubs to crush them varies between \$125 and \$150 per acre (\$309 and \$371/ha), and applying a chemical from \$10 to \$150 per acre (\$25 to \$371/ha). Costs for burning, either by hand or aerial ignition, range from \$100 to \$350 per acre (\$247 to \$865/ha).

Site preparation by means of chemical treatment has few long-term deleterious effects on the soil or its nutrition. Short-term, increased amounts of organic material are created that can tie up nitrogen, but this usually is ameliorated by increased moisture retention and microbial action.

## Use of Fire

Fire is increasingly used to aid in preparing brushfields and harvested areas for planting (*fig. 7*). In brushfield rehabilitation, mature shrubs rarely can be treated by fire alone. The large amount of green material will not carry a fire effectively. Consequently, a combination of methods is used. Crushing the shrubs or killing the upper portion with an herbicide (a practice called "browning"), using fire to remove them above ground, and controlling sprouts or shrubs from seed with a different herbicide is an example.

Fire can be applied several years in advance of harvest or immediately after. The use of fire as a means of preharvest site preparation, or more specifically to control or reduce the amount of unwanted vegetation beneath tree crowns before harvest, has considerable promise (Martin 1982). Many species of plants that grow in the shade of existing trees and among tree roots tend to be stressed, and hence are more susceptible to control than if present in environments where resources are less limited. Areas having an abundance of understory shrubs or hardwoods, and areas where dormant shrub seeds in the soil are thought to be plentiful, seem likely candidates for application of preharvest treatment.

In the northern Sierra Nevada, tanoak (*Lithocarpus densiflorus* [Hook. & Am.] Rehd.) often is an abundant understory species in mixed-conifer forests. Although small and slow-growing in the understory (Tappeiner and McDonald 1984), some tanoaks have potential to grow rapidly after the overstory is removed, particularly if stem diameter is larger than 1.0 inch (2.5 cm) (McDonald and Tappeiner 1987). In a study involv-



**Figure 7**—With careful application, prescribed fire removes most of the fine slash and greatly reduces the heavy slash.

ing various intensities of spring and fall burns, up to 80 percent of small tanoaks were killed by high fuel consumption burns in early fall and late spring. In an area nearby, moderate intensity burns stimulated germination of thousands of seed that led to over 107,000 deerbrush seedlings per acre (264,290/ha) (Kauffman and Martin 1985). Tanoak seedlings weakened by the first burn and most of the deerbrush seedlings would be vulnerable to a second burn, which should reduce the weed populations even more.

The effectiveness of a second burn was demonstrated by a study in central Oregon where burning took place beneath a ponderosa pine forest (Martin 1982). High percentages of snowbrush, antelope bitterbrush (*Purshia tridentata* [Pursh] DC), and greenleaf manzanita were killed in a fairly high fuel consumption fire.

Burns should be scheduled as close together as possible to take advantage of weakened or young plants. Although not specifically applicable to ponderosa pine, shrub mortality in California chaparral and related communities increased when burns were conducted in consecutive years and decreased as time between burns lengthened (Zedler and others 1983).

The cost of preharvest burning usually is greatest for the first burn when high fuel loadings and fuel ladders are present. Fire lines must be installed and relatively large crews employed to control the fire should it escape. Subsequent burns utilize the same firelines, and take fewer people to implement and patrol the fires. Costs vary with a large number of site, climate, and fuel variables, but are in the range of \$50 to \$200 per acre (\$124 to \$494/ha) for the first burn and \$50 to \$150 per acre

(\$124 to \$371/ha) for the second.

The use of prescribed fire to remove slash and at least weaken vegetation remaining after harvest is a widespread practice in California. It is particularly useful on ground too steep for machines such as bulldozers and masticators. Prescribed burning has the limitation of being applicable only when rather rigid conditions of weather and fuel moisture are present. Fuel moisture must be low enough to permit burning, but duff and litter moisture must be high enough to prevent damage to the soil. Weather conditions must be conducive to safe burning and dispersal of smoke as well. Because of these limitations, the burning "window" often is narrow and sometimes not realized. Many a slash burn planned for the fall has to be postponed until spring or even to the next fall (McDonald 1983b). Many spring burns are delayed until fall as well.

Both an advantage and a limitation of the method is species adaptation to fire. On one hand, some of the most valuable timber species in the United States are invader or pioneer species that establish after fire. On the other hand, some pioneer shrub and hardwood species have adapted for millennia to take advantage of disturbance from fire. Seedbanks in the soil and sprouting, coupled with capability of rapid growth, are adaptations that often allow competing vegetation to dominate (McDonald and Tappeiner 1986). Dormant, but viable seeds in the soil often need heat to break dormancy, and species of shrubs from such seeds benefit in particular from burning. They constitute a major disadvantage for the use of prescribed fire.

This disadvantage can be overcome, at least partially, by

delaying germination of dormant seeds. Burning that leaves 1 or 2 inches (2.5 or 5 cm) of duff on the surface has been observed to delay germination of deerbrush seeds, at least until the duff decomposes, a process that takes about a year. Fire management specialists have the capability to achieve such burns with reasonable certainty (Sandberg 1980).

The cost of burning ranges from \$150 to \$450 per acre (\$371 to \$1112/ha). Because personnel and equipment needs are keyed to preventing escape of the fire, large compartments require almost the same amount of staff and equipment as small compartments. Spring burns can be expensive because of an increased need for standby crews, putting out fire remnants (mop-up), and patrol.

Burning is likely to involve some loss of nitrogen from the total soil-vegetation profile through the process of combustion and to cause an increase of nitrogen in the ash at the soil surface. In Oregon, "nitrogen losses from broadcast burning are primarily determined by the amount of duff consumed" (McNabb 1985, p. 6). A superficial burn that only scorches the litter with surface temperatures of about 1220 °F (660 °C), for example, will release only 1,200 pounds per acre (1,345 kg/ha) of nutrients (calcium, potassium, phosphorus, nitrogen). A hotter burn that destroys all the litter with surface temperatures of more than 1750 °F (800 °C) will make about 3,000 pounds (3,360 kg) of nutrients soluble and thus available for tree growth (Norum and others 1974). Of course, the soluble nutrients may be lost through leaching and erosion as well. In general, the effect of heating decreases rapidly with soil depth and amount of soil moisture. Depths below 2 inches usually are not affected greatly (Roe and others 1971). Wet mineral soil covered with wet duff had a peak temperature reduction of 932 °F (500 °C) relative to a dry soil. Temperatures in wet mineral soil did not exceed 194 °F (90 °C), and the heat load into the wet mineral soil averaged 20 percent of that into the dry mineral soil (Frandsen and Ryan 1986).

Both short- and long-term effects of broadcast burning on forest soils vary because of variables and interactions too numerous to mention. Short term, "the effects of slash burning on physico-chemical and microbiological properties of the soil appeared beneficial to fertility, but over a period of a year, apparently lessened in desirability" (Neal and others 1965, p. 2). Longterm, broadcast burning did not produce statistically significant differences in chemical and physical properties of burned and unburned soils after 25 years (Kraemer and Hermann 1979). Given a wildfire frequency rate of 4 to 20 years, which seems to be common in western forests (Kilgore 1973), another burn—probably a comparatively moderate one—would not cause major differences.

Of all the site preparation methods, broadcast burning seems to favor the *Ceanothus* species most. This is because the high temperatures of burning rupture the membrane covering the hilar fissure and permit moisture to enter—a process that begins to unlock the dormancy of the seed. Because *Ceanothus* species are nitrogen fixers, they often are thought of as being a more benign form of competition. Nearly all studies, however, have shown that negative effects from competition far out-

weigh possible nutritional gains. Only in the long term will possible beneficial effects from nitrogen fixing by *Ceanothus* species be ascertainable.

The impact of disturbance on mycorrhizae was demonstrated in a study in southwestern Oregon and northern California. Ectomycorrhizal infection was greatest on ponderosa pine and Douglas-fir seedlings growing in undisturbed forest, about 20 percent less on seedlings grown in soils from unburned clearcuttings, and 40 percent less on seedlings grown in clearcuttings that had been burned (Parker and others 1984). In western Montana, numbers of active mycorrhizal root tips were significantly reduced in an area broadcast burned 1 year after harvest (Harvey and others 1980). In Oregon, slash burning reduced mycorrhizal fungi and this reduction varied with the intensity of burn and season of burning (Wright 1971). In all instances, however, the reduction was temporary and soil microflora regained a more normal makeup the second year.

## **Combination of Treatments**

An increasingly used means of removing harvest slash and getting the site ready for planting is to use a combination of site preparation methods. A typical example is to burn the slash and apply a soil-active herbicide to control potential competing vegetation. Preharvest burning to condition shrubs followed by a postharvest mechanical treatment also is increasing. Although combination treatments are costly, they often are successful. Regeneration failures or even partial failures would be much more costly in the long run.

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## **VEGETATION CONTROL**

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### **Strategies**

When controlling competing vegetation, the goal is to provide a level of site resources that will enable the pine seedlings to grow at the potential of the site. This means that the pines must be well separated from the weeds, especially below ground. It is not enough to remove competing plants from a small radius around a pine seedling. Weeds on the edge of a small cleared area rapidly extend their roots into it, thus denying the pine seedling the competition-free environment needed for best growth (*fig. 8*). Some silviculturists and natural resource managers strive for levels of coexistence between desired vegetation and weeds. But in young pine plantations, no level of coexistence is acceptable within the space needed for maximum growth by each pine seedling during the establishment period (first 3 years) and perhaps beyond. The first year is particularly critical. The establishment period truly is the time when the base of moisture- and nutrient-absorbing roots needed



**A**



**B**

**Figure 8—**(A) Growth of this 2-year-old ponderosa pine is being slowed by grasses and forbs whose roots have invaded the 2-foot-radius opening, manually grubbed twice. (B) Growth of this 7-year-old ponderosa pine is severely impacted by roots of woody shrubs that have invaded a 4-foot-radius opening manually grubbed once.

for gathering the resources necessary for rapid growth, is developed.

From a purely biological viewpoint, the best strategy for successful pine plantations is to establish seedlings before competition captures scarce resources. Even a small amount of competitors for a short time takes a toll of growth. For example, in a trial in the northern Sierra Nevada, part of a ponderosa pine plantation was maintained in a vegetation-free condition, and part was hand grubbed to a 4-foot radius after the second and third growing seasons, and to a 5-foot (1.6 m) radius after the fourth season.<sup>6</sup> In addition, 3- to 4-foot squares of black plastic were placed around each seedling at the end of the first growing season. The principal competing vegetation was deerbrush, which amounted to 0.5 to 1.5 million plants per acre (1,235,000 to 3,705,000 plants/ha) after 1 year. Stem diameter of ponderosa pine was measured at 6 inches (15 cm) above mean groundline. After four growing seasons, stem caliper and height were 47 and 17 percent greater if free to grow:

| Treatment:   | Height      | Stem diameter |
|--------------|-------------|---------------|
|              | inches (cm) |               |
| Free to grow | 75 (191)    | 2.8 (7.1)     |
| Annual grub  | 64 (163)    | 1.9 (4.8)     |

Allowing new shrubs from seed 1.5 to 2.0 feet (0.5 to 0.6 m) away from the pines to grow each season for 4 consecutive

<sup>6</sup>Teberg, Michael. Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Redding, California.

years constituted enough competition to cause the difference in pine height and diameter.

Absence of weeds during the establishment period apparently benefits pine seedlings in many ways. It allows maximum development of the root system, increases intake of resources, and accelerates growth above and below ground (fig. 9). If competitors cannot be eliminated before planting, then their effect should be minimized by early treatment—as soon as most of the competitive plants are present, usually at the end of the first growing season.

From a management viewpoint, flexibility to meet economic, political, or multiple-use considerations may mean that some weeds in a plantation will be tolerated. For example, the budget may not allow repeated expenditures of control funds and resorting to encouraging or introducing a low-competition species that will keep out a more competitive species (biological [sic] control) may be necessary. To meet multiple use goals, cattle or sheep might be used to provide additional income and to control weeds to some degree.

## Techniques

Because the degree of competitiveness and treatment costs differ between weeds that originate from seed and those that originate from sprouts, this section is divided into these two sources of origin. For each source, control techniques are presented both to *prevent* competition and to *minimize* its effect. The material that follows is based on three background



**Figure 9**—Well developed crowns and increasing leader length are typical of rapidly growing 5-year-old ponderosa pines free of almost all competing vegetation.

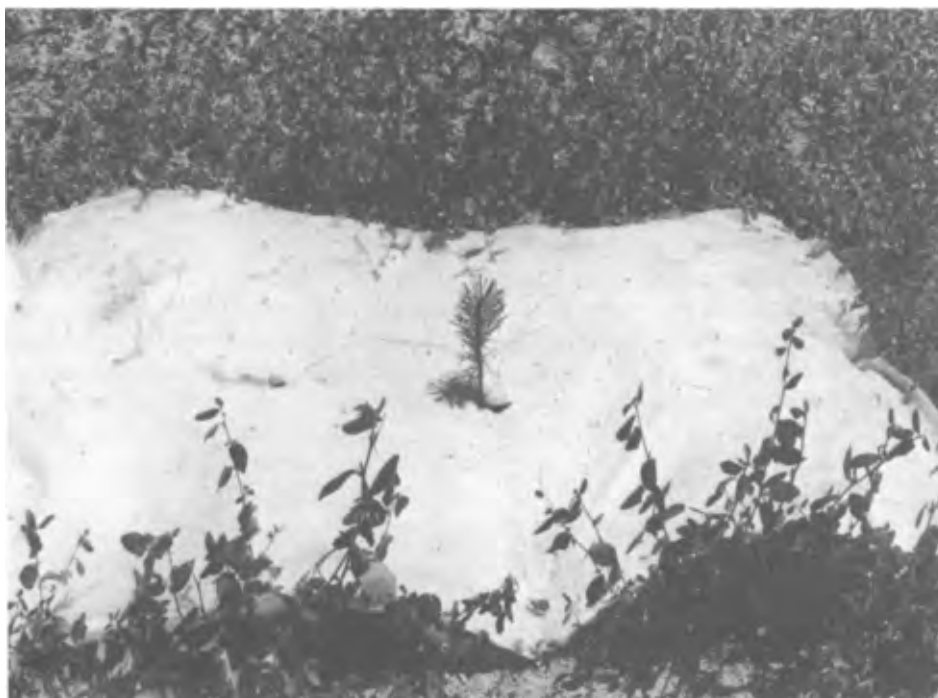


**Figure 10**—By providing some growing space, this 5-foot square polyester mat aids survival of a year-old ponderosa pine seedling growing in a dense stand of deerbrush seedlings.

assumptions: (1) the site has been properly prepared as noted earlier, and its characteristics known; (2) the bare-root ponderosa pine seedlings are representative of stock currently planted on commercial forest land in California; and (3) the major alternatives for controlling competing vegetation (chemicals, manual techniques, mechanical means, and grazing animals) are available (Fiddler and McDonald 1984).

### Weeds From Seeds

Seeds are carried into a plantation by wind or animals, or are already present in the soil in a dormant state. Techniques to prevent competition include applying a preemergent herbicide after planting and a similar or different herbicide again at age 2 or 3 as needed. Such herbicides as atrazine, hexazinone, and glyphosate have been demonstrated as effective for controlling forbs and grasses; hexazinone and glyphosate for controlling woody shrubs. Cost of application, excluding chemical costs, ranges from \$10 to \$150 per acre depending on method of application, rate, and other factors. Installing mats (sometimes referred to as collars or mulches) is another preventive technique (*fig. 10*). Should the mats degrade after 3 or 4 years, hand grubbing or direct spraying with herbicide to a 5-foot radius should be applied as needed. Mats made of polyester felts, although relatively new for this use, show promise of not degrading for at least 5 years. Those that do not degrade, but allow water to pass through and prevent growth of weeds beneath them, function as an aid to survival and growth. If at least a 5-foot radius around 250 to 350 crop trees per acre (618 to 865/ha) is covered when initially installed, mats could preclude the need for subsequent treatment.

The cost of using mats depends on essentially three factors: the cost of the mat, the cost of installing it, and the cost of making sure that it stays in place. Because the material that mats are made of varies from black plastic to fiber impregnated paper to special polyester fibers, cost varies widely—from \$0.22 to \$1.41 per 4- by 4-foot mat.<sup>7</sup> At a rate of 300 mats per acre (741/ha), the cost would range from \$66 to \$423 per acre (\$163 to \$1045/ha). Installation costs also are high. Just carrying the mats to the site is a big job, and pinning them down or placing soil, rocks, or logging debris on them takes time. On a 20 percent slope, installation of this size of mat costs between \$85 and \$130 per acre (\$210 and \$321/ha). Maintaining the mats and making sure they do not break loose and cover the seedlings involves one or two visits per year and minor additional pinning. Such costs range from \$0.10 to \$0.50 per acre (\$.25 to \$1.25/ha). In a small-scale test, the cost of purchasing special long-lasting 10- x 10-foot (3- x 3-m) polyester mats ranged from \$6.39 to \$8.42 per mat depending on grade. The installation cost was \$320 per acre (\$790/ha).<sup>8</sup>

Techniques to minimize the effect of competing vegetation are based on controlling it as soon as most propagules have begun to grow. Direct control methods, using manual or chemical treatments are recommended. Re-treatment, if necessary, should be done no later than 2 years after the initial

<sup>7</sup>Craig, Stewart. Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Redding, California.

<sup>8</sup>Smith, William. Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Redding, California.

treatment (*fig. 11*). Initial manual and chemical applications should cover the entire treatment area or form a radius around each pine seedling of at least 3 feet in grass and (orbs or 5 feet in woody shrubs. With 300 seedlings per acre (741/ha), a 5-foot radius would cover 54 percent of each acre. If the grasses and forbs are relatively large and aggressive, the radius probably should be expanded to 5 feet when re-treating. The chemical treatment should utilize the best available herbicide applied aerially or as a directed spray. For grasses and forbs atrazine/dalapon, hexazinone, 2,4-D, and glyphosate have been shown to be effective (*fig. 12*). For woody shrubs, hexazinone, 2,4-D, and glyphosate have demonstrated good control.

Costs of manual release for the initial treatment range from \$100 to \$160 per acre (\$247 to \$395/ha), and for chemical

release (excluding the chemical) from \$10 to \$150 per acre (\$25 to \$371/ha). The second round of treatments generally costs less than the first—the reduction amounting to 10-30 percent—because less chemical is used.

Another method for minimizing the effect of competing vegetation is to use grazing animals. Both cattle and sheep (*fig. 13*) have given good control of palatable weeds when rancher and forester cooperate (McLean and Clark 1980, Monfore 1983, Thomas 1984). *Ceanothus* species seem well suited to this form of control. New seedlings of deerbrush and snowbrush are virtually nonexistent in browsed plantations even though dormant seeds are in the soil and are available from nearby areas. Grazing and trampling are suspected reasons for this. Cattle and sheep physically pull out smaller shrub seedlings and browse others to the root crown. Subsequent growth



**A**



**B**



**C**

**Figure 11—** (A) A 4-year-old ponderosa pine in the center of a manually grubbed opening that was expanded from a 2- to a 4-foot radius. (B) A 4-year-old ponderosa pine in the center of a manually grubbed opening that

was expanded from a 4- to 6-foot radius. (C) Manually grubbing the entire area three times is expensive but permits rapid growth as the full needle complements and thick stems of these ponderosa pines attest.



**Figure 12**—Glyphosate herbicide has created a weed-free growing area for this ponderosa pine seedling.

also is utilized heavily. Moving the animals into the plantation at the right time, and moving them out just before they start eating young pines is critical. Heavy utilization of existing forage (65 to 80 percent) is desirable. The animals would graze the plantation beginning [sic] at age 2 and continue each year thereafter. Not only would the animals control the shrubs, but also provide a second yield from the land.

Costs for this technique are administrative minus the remuneration paid by the permittee. The administrative cost varies with the permittee and the time needed to insure that grazing is conducted properly. Although difficult to determine, the cost of using cattle and sheep is low relative to other vegetation control methods. If the permittee was experienced and needed little checking, a net gain could accrue.

Encouraging or introducing less-competitive vegetation is a relatively new and untested method for minimizing competing vegetation. It is attractive because it could end the need for a second treatment, reduce expenditures for crews or chemicals, and eliminate the lengthy process of getting permission to apply an herbicide. Utilizing less competitive vegetation consists of encouraging a local perennial forb or sowing a site-enhancing legume to keep out more competitive vegetation. An example of exclusion is preventing dormant seeds from germinating by chemical (allelopathic) or physical interference. The introduced species must be shallow rooted and not utilize much of the resources needed by the pines. Woolly nama is a good example of a shallow-rooted forb. Finding and establishing similar species should be considered.

### Weeds From Sprouts

Sprouts arise from dormant buds on burls located at or just below groundline on woody shrubs and hardwood trees. Preventing competition from sprouting shrubs and hardwoods means minimizing loss of site resources by keeping sprouts from forming. More specifically, it consists of removing or killing the sprouting platform or burl. One technique, which is still experimental, involves the use of a portable machine that grinds out the burls. It has given acceptable results on relatively level ground, but the cost is high—\$711 per acre (O'Hanlon 1986). On 35 to 60 percent slopes, an excavator (modified backhoe) removed 400 to 500 tanoak stumps per acre (1235/ha), 6 to 10 inches (15 to 25 cm) in top diameter, at a cost of \$450 per acre (\$1112/ha) (Heavilin 1986).

More operational approaches include applying an herbicide with a spot gun near a clump or stump of a sprouting species. Hexazinone currently is the chemical used, with the application rate being proportional to the circumference of the stump being treated. Sprouting also can be prevented by applying herbicides directly to the living stem by means of tree injectors, hypohatchets, or frill and squirt techniques. The chemical used most in the pine region of California is the amine form of triclopyr. It generally provides at least 75 percent kill or near-kill at a cost of \$40 to \$100 per acre (\$99 to \$247/ha). Spraying or daubing a freshly cut shrub or tree stump with the amine form of triclopyr also is effective for preventing sprouting. Costs average between \$220 and \$330 per acre (\$543 and \$815/ha).

Minimizing competition from sprouts of shrubs and hardwoods involves use of herbicides applied by helicopter, from booms mounted on trucks, or by hand. Hexazinone, 2,4-D, and



**Figure 13**—With proper herding, 3-year-old dry ewes on the Tahoe National Forest heavily browse deerbrush and perennial grass plants but avoid ponderosa pine seedlings.

glyphosate are the chemicals applied most often for this purpose in California. Triclopyr generally is not recommended for use with ponderosa pine but fall application with covered seedlings has proven successful in at least one instance (McNamara 1985). Chemicals should be applied to sprouts after the first growing season. Second or even third applications of the best available chemical may be needed. Costs range from \$10 to \$200 per acre (\$25 to \$494/ha) per application.

When chemical application is not possible and sprouts are vigorous, a series of manual grubbing and chainsaw release treatments may be applied. Grubbing a 5-foot radius around each pine seedling for the first and second years eliminates many sprouts. Cutting the shrubs as close to the ground as possible the third and fifth year reduces some competition and increases light levels. Cost of the four treatments is high—\$1,100 to \$1,400 per acre (\$2717 and \$3458/ha), and hence this series of treatments probably is limited to sites of good quality.

If the sprouts are palatable, cattle or sheep can use them as forage. Costs would be similar to those for grazing weeds from seed.

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## SUMMARY AND RECOMMENDATIONS

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A major step in achieving successful ponderosa pine plantations is to create an environment that enables the pines to

develop vigorous, expanding root systems. In the competitive struggle for limited site resources, a premium results to the pines if they become established first, preempt resources, develop large fine-root systems, and accelerate in growth. Not only is it economically sound to control competing vegetation early, it also is biologically sound to control this vegetation before it benefits from increased sunlight and nutrients liberated during harvest and site preparation.

The following recommendations include guidelines for preparing an area for reforestation, monitoring the plantation, controlling competition, and managing the plantation.

### ***Preparing the Site***

Specifically needed are alternative methods, operational guidelines, estimated costs, and a discussion of advantages and disadvantages of the sequence of site preparation techniques chosen.

- When deciding on a site preparation treatment, learn the biological, physical, and environmental impacts of different types of equipment, methods, and timing.
- Throughout treatment, pay particular attention to nutrient losses and gains, existing vegetation, impacts on mycorrhizae, and effects on dormant shrub seeds in the soil.
- On sites with gentle to moderate slopes that are low in soil organic material, or where competition from understory vegetation inhibits early conifer establishment, dispose of slash by means other than broadcast burning, and prepare the seedbed mechanically.
- When broadcast burning for site preparation, leave at least 1

inch of duff to protect the soil, preserve nutrients, and inhibit the germination of dormant shrub seeds.

## Monitoring the Plantation

Some parameters are better than others for predicting plantation performance:

- When assessing the vigor of ponderosa pine seedlings, evaluate stem caliper at 12 inches above mean ground line, rather than stem height. Caliper better reflects the severity of competition.
- Use foliar cover as a *practical* measure of competition; it is easy to estimate and has meaning to the technician and manager alike. "Competition is costly, but excessive competition is ruinous" is an important proverb of the business world. Concomitantly, when considering treating an entire area, competition from shrubs becomes ruinous (they dominate) above 10 to 20 percent foliar cover on poor sites and above 20 to 30 percent on good sites.
- Evaluate plantation success or failure not just in terms of survival, but also in terms of growth. Survival alone is inadequate because seedlings may survive for a decade or more under severe stress, but with little or no growth.

## Controlling Competition

Controlling competing vegetation and getting the seedlings off to a good start can preclude further treatments and expenses, and in turn, lessen exposure to erosion, unsightliness, and possible adverse public relations. Control of herbaceous vegetation is as important, or perhaps more so, than controlling shrubs. Where shrubs and herbaceous vegetation from seed are present during the first growing season, pine growth likely is influenced more by the herbaceous vegetation than by the shrubs. The shrubs probably have a greater influence in subsequent growing seasons.

Controlling herbaceous vegetation is important because it can be extremely variable—consisting of one to many species of forbs and grasses, each with different competitive strategies and moisture and nutrient requirements. Many of these species often are small and inconspicuous. Their numbers can increase dramatically, have a strong negative effect on pine survival and growth, and if they have short life cycles, can dry up and disappear. Herbaceous vegetation can also attract animals such as pocket gophers which have high potential to seriously damage or even destroy a pine plantation.

- Know plant succession, or be aware of forbs and grasses that are in a position to invade.
- Clear a 5-foot radius around pine seedlings to allow them time to develop a fast-growing root system. Smaller radii do not allow enough competition-free time.
- Replace a more competitive plant species with one that is less competitive. Such biological control has promise, especially for saving the cost of additional treatments. Consider stimulating native species, introducing dwarf horticultural varieties

of grasses or legumes, and treating large or aggressive native species with growth-reducing agents at the earliest opportunity.

## Managing the Plantation

Forest land managers today are confronted with a myriad of often-conflicting demands: biological, economical, environmental, and political. How they manage their plantations reflects these demands and results in emphasis being placed differently by different managers. Consequently, the material that follows is presented not as recommendations but for thoughtful consideration.

Planting fewer conifer seedlings, but giving them more intensive care, is a management alternative. Plant about 300 seedlings per acre (741/ha), say at a spacing of 12 feet (4 m) on the square, and prevent or minimize competing vegetation. This alternative provides a tradeoff between high costs of intensive treatments, and increased odds of high survival and growth. Total plantation costs could be lowered by purchasing and planting this lower number of seedlings and controlling the competing vegetation before emergence or after one growing season when plants are small and not yet well established. If the lower number of seedlings planted reduced nursery costs, savings would be even larger. One danger of wide spacing, however, is that tree form could be affected. Branches could be larger and persist longer, and more lammas whorls would be present (Carter and others 1986). If the competing vegetation were tall shrubs and a radius treatment was prescribed, the shrubs could counter the effect of the wide spacing. Where low competing vegetation is present or whole-area control is prescribed, pruning might be necessary.

Because the few competing plants present after almost all control treatments may have the potential to quickly reoccupy the site, plan a sequence of treatments. Treatment alternatives should consider the forbs, shrubs, animals, and insects that are likely to appear. The goal of the treatments should be to manipulate the vegetation to minimize disturbance to desirable species, maximize their response at a reasonable cost, and maintain or enhance the production gains secured by the initial treatment. Such planning should be an ongoing process with close examination of the plantation occurring after each round of treatments.

Even when growing timber has been chosen as the dominant use for the land and money has been spent for site preparation and the establishment of conifer seedlings, leaving bare ground even for the short establishment period is controversial. But the ground is seldom truly bare. Conifer seedlings are present and if given the resources to grow, will soon cover the area. And the likelihood of at least some forbs appearing during the first growing season is high. Advantages of near-bareground weed control are: (1) increasing evidence that conifers exceed predicted mean annual increment for the site, and (2) fertilizer, if applied, is utilized by conifers, not competing plants (Newton 1987). Disadvantages are unsightliness and possible loss of site productivity from erosion.

Too often the words "seedling survival good, but growth poor" summarize the state of a plantation. Usually such a statement is followed by an urgent request to do something to control the competing vegetation, which by this time is dominant. At this point, decide whether to accept the growth already lost, to endure the growth lost until the seedlings recover (neither of which will ever be made up), and withstand the cost of releasing the plantation one or more times, or to start over by preparing the area and planting again. If the competing species are vigorous sprouters and the alternatives for control are few, the best decision may be to start over.

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## CONCLUSIONS

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It cannot be overemphasized that the time and money required to shift dominance in favor of ponderosa pine seedlings increases significantly with the length of time that competing vegetation is present. No competing vegetation equates with no growth loss, a light amount of competing vegetation equates with moderate growth loss, and a moderate amount of vegetation often equates with complete loss of the plantation. This relationship is the most important point of this report and constitutes a governing principle for vegetation management as a whole.

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- Participation with other agencies in human resource and community assistance programs to improve living conditions in rural areas
- Research on all aspects of Forestry, rangeland management, and forest resources utilization.

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