United States
Department
of Agriculture
Forest Service

Pacific Southwest
Research Station

General Technical Paper
PSW-GTR-190

Ecology and Manipulation of Bearclover (*Chamaebatia foliolosa*) in Northern and Central California: The Status of Our Knowledge

Philip M. McDonald **Gary O. Fiddler** **Donald A. Potter**

Publisher

Pacific Southwest Research Station

Forest Service
U.S. Department of Agriculture

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

(510) 559-6300
http://www.fs.fed.us/psw

March 2004

Abstract

McDonald, Philip M.; Fiddler, Gary O.; Potter, Donald A. 2004. **Ecology and manipulation of bearclover (*Chamaebatia foliolosa*) in northern and central California: The status of our knowledge.** Gen. Tech. Rep. PSW-GTR-190. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 26 p.

Long the bane of foresters, but of interest to ecologists, bearclover inhabits thousands of acres of forest land in northern and central California. Little quantification of its recovery after disturbance is available because knowledge on the morphology of flowers, seeds, and rhizomes is fragmented, and physiological processes, especially plant moisture and photosynthetic relationships, are unknown. Consequently, most of the dozens of treatments that have been tried to manipulate bearclover have failed. Bearclover's rhizomes efficiently gather soil moisture and together with high rates of photosynthesis promote rapid growth and site capture. Using all available water limits species richness, and the plant community in established stands is limited to a few hardy species. Above-ground stem density of bearclover also is high. Because of nearly total site capture both above and below ground, successful long-term manipulation of bearclover is limited. The most effective treatments are those that kill bearclover rhizomes, and herbicides such as Roundup and Velpar are effective. In local environments, treatments such as the winged subsoiler and perhaps repeated fire at the time of flowering may prove to be effective. However, no treatment completely eliminates bearclover, and it persists as part of the plant community.

Retrieval Terms: bearclover, morphology, plant community, species development, vegetation management

The Authors

Philip M. McDonald was, until his retirement, a Research Forester with the Pacific Southwest Research Station's Western Forest Management Unit, 2400 Washington Avenue, Redding, CA 96001: e-mail: pmcdonald@fs.fed.us. **Gary O. Fiddler** is a silviculturist with the Ecosystem Conservation Staff, Pacific Southwest Region, USDA Forest Service, San Francisco, and stationed at Redding, CA. **Donald A. Potter** is a zone ecologist with the Stanislaus National Forest, USDA Forest Service, Sonora, CA 95370: e-mail: dpotter@fs.fed.us.

Ecology and Manipulation of Bearclover (*Chamaebatia foliolosa*) in Northern and Central California: The Status of Our Knowledge

Philip M. McDonald Gary O. Fiddler Donald A. Potter

Contents

Pacific Southwest Research Station

USDA Forest Service
General Technical Paper
PSW-GTR-190

March 2004

In Brief. . .

McDonald, Philip M.; Fiddler, Gary O.; Potter, Donald A. 2002. **Ecology and manipulation of bearclover (*Chamaebatia foliolosa*) in northern and central California: The status of our knowledge.** Gen. Tech. Rep. PSW-GTR-190. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture: 26 p.

Retrieval Terms: bearclover, morphology, plant community, species development, vegetation management

Bearclover, which is a widespread and well-adapted shrub in the northern and central Sierra Nevada and southern Cascades of California, is an enigma to ecologists and foresters. It produces an abundance of flowers, which presumably lead to seed, but very few seedlings have been observed. Its rhizomes, which extend the species over the landscape, seem to grow rapidly in some environments but not in others. Disturbance seems to aid the spread of rhizomes, but bearclover on the edges of plots treated with a variety of herbicides has not expanded for a decade or more. Bearclover fixes nitrogen, which should benefit conifer seedlings, but most die when this shrub is nearby.

Answers to these perplexing enigmas, plus a chronological history of the many vegetation management techniques that have been attempted to manipulate bearclover, comprise the bulk of this paper. Understanding the functions of the various plant organs and internal physiological processes helps to explain why some manipulative treatments have failed and others have succeeded.

The morphology and physiology of bearclover combine to enable it to outgrow most other plant species and to capture a site. In the spring, the dense mass of rhizomes efficiently gathers moisture, and the plant uses it to attain maximum photosynthesis and early growth. In midsummer, when soil moisture is low, bearclover plants endure high internal moisture stress, reduced photosynthesis, and low growth rates. The strategy of maximizing early growth, using all available soil moisture, and then withstanding the environmental stress of summer and fall denies soil moisture to competing plants, including conifer seedlings, and helps to ensure their absence.

Because of bearclover's long and consistent record of endangering young conifer plantations, silviculturists have applied a large number and variety of treatments to manipulate it both for site preparation and for plantation release. These include manual methods (hand grubbing), mulching (sheets of plywood, paper/fiberglass/asphalt sandwiches, black plastic, polypropylene), mechanical techniques (rotary mowers, dynamite, disking, plowing, ripping, subsoiling, terracing), burning (different dates and intensities), and herbicides (2,4-D; 2,4,5-T; Roundup; Garlon; Hexazinone; and others). Many combinations of the above also were attempted. Some treatments were outright failures; most provided a short-term increase in conifer seedling survival, but not growth; and a few were effective. Those that were effective enhanced not only survival, but also seedling stem and crown growth. Many treatments looked promising at first, but too often bearclover reinvaded and the conifer seedlings stopped growing and died after a few years.

Because the below-ground reproductive system of bearclover is extensive, deep in the soil, and primed for regrowth, it is not enough to simply damage it. Most of the roots and rhizomes have to be killed. Because selective herbicides do this, they appear to be the primary means for manipulating bearclover. Reducing bearclover density allows enough time for conifer seedlings to survive, grow at an acceptable rate, and become trees. However, even the most effective herbicides do not completely eliminate bearclover, and it remains on the site, albeit at a lower density, contributing to the diversity of the plant community.

Introduction

In this age of ecosystem management, every plant species has value as an integral component of an ecosystem, as sustenance for animals, or even as a provider of medicines or food for humans. To fully practice their art, ecosystem managers are going to need information—lots of information—on every plant species in their area of responsibility. Because detailed information on many, indeed most, plant species is absent or widely scattered, this will be a huge job. This paper on bear-clover *(Chamaebatia foliolosa* Benth) (*fig. 1*) is a start.

Bearclover, which is a member of the family Rosaceae, is a perennial evergreen shrub that is endemic to northern and central California. Its two other common names, bearmat and mountain misery, are often found in the literature. Bearclover has long been regarded as a strong competitor to natural and planted conifer seedlings, and most of the work on it has been done in an attempt to increase survival and growth of these seedlings.

Unfortunately, research on the ecology and manipulation of this shrub is scant and information is fragmented. Most information was anecdotal or from small unreplicated studies. Later larger, more detailed studies were installed, and results from them are becoming available. Nevertheless, most of the work has been concentrated at a few locations where the trials have been case histories. If there is a strength, it is that most of the major components of bearclover morphology, physiology, and manipulation have been examined, albeit not in depth. Thus, the silvicultural concepts and principles presented in this paper have support, but the data are site-specific in many instances.

The objectives of this paper are to bring together available ecological and silvicultural information on bearclover and specifically to show how the species' external organs and internal processes make it a formidable competitor to other plant species. A related objective is to translate this knowledge into methods and techniques that can be used to manipulate the development and density of bear-clover to accomplish the establishment of more desirable species.

Location and Site Characteristics

Bearclover is prevalent on south- and west-facing slopes at elevations between 1,000 and 6,000 feet in the Sierra Nevada of California and, to a lesser extent, on

Figure 1—A 4-year-old patch of bearclover with typical fern-like foliage and showy flowers.

lower slopes in the southern Cascade Range (Hickman 1993, Little 1979). This shrub is capable of occupying almost all aspects, site qualities, and soil types within its natural range (Potter 1976). However, it is less common on north and east aspects, mostly because conifer and hardwood stands are more dense on these aspects and more fully occupy the sites. With the exception of isolated stands near Burney in Shasta County, near Greenville in Plumas County, and in Kern County in southern California, most stands of bearclover are located between Yuba and Tulare Counties in the Sierra Nevada (*fig. 2*) (Potter 1976).

This shrub develops best in partial shade but grows well in a sunlit environment. In shady environments, it has sparser foliage and taller stems. Overall, it is a remarkably persistent species and, once established, maintains its presence for long periods of time.

Bearclover occupies areas that range from small patches to hundreds of acres and, in places, forms almost pure stands (*fig. 3*). Individual bearclover plants are short in comparison to associated shrub species, and rarely do plants exceed 1.5 feet in height. Disturbance, such as that from fire or logging, aids the species by removing taller trees and shrubs, thus providing additional site resources.

Figure 2—Schematic of bearclover natural range and study areas.

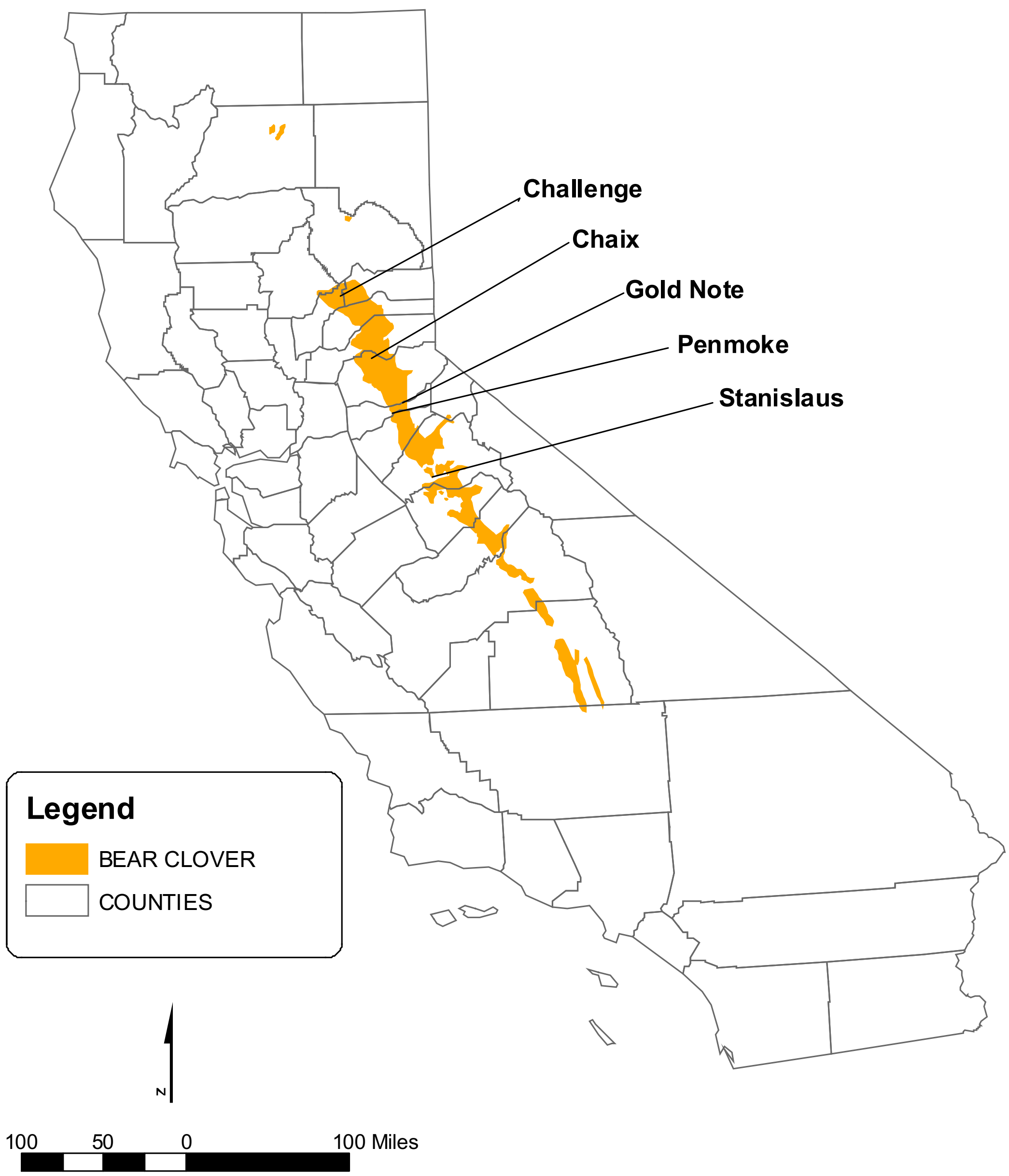


Figure 3—A mature bearclover stand in partial shade. Note the high density of bearclover and the lack of other plant species.

Because of its broad elevational range and ability to develop well in a wide range of environments, vegetative associates are numerous. The most common tree associates are ponderosa pine *(Pinus ponderosa* Dougl. ex Laws. var. *ponderosa),* incense-cedar *(Libocedrus decurrens* Torr.), and California black oak *(Quercus kelloggii* Newb.), followed by interior Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii),* California white fir *(Abies concolor* var. *lowiana* [Gord.] Lemm.), and sugar pine *(Pinus lambertiana* Dougl.). Common shrubs include those in the genera *Arctostaphylos, Ceanothus, Chrysothamnus, Rhamnus, Ribes, Rubus,* and *Toxicodendron.* Abundant annual and perennial herbaceous plants are of the genera *Cirsium, Epilobium, Eriophyllum, Galium, Lotus, Madia, Potentilla, Vicia,* and *Viola.* Grasses tend to be common associates of bearclover, and some of the most abundant species are in the genera *Bromus, Elymus,* and *Festuca.* Introduced cheatgrass *(Bromus tectorum* L.) often invades recently disturbed stands of bearclover.

This shrub appears to be virtually immune from attack by insects and disease; drought, heat, frost, and other abiotic agents rarely kill the plant. Seeds and leaves are beneficial to wildlife. Potter (1991[1]) placed numerous seeds on a board in the forest and left them exposed overnight. All had disappeared by morning; rodents were the likely culprits. Browsing by deer has been observed, particularly in the spring or after a recent burn when tender new growth is available (Adams 1969, Gibbens and Schultz 1963). Additional attributes are erosion control, use as a medicine by Native Americans (Anderson 1997), and as a source of dark, tasty honey.

Information and data for this paper have been gathered from numerous sources throughout the range of the species and from four recent studies. These studies are entitled Chaix, Challenge, Gold Note, and Penmoke. All were located in northern and central California in the Sierra Nevada Range. They were established in clearcuttings that had been created by timber harvest and site preparation. Site preparation involved removing the unmerchantable conifer and hardwood trees, as well as logging slash and shrub clumps, with a bulldozer and piling this material into windrows for eventual burning. The study areas were located at moderate elevations, on medium slopes, with average or above site quality, and plentiful rainfall (*table 1*). Gold Note (McDonald and Fiddler 1999) and Penmoke (McDonald and Everest 1996) had substantial bearclover populations, and Chaix (McDonald and others 1999) and Challenge (McDonald 1999) had more diverse plant communities not dominated by bearclover.

[1]Unpublished data on file at the Stanislaus National Forest, Sonora, Calif.

Table 1—*Physical characteristics of study areas in the northern and central Sierra Nevada of California*

Study	Site quality	Slope	Elevation	Average annual precipitation
		pct	*ft*	*inches*
Chaix	High	23	3,700	50
Challenge	High	20	2,750	68
Gold Note	High	20	4,000	40
Penmoke	Medium	15	5,000	55

The Chaix, Gold Note, and Penmoke study areas had three to six replications, including a control, and all had planted ponderosa pine seedlings growing in them. The Challenge study area differed from the others in that it was not replicated and had natural pine regeneration. In each replication, there were at least five permanent milacre (0.001 acre) plots on which vegetation was periodically measured. Because individual bearclover "plants" were impossible to determine, stems were carefully counted on each plot and presented as a per-acre value. Foliar cover was estimated to the nearest square foot, recorded as a per-acre value, and then converted to a percentage. If less than 0.5 square foot, foliar cover was denoted as a trace (T). Height was calculated as the average of the three tallest stems on a sample plot. One factor common to all areas where bearclover is found is the Mediterranean climate, which is characterized by long, hot, dry summers and cool, wet winters. May through September often are rainless. In this climate, almost all plant species have adopted a strategy to grow as fast as they can as soon as they can, and to set seed before the onset of summer drought.

Ecology

Morphology

Extensive literature and numerous observations describe the propensity of bearclover to produce abundant flowers almost every year. The flowers are white to cream colored, small, and showy, suggesting that insects are the primary pollinators. At the Challenge Experimental Forest in north-central California, time of flowering for bearclover was recorded in 1976 and 1979 at 2-week intervals. This highly productive site is located at the 2,750-foot elevation. Flowers were first produced from May 7 to May 25 and last produced from September 10 to September 15 (McDonald 1980[2]). However, one or two plants were still flowering in early November. In partial shade on the Stanislaus National Forest in central California, again on a highly productive site, peak flowering occurred from May 26 to June 12, 1989, and within a week of these dates for the next 2 years (Weatherspoon 1989).

Thousands, if not millions, of seed are produced, but bearclover seedlings are rarely seen. After many hours of searching on hands and knees, no seedlings were found on study plots in clearcuttings in several study areas in northern California. However, in another study in central California, where bearclover was growing beneath a partial overstory of ponderosa pines, more than 50 new bearclover seedlings were found at three locations over a 3-year period (Everest 1996). The seedlings were present in both burned and unburned plots during March through June, and many were beneath mature bearclover plants. Seedlings were 0.5 to 1.5 inches tall, and some still had the remains (cotyledons) of the seeds attached (*fig. 4*). Sixteen of these seedlings were flagged in 1996 and searched for in September 2001. No trace of any seedling was found, and competition from the mature plants was the likely cause of mortality.

[2]Unpublished data on file, Pacific Southwest Research Station, Redding, Calif.

Figure 4—Tiny just-emerged bearclover seedlings with cotyledons still attached. Distance from the base of the cotyledon to top of most developed plant is 1 inch.

Reigel (l991) germinated bearclover seed in a greenhouse and found 93 percent germination. After 6 months, survival was described as high. The growth pattern of bearclover seedlings (from seed) is to initially form a taproot and then to produce lateral rootlets. Tappeiner (1989) collected seed from mature bearclover plants in central California and grew seedlings in the laboratory. Rhizomes were not produced during the first 3 years.

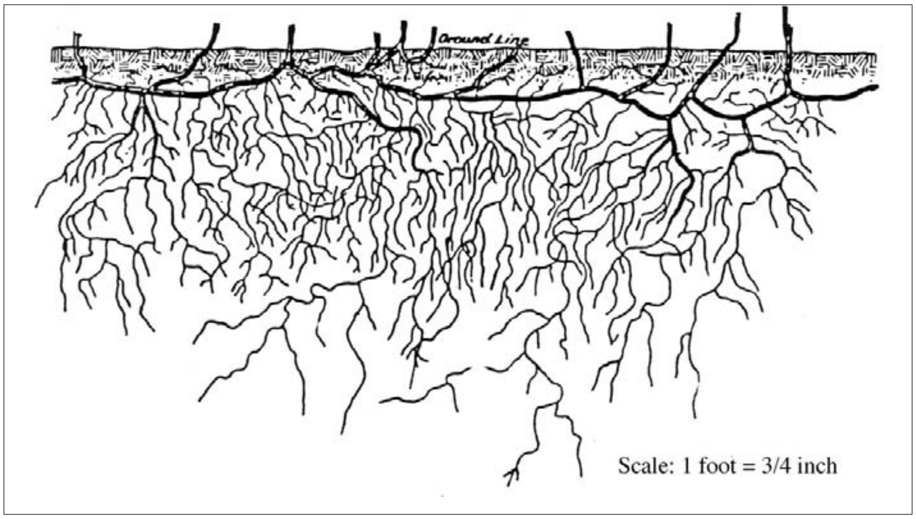
In 1978, Potter[3] tested the sprouting ability of severed pieces of bearclover. He built wooden boxes, filled them with soil, screened them to be sure no bearclover was present, and then buried pieces of living bearclover roots and rhizomes in them. Many pieces sprouted at the nodes and turned the soil surface in the boxes "green." On the Eldorado National Forest, Lyons (1913) noted that bearclover seedlings grow from 3 to 5 inches tall the first season, then branch out, and grow very slowly in height thereafter. For immature plants, stem elongation is rapid in the spring, with most growth accomplished while soil moisture is present. For mature plants, height growth virtually ceases, and crown expansion is lateral, provided that space is available. Many plant stems die after age 12 and are replaced by new shoots from the root crown. On the Stanislaus National Forest, Wulff (1914) counted rings on bearclover stems and found their age to vary between 9 and 18 years.

Bearclover produces new leaves each year, retains its old leaves for about 2 months, and then sheds them (Rundel and others 1981). Thus the stem is always clothed. Leaves are heavily scented, glandular, and have a fern-like structure. They are produced on short flexible stems that arise from below-ground organs. The glandular secretion has been described as highly resinous, hydrophobic, and amounting to about 140 pounds per acre in a medium density stand (Fredrickson 1994). Large numbers of stems (up to 104 per square foot; Munns 1922), relatively high volume (5,316 ft^3/acre at age 4; Lanini 1981), and rapid growth (6 to 8 inches the first year after disturbance) virtually exclude colonization by other plant species.

The root system consists of an extensive network of rhizomes 4 to 16 inches below the soil surface and taproots that often extend to depths of 6 feet or more (Potter 1976). Fredrickson (1994) dug trenches through bearclover stands and mapped rhizomes on the sidewall. He found that most rhizomes were located in the surface 12 inches of soil with statistically fewer in the 12- to18-inch strata. Munns (1922) excavated part of a bearclover root system and sketched the density and distribution of the roots (*fig. 5*). Lateral extension of rhizomes from mature

[3]Unpublished data on file at the Stanislaus National Forest, Sonora, Calif.

Figure 5—Typical rhizome/root system of bearclover (Munz 1922).



plants in undisturbed areas is reported in general as slow (Coombes and McHenry 1984, Potter 1976), but rapid after disturbance, especially burning (Rundel and others 1981). Several investigators (Fredrickson 1994, McDonald and Fiddler 1999, for example) have noted that sprouting, which occurred in disturbed areas, stopped abruptly at the edge of the treated zone. But whether slow or rapid, extension over time is impressive. One rhizome in a previous study was traced horizontally for almost 90 feet (Munns 1922).

To study rhizome elongation, two 10-foot-long permanent transects with 11 evenly spaced metal pins were installed in a clearcutting in central California in fall 1986 (McDonald and Fiddler 1999). Logging slash, unmerchantable trees, and shrubs had been pushed into windrows and burned. Both transects were located in the middle of an area of bare ground with a patch of bearclover at least 3 feet away. On one transect the bearclover grew uphill toward the transect; on the other, downhill. The slope was about 12 percent. After each growing season, a pin was placed on the bearclover stem nearest the corresponding metal pin on the transect. The 11 distances from transect pin to pin were averaged each season to arrive at the amount of annual rhizome elongation.

After three successive growing seasons, bearclover rhizome extension, as denoted by above-ground stems, was 29.7 inches if growing uphill and 9.6 inches if extending downhill. Growth was best the second year and virtually nonexistent the third growing season. During the fourth season, tiny new bearclover plants appeared within the bare area. Pulling on them revealed that they originated from deep in the soil, apparently from structures deeper than the rhizomes whose elongation we were quantifying. The study ended at this point. Fredrickson (1994) also noted the propensity of bearclover to sprout in the centers of disturbed areas, presumably from underground roots.

Physiology

Near Nevada City in the north central Sierra Nevada, Lanini (1981) measured internal moisture (xylem sap tension) and photosynthesis of bearclover from June through October 1979. Xylem sap tension increased from about -1.5 MPa in June to -4.0 MPa in September (MPa = megapascals; 1 = 10 bars), indicating the plants' capability to withstand very high levels of moisture stress. Relative to other shrub species in the plant community (manzanita, ceanothus), bearclover had the highest internal moisture stress of any species, and these values occurred earlier in the growing season. As xylem sap tension increased, photosynthesis decreased from 27 to about 7 mg of CO_2 per dm^2 per hr. Thus, bearclover apparently uses much of the available soil moisture early in the spring to attain a maximum amount of photosynthesis at the expense of reduced photosynthesis and growth later in the season. Ramifications of this relationship are twofold: (1) the species apparently has efficient stomatal control, and (2) bearclover causes rapid soil depletion that limits the amount of moisture available to other species.

Tappeiner and Radosevich (1982) also studied soil moisture in the same general area and emphasized that high pre-dawn xylem sap tension was found for bearclover as the season progressed from spring through summer, thus indicating a rapid depletion of available soil moisture.

Two other competitive mechanisms involving physiology include the production of nodules on fine roots that are probably active nitrogen fixers, and allelopathy, or the ability of one plant species to inhibit the development of a plant part or interfere with a metabolic process in another species.

Heisey and others (1980) found direct evidence of nitrogen fixation on nodulated bearclover plants in an area with little organic matter on the soil surface because of an intense forest fire a decade earlier. No nodulation was found in an undisturbed area nearby that had a deep organic layer. They noted that nodulation was uncommon on nonleguminous plants, especially among the Rosaceae (which includes bearclover). Furthermore, in cross-section, the nodules were strikingly similar to those of snowbrush (*Ceanothus velutinus* Hook., family Rhamnaceae) (Furman 1959) and to those of deerbrush (*Ceanothus integerrimus* Hook.& Arn.) (Newcomb and Heisey 1984)—two common associates of bearclover.

In a relatively pure stand at the 5,300-foot elevation in Sequoia National Park in central California, Rundel and others (1981) evaluated the effect of seasonal burning on the productivity and nutritional response of bearclover. They found that the burning of above-ground biomass and litter produced large deposits of nutrient-rich ash on the soil surface that was rapidly mineralized into the upper soil horizon. Although nitrogen and phosphorus were lost due to volatilization, the net above-ground uptake immediately following the spring burn was nearly three times greater than for the adjacent unburned control over the same period.

Allelopathy has been noted visually in the field (Potter 1976) and in the laboratory (Powers 1972). In the latter study, viable seeds of four conifer species were sown in intact layers of soil and organic matter carefully gathered from beneath pure bearclover stands. The intact layers were brought into the laboratory and maintained in a controlled atmosphere. Analyses of conifer seed germination and root length suggested that chemical growth inhibitors were produced by the foliage of bearclover.

Plant Diversity

After disturbance, such as from fire or site preparation, species composition of the bearclover community tends to be highly variable. Some species arise from root crowns or rhizomes, some from windblown seeds, and still others from dormant seeds in the soil (Grime 1979). The distribution of plant species ranges from clumpy for some species to random for others. Number of species depends on several factors, including the degree of disturbance, time since disturbance, availability of invading propagules, and rapidity of colonization by early invaders. Herbaceous species often contribute most to species richness just after disturbance. However, because bearclover recovers rapidly from disturbance and tends to form dense stands, its very presence tends to lower species richness quickly. Invading species are often relegated to bare areas among bearclover clones. However, a few species such as bull thistle *(Cirsium vulgare* [Savi] Ten.) and death camas *(Zigadenus exaltatus* Eastw.) grow well in bearclover stands apparently because of the ability to grow tall early in the season (McDonald and Everest 1996).

For the four recent studies, the number of plant species was recorded for four to eleven growing seasons after disturbance (*table 2*). Species numbers ranged from 13 at Gold Note to 62 at Challenge. Where bearclover is the dominant species, at least in terms of density and foliar cover, the number of species tends to be low

Table 2—*Number of species by vegetation category after various numbers of growing seasons, northern and central California, 1980-1996*

Study area	*Growing seasons*	*Conifers*	*Hardwoods*	*Shrubs*[1]	*Forbs*	*Graminoids*	*Fern*	*Total*
Chaix	6	1	4	8	41	6	1	61
Challenge	5	3	2	12	38	6	1	62
Gold Note	11	1	0	5	4	3	0	13
Penmoke	4	3	2	4	5	4	1	19

[1]Includes bearclover

initially and to remain low. For example, both density and foliar cover were high at Gold Note, and number of species after the first growing season was 12 and after eleven seasons was 13. A likely reason is that bearclover dominated below-ground after site preparation and dominated both above- and below-ground shortly after. Other species could not compete.

Plant Development

Data from the four recent studies noted earlier portray developmental trends in bearclover density, foliar cover, and height. Initial bearclover density values (reported one to three growing seasons after site preparation) ranged from an average of 630 stems per acre at Challenge to 152,200 per acre at Gold Note (*table 3*). Ending values ranged from 2,267 stems per acre at Challenge to 282,000 per acre at Penmoke. Initial foliar cover ranged from a trace at Challenge to 20 percent at Gold Note. Ending values spanned the range of 1 percent at Challenge to 63 percent at Penmoke. Of interest is that foliar cover at Gold Note increased from 20 percent to 57 percent after five growing seasons and then decreased to 36 percent after 11 seasons. The decline probably can be attributed to competition from the ponderosa pine seedlings. Bearclover height averaged about 0.6 foot initially on all study areas and ranged from 0.6 to 1.4 feet by the end of the studies.

Manipulation

Foresters began studying bearclover in California in 1911 (Munns 1922). Early studies, usually in areas having natural conifer regeneration (Tappeiner and Helms 1971 for example), detailed the capability of bearclover to recover rapidly from natural disturbance and to restrict the establishment of conifer seedlings. Observers noted that conifer seeds often were caught in the dense foliage of bearclover crowns and never reached the ground. Those that did reach the ground had difficulty penetrating the deep litter layer. Once in mineral soil, competition for site resources among the mass of bearclover roots was fierce. Rarely could conifer seedlings become established, and for those that did, growth was poor. Death almost always was ascribed to competition-induced drought.

Planted conifer seedlings often fared no better, and as noted by Potter (1985) survival often was less than 20 percent where bearclover was the primary competitor. Height growth almost universally was described as inadequate. Foresters often were surprised how fast bearclover recovered after fire or disturbance. Areas that were visually devoid of bearclover turned green after a few months. Worse, ineffective treatments that provided only temporary or partial control actually rejuvenated bearclover and increased its potential to dominate. For example, Tappeiner and Radosevich (1982) concluded that after 19 years, bearclover appeared to be more dense and vigorous on plots sprayed with a mixture of herbicides than on those receiving no treatment.

Over the past 65 years, an amazing variety of treatments has been employed to control bearclover in young conifer plantations. Herbicides were suspended by the

Table 3—*Average density, foliar cover, and height of bearclover on four study areas in northern and central California, 1976-1996*

Study area	Year	Density		Foliar cover		Height	
		Mean	SE[1]	Mean	SE	Mean	SE
		Number/acre		*pct*		*ft*	
Chaix	1992	28,067	8,156	11	3	0.6	0.1
	1995	45,625	8,803	10	2	0.6	0.1
Challenge	1976	630	73	T[2]	-	0.5	0.1
	1980	2,267	301	1	-	0.7	0.1
Gold Note	1986	152,200	38,504	20	3	0.6	0.1
	1990	152,333	32,119	57	3	0.8	0.1
	1996	117,200	21,803	36	3	1.4	0.1
Penmoke	1991	-	-	-	-	-	-
	1994	282,000	85,000	63	26	1. 2	0.2

[1]SE = Standard error

[2]T = Trace

USDA Forest Service in March 1984 in response to Federal court rulings (Click and others 1989). This moratorium was lifted in January 1991, but during the 7-year interval, the variety of treatments used by vegetation managers increased even more. Most of these were performed "to buy time" for planted conifer seedlings until better techniques became available.

Techniques for manipulating bearclover are placed in five categories: manual, mulching, mechanical, burning, and herbicides. Sometimes two or more categories were involved. These combinations are presented in the category having the last treatment.

Manual

Manual techniques generally are those that are performed by hand. They can be used in both site preparation and plantation release, but most often are used in release. Techniques include grubbing small plants with hand tools, or severing larger plants with power tools. Both operations can be done one or more times. Steepness of slope is not a limiting factor.

On the Stanislaus National Forest, Potter (1985) reported that several attempts had been made to hand-grub bearclover in plantations including a 4-foot circle around individual conifer seedlings. Within a year, new sprouts occupied nearly 100 percent of the grubbed area. On the Eldorado National Forest, Parsons (1991) observed that "lots of manual release is being performed here." Like so many other trials when only the above-ground portion of bearclover was removed, the treatment appeared to be effective at first, but soon failed. Click and others (1994) recommended that manual release not be done "even as a last resort."

Mulching

The first attempt to control bearclover with mulches took place in Eldorado County in the late 1950s and early 1960s (Potter 1985). Large (4- by 8-foot) sheets of plywood were laid over existing bearclover plants. One year later the bearclover was dead aboveground and soil moisture had increased beneath the plywood. The plywood was then removed, and a few years later the area was again covered with bearclover. More trials with different mulches took place in the early 1980s in Stanislaus County. Newspapers, black plastic in 4- by 8-foot segments, and heavy kraft paper/fiberglass/asphalt sandwiches were tried, but all were expensive to install and maintain. These materials also broke down rapidly and were subject to tearing by sharp stems, cattle, and deer.

Another mulching study took place in Eldorado County in 1991 on land that was occupied by bearclover and scattered ponderosa pines (McDonald and Everest 1996) and then logged and broadcast-burned. Mulches were made of woven black polypropylene, 5 feet square (*fig. 6*), and applied around planted ponderosa pine seedlings and over bearclover stubs soon after the burn. Each mulch was held in place with nine 8-inch, flat-headed U-shaped pins. Several mulches were lifted in September 1994 and rhizome development examined to shovel depth (8 inches). The soil was bone-dry. Living rhizomes were numerous in the soil beneath the mulches. No new roots had developed at rhizome nodes, however. Where above-ground stems had burned, a new white horizontal rhizome was present at the nearest node on some plants. Occasionally, this rhizome gave rise to a new plant at the slit where the pine seedling came through the mulch. Just beneath the mulches were rhizomes with chlorotic leaves that had obviously been pushing against the mulches. These were dying from heat conducted from the mulch to them. The combination of burning and mulching was judged as ineffective because the rhizomes were still present and competitive belowground, and the pine seedlings were obviously stressed and growing poorly.

Mechanical

As its name implies, this treatment involves the use of techniques or large machines that either scrape off undesired plants above ground or gouge them out or tear up their roots or rhizomes below ground. Mowing, dynamiting, disking, plowing, subsoiling, and terracing have all been attempted to lessen the competitiveness of bearclover. Most have been used in site preparation, and several have been employed many times in a variety of soils and slopes. Foresters reasoned that they could reduce much of bearclover's competitiveness if they could damage the top 18- to 24-inches of its root system. Soil disturbance was a constant concern, and steps were taken to minimize it. Leaving untreated (filter) strips on the contour was one example.

Potter (1976) noted that mowing bearclover with a rotary-type mower had been tried several times. Plants were cut as close to the ground as possible. Apparently, the treatment was successful in some cases and not in others. No mention of

Figure 6—Five-foot-square sheets of woven black polypropylene surrounded by 4-year-old bearclover on the Eldorado National Forest. The pine seedling in the center of the mat has died.

what constituted success was noted or how long after treatment the assessment was made.

A more controversial attempt to dislodge bearclover both above- and belowground employed the use of dynamite. The goal was to build small terraces or openings in established bearclover by blasting, and then to plant conifer seedlings in the cleared areas (Potter 1985). As might be expected, much bearclover remained and rapidly invaded the cleared areas.

Vegetation managers have long observed that old skid trails through bearclover, which gouged the soil for 2 to 4 feet, often created areas where conifer seedlings had become established and grown well. Based on these observations, treatments that disturbed bearclover's root system such as disking, plowing, and subsoiling were thought to have potential. Slopes of up to 35 percent can be treated with these techniques.

One of the early trials that disturbed bearclover belowground took place on the Stanislaus National Forest (Stowell and Lloyd 1935). A Caterpillar "fifty" tractor and an angled blade were used to clear mature bearclover in strips on relatively flat ground (*fig. 7*). The strips were about 9 feet wide and about 2 feet apart. All topsoil to a depth of 6 inches was piled in the narrow intervening strips. Ponderosa pine and sugar pine seedlings (1-1) were planted and seed-spotted in one to three rows in each strip. Rodents were controlled with poisoned grain. Although results were not presented, the authors noted ominously that "bearclover sprouts had appeared over the entire eradicated area."

Another early trial also took place on the Stanislaus National Forest in 1952 (Adams 1969). A heavy disk was used but was ineffective because new sprouts from rhizomes quickly regained control of the site. Another trial, which took place on the Stanislaus National Forest in 1955, was reported by Potter (1976). It involved using a disk that had 22-inch blades and weighed 8,000 pounds. After 3 years, ponderosa pine seedling height growth (40 inches) and survival (73 percent) were promising. However, 18 years later the plantation was judged a failure due to poor pine survival and lack of growth. In another trial, a heavy agricultural disk with six 18-inch blades was pulled behind a tractor (Potter 1985). Although the blades tore up the bearclover, small pieces of rhizomes sprouted, and a vigorous stand of bearclover was present one year later.

In June 1988, Craig (1989) used a more involved technique to control mature bearclover in a loamy-sand soil. He employed a heavy disk (18-inch blades) with

Figure 7—An early attempt to control bearclover on the Stanislaus National Forest was with a tractor and blade, June 1934.

one pass up and down the slope and another pass across the slope. Because grasses and forbs invaded the area and were considered a threat to planted ponderosa pine seedlings, the site was again disked in April 1989. This was a light disk that went about 6 inches into the soil. It was effective for removing competing vegetation, including severed pieces of bearclover rhizomes, and was judged as being a critically needed step. Although no long-term results are available, the appearance of the area and the early growth of the pine seedlings indicate the technique is promising.

A variation of disking was to use it in combination with the spraying of herbicides. This was attempted several times on the Stanislaus National Forest in the 1960s with mixed results (Adams 1969). The herbicides were esters of 2,4-D and 2,4,5-T.[4]

Plowing was another early technique employed to control bearclover. Potter (1985) noted that a single-tooth agricultural plow was used to create a furrow that would be beneath the majority of the rhizomes. Conifer seedlings would then be planted in the bottom of the furrow. Unfortunately, vigorous sprouts from severed rhizomes and roots quickly developed, and the plantation failed after 2 years.

Contour ripping of bearclover roots belowground was first tried in Amador County in fall 1960 using a D-9 bulldozer with a two-shank road ripper attached to the rear (Adams 1969). Natural regeneration of ponderosa pine in the disturbed area was described as "more than adequate," but seedling growth and the status of the plantation at a later date were not mentioned. Another method of mechanical site preparation is ripping with a winged subsoiler (*fig. 8*). This machine differs from a conventional ripper in that each of the three shanks has a winged shoe about 20 inches across that resembles a delta wing on an airplane. Each shank is adjustable for depth, and each can trip (raise) when a large boulder or stump is encountered. Operational depths range from 12 to 34 inches (Nelson 1990). The winged subsoiler also is pulled behind a heavy tractor and is applicable on slopes up to 30 percent. One advantage of this machine is that bearclover rhizomes tend to travel up the shanks and are pulled from the ground.

Rutty (2002) stressed the importance of using the winged subsoiler in the summer when the soil is dry. Dry soil breaks into large clods and in turn breaks up the bearclover rhizomes in them. Without soil moisture, the rhizomes dry out and die; with soil moisture, they readily sprout. Soil permeability and root growth also are improved.

In July 1988, Nelson (1990) investigated the applicability of the winged subsoiler to control bearclover on the Eldorado National Forest and compared it to standard disking. The study was performed on soils having a variety of textures and on slopes that ranged from 5 to 30 percent. Cross-ripping (two-way) was superior to one-way contour ripping because the operator could get closer to stumps and other obstacles and more of each acre could be treated. After 15 months, reinvasion of bearclover was minimal, especially in fine textured soils. It was not as effective in coarse textured, rocky soils. Nelson also noted that use of the winged subsoiler provided superior short-term control of bearclover and made it vulnerable to subsequent treatments.

Click and others (1994) discussed a two-step site preparation method using a large tractor pulling a machine with subsoiler shoes followed by a smaller cultivator-like machine equipped with five to seven shanks. The objective was to smooth the furrows created by the large machine and to control invading forbs, grasses, and sprouting pieces of bearclover. Even with this rather intensive treatment, they noted that conifer seedling survival was highly variable (30 to 90 percent) because of competition from invading plants. Further, they cautioned that the long-term effectiveness of the method was unknown. However, Campodonico (2002) reported good survival and pine height growth on the Stanislaus National Forest on slopes of 20 to 35 percent 10 years after treatment with a similar double-pass technique.

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

Figure 8—Shanks and blades of the winged subsoiler.

An even more intensive treatment to control bearclover belowground was terracing (*fig. 9*), which was tested extensively on the Stanislaus National Forest (Potter 1976). In general, the technique was applicable on slopes between 15 and 40 percent. Below 15 percent, not enough excavation occurred, and over 40 percent too much soil was removed. In both instances, much topsoil was lost (Potter 1985). Delapp (1975) prepared operational guidelines for the design and construction of terraces, as well as considerations for soil erosion, and stocking/spacing arrangements for planted conifer seedlings.

Potter (1976) noted that terracing often gave conifer seedlings a 5- to 7-year headstart, and in a few instances, particularly on highly productive sites, they maintained acceptable height and diameter growth rates. However, bearclover eventually invaded the site. For example, areas terraced and planted in 1959 were totally covered with bearclover in 1976 (Potter 1985). Results from extensive terracing trials conducted from 1955 (Adams 1969) through the early 1980s have followed the pattern of planted conifer seedlings growing well at first and then slowing as competition from bearclover increased.

Burning

Like most plant species in California that are short and have major reproductive capability from underground organs, bearclover is both susceptible to fire and enhanced by it. The species has several structural and chemical characteristics that lead to its flammability. Bearclover is well adapted to burning, with many anecdotal accounts of the species burning within a few hours of a rain storm or with snow still on the ground. Furthermore, the species has finely dissected leaves and fine branch structure that provide high surface-to-volume ratios and good convective air circulation. The foliage also has a high ether extractive content that reaches a peak of 7 to 9 percent in late summer (Rundel and others 1981).

Figure 9—An 8-year-old terrace on the Stanislaus National Forest. Although ponderosa pine survival is good, crown development and growth are poor.

Silviculturists have long noted that burned snags and logs often were present in the healthiest of bearclover stands. They also noted that burns typically were hot in these stands and that bearclover recovery often was delayed. The first trial that used burning to control bearclover occurred in 1911, when Munns (1922) began a study in a naturally burned area on the Stanislaus National Forest. By 1921, bearclover was considered dense on more than 71 percent of the area. The only area that was free of bearclover was occupied by a dense stand of trees.

A somewhat unique burning technique was to treat individual stems (sprouts) of bearclover with a blow torch (Potter 1985). This usually was done after site preparation. Although no followup information on effectiveness or cost was found, the area was soon fully occupied by bearclover.

The combination of burning followed by an application of herbicide was studied extensively in the 1960s on the Stanislaus National Forest (Adams 1969). The fires were of both natural and prescribed origin. The herbicides used the most were 2,4-D and 2,4,5-T applied with a mist blower or back-pack sprayers at various rates and times of the year. In general, summer application was the most effective. Less sprouting occurred and lower dosages could be applied at this time. However, higher dosages were effective with application in the fall. Although this combination treatment was described as being effective and giving good control of bearclover, some trials gave mediocre results and at least one was a failure. Of note was that grasses often invaded the treated areas and became quite dense.

Almost all early trials with controlled burning were performed in the spring or fall— a time when the risk of escape was low (*fig. 10*). Potter (1985) noted that after burning resprouting was vigorous and, furthermore, that the general consensus among silviculturists was that burning does not control or eliminate bearclover, but rather stimulates it (Potter 1976). Rundel and others (1981) found that while spring (pre-growing season) and fall (post-growing season) fires stimulated regrowth, summer burns (mid-growing season) appeared to inhibit regrowth for at least 2 years.

Weatherspoon and others (1991) expanded this finding and, in a preliminary study, noted that although bearclover did not respond much differently among burning dates in a single growing-season, it recovered much more slowly after a second growing-season treatment (actually a manual grub because of inadequate fuel) applied the next summer. Results after a third successive growing-season burn continued the trend of slowing recovery (Weatherspoon 2002). An additional

Figure 10—Fall burning in a mature stand of bearclover.

finding was that burning in mid-June was more effective than burning in mid-May or mid-August— a finding that corresponded to the time of peak blooming. Some evidence also suggested that bearclover was stressed more by the combination of resource drain by overstory trees and burning than from burning alone.

Herbicides

Many factors influence the ability of a herbicide to control undesirable vegetation. These include the ability of the herbicide to penetrate the leaves, the availability of enough water in the leaves and stems to translocate the herbicide to the intended plant part, and the capability of the herbicide to effectively damage the plant to the point that it becomes moribund. Several morphological and physiological factors are important and relate to plant size and leaf age. It stands to reason that small plants are more easily affected than large plants: they have less biomass and less sprouting potential. Recently developed leaves have not had time to develop thick epidermal layers or oily and waxy coverings and therefore are more easily penetrated by the herbicide. They also are developing at a time when internal moisture levels and photosynthesis are high, and thus translocation and assimilation of the herbicide are increased.

A definitive physiological study on bearclover was performed by Lanini (1981), who found that this shrub was sensitive to soil moisture and photosynthesis. Photosynthesis was reduced more than 50 percent as water stress increased throughout the season. A reduction in bearclover cover was correlated to lower photosynthesis, especially for the two most effective herbicides, glyphosate (Roundup) and triclopyr (Garlon), with water stress providing a smaller (but positive) correlation coefficient.

The first attempt to control bearclover with herbicides took place on the Stanislaus National Forest in 1945 (Schubert 1955). Mature plants were sprayed with 2,4-D at five different concentrations on four different dates spanning May through October. In general, topkill was achieved, but resprouting took place and rendered the treatments ineffective. Many trials with other herbicides have since taken place (Adams 1969, Coombes and McHenry 1984, McHenry and others 1980, Potter 1985). Results were mixed: some trials aided site preparation but not plantation release; some were effective for release in the spring, others in the fall; many were only moderately effective; some were totally ineffective. Observations at specific sites with specific environments, short-term studies, and unreplicated trials added confusion. A general conclusion was that a single application of a herbicide was ineffective. For example, a long-term study, begun in 1961 on a good site in Eldorado County, concluded that after 19 years, no adverse effect to bearclover had resulted from either a single herbicide application with 2,4-D and 2,4,5-T or competition from the planted ponderosa pine seedlings (Tappeiner and Radosevich 1982). However, some findings common to these early studies are important: (1) a short-term increase in conifer seedling survival often occurred but was misleading because no stimulus in seedling height growth took place, (2) topkill of bearclover by herbicides—even almost 100 percent topkill—did not indicate an effective treatment, and (3) herbicides were more effective for treating bearclover in late spring/early summer and less effective in early spring or late summer, although higher dosages seemed to increase effectiveness at these times.

One trial that provided effective control of bearclover began in Eldorado County in 1961. It involved spraying once with 2,4-D and 2,4,5-T, hand clipping sprouts during spring 1962, and installing a 4.9-foot-deep polyethylene-lined trench around the plots (Tappeiner and Radosevich 1982). After 19 years, no bearclover was present on these intensively treated areas.

More recent studies with new herbicides like hexazinone (Velpar, Pronone), glyphosate (Roundup, Accord), and Escort proved to be more effective. Hexazinone is a soil-active herbicide; glyphosate and Escort are foliage-active. These later studies also differentiated between undisturbed, mature bearclover, usually growing under a scattered overstory, and newly-sprouted bearclover, usually in young conifer plantations.

On the Blodgett Experimental Forest in northern California, Heald (1987) found that Roundup effectively controlled mature, 6-inch-tall bearclover in a partially shaded environment. In central California, Jackson and Lemon (1988) applied Roundup herbicide several times during the year and found that a May-June application was the most effective. An October application was surprisingly effective as well. May-June was the time of full flowering and adequate soil moisture, and October corresponded to the time of carbohydrate movement to the roots. These authors recommended that this herbicide be used before timber harvest, which suggested that at least a partial overstory of trees was present. Ballew (1989) found that a mature bearclover stand had too much biomass to be successfully treated with a single application of herbicide. He recommended that bearclover be treated with Garlon or Roundup followed by an application of Velpar. Velpar was particularly effective because it killed bearclover sprouts as well as the inevitable grasses and forbs.

Herbicide technology, especially for application in young conifer plantations, continued to improve as new herbicides, new information on rates and applications, and more knowledge on the fate of herbicides in the environment was developed. Johnson (1988) showed that Pronone controlled bearclover in Eldorado County for at least 2 years after site preparation in a young conifer (ponderosa pine and Douglas-fir) plantation. No crop phytotoxicity was detected. On the Eldorado National Forest, Fredrickson (1994) demonstrated that Roundup inhibited the sprouting of bearclover for up to 5 years after treatment. He also noted that treated areas were quickly occupied by grass. In central California, Garlon 4 herbicide at 1 percent and 2 percent with 1 percent Mor-Act as a surfactant and Garlon 3A at 1 percent and 3 percent with Mor-Act provided excellent control of bearclover when applied in November (Anonymous 1994).

On the Eldorado National Forest northeast of Jackson, California, McDonald and Everest (1996) conducted a more intensive study involving a tank-mix of two herbicides followed a few months later with a third herbicide. The tank-mix was 1.5 percent Accord, 1 percent Garlon 4, Bivert adjuvant, and a surfactant, applied in August 1991. The second herbicide was Pronone 10G (20 pounds per acre hexazinone) applied in November 1991. In fall 1994, mean density, foliar cover, and height of bearclover in treated plots and control (*fig. 11*) were:

Figure 11—Sampling is a big job: every bearclover stem inside this milacre frame will be counted to arrive at density values.

Treatment	Density		Foliar Cover		Height	
	Mean	SE	Mean	SE	Mean	SE
	stems/acre		*pct*		*ft*	
Herbicide	3,667	3,371	1	<1	0.7	0.07
Control	282,000	85,000	63	26	1.2	0.20

In 1994, 100 percent of planted ponderosa pine seedlings in the herbicide plots had survived, and mean stem diameter and height were more than twice as large as counterparts in the control. Cheatgrass invaded in 1992 and in 1994 numbered more than 743,000 plants per acre in the control and more than 130,000 plants per acre in the herbicide plots.

Another study in central California strived to evaluate the long-term effect of three herbicides on bearclover. The herbicides were Roundup, Velpar L, and Escort (*fig. 12*). After 11 years, bearclover density ranged from more than 7,700 plants per acre with Roundup to more than 117,000 plants per acre in the control,[5] foliar cover varied from a trace with Roundup to more than 36 percent in the control (*fig. 13*), and height differed from 0.8 foot with Roundup to more than 1.4 feet in the control. Velpar L ranked a close second to Roundup in effectiveness, with Escort being a distant third. Roundup and Velpar L produced values that differed significantly from those in the control at the 5 percent level. Grasses, chiefly of the genera *Achnatherum* and *Bromus* (including *B. tectorum),* invaded the study area and were highest in the Roundup plots (618,600 per acre), next highest in the Escort plots (493,660 per acre), and lowest in the Velpar plots (194,100 per acre). Of interest is that after 5 years, grass density in the Velpar plots was about 26,000 plants per acre, and in the Roundup and Escort plots more than 2 million and 1 million plants per acre, respectively.

At the 3,200-foot elevation in Calaveras County, Potter (1997) reported results of trials with nine herbicides after 7 years. Different dosages, tank-mixes, and times of year were part of the study. Herbicides that were effective in reducing bearclover below pretrial conditions and substantially below the control were Velpar L applied in the fall and Escort at 4 ounces per acre. Virtually no herbicides completely controlled annual grasses. Even the most effective herbicides did not eliminate bearclover, and substantial numbers were present after 7 years.

[5]Unpublished data on file, Pacific Southwest Research Station, Redding, Calif.

Figure 12—Applying an herbicide with a carbon dioxide pressurized boom in central California. The man in the background is standing at the edge of the swath.

Figure 13—Effect of Roundup herbicide (A) and Velpar herbicide (B) relative to control (C) on newly-sprouting bearclover after 11 years.

A

B

C

Cost

The cost of manipulating bearclover over the years has varied tremendously from $70 per acre for plowing in 1975, to $500 per acre for dynamiting in 1985, to $300 per acre for hand grubbing in 1994. Because many of the older treatments were ineffective or expensive, costs are presented only for those treatments judged as having the highest potential for effectively manipulating bearclover. In 2002 these were winged subsoiler, successive growing-season treatments (burns), and herbicides.

The cost of the winged subsoiler depends on whether one or two passes are made, steepness of slope, and other considerations. Campodonico (2002) found that a two-pass operation on steep slopes cost about $300 per acre. Because bearclover can be burned at low-risk times of the year, the cost of successive controlled burns should require a minimum of cleared lines and standby equipment and crews. The cost should be low initially and decrease each year. Weatherspoon (2002) suggested that about $50 per acre for the first burn was reasonable, with the cost decreasing to about half that after two burns.

The two most effective herbicides for controlling bearclover are Velpar (6 qt/ac) and Roundup (1.5 qt/ac). Aerially applied Velpar costs about $92 per acre for both the chemical and its application, and backpack application costs about $110 per acre for both. Aerially applied Roundup costs about $30 per acre for both chemical and application, and the cost of backpack application is $92 per acre for both. Although Escort was moderately effective in one study, it is not registered in California.

Discussion and Conclusions

A major need in forest silviculture and ecology today is to develop knowledge on the plant community that develops after different levels of natural and human-caused disturbance. More specifically, knowledge is needed on the changes in the community over time. The density and growth of individual species and their eventual ascendance or decline, a process called plant succession, are particularly important. Equally important is to recognize the changes to plant communities brought about by different levels of human-caused disturbance. Such levels, termed treatments, often alter the rate of plant succession but seldom have long-term effects on the eventual species composition of the community.

Unfortunately, the development of knowledge on plant species composition and development after disturbance generally is limited and often tied to competitive species that limit the survival and growth of economic species. Such is the case for bearclover, which is notorious for its limiting effect on conifer seedling survival and growth. Understanding the morphology and physiology of bearclover, relating them to the capture of site resources and plant growth, and tying such knowledge to a range of treatments is a major emphasis of this paper.

Much is known; more knowledge is needed. The production and fate of bearclover seed are a case in point. Thousands of seeds are produced, but how many are sound and how many of them reach the soil? Once in the soil, do they die or do they form a seedbank? Given the overwhelming success of vegetative propagation and the likelihood that extensive areas are of the same genotype, it is possible that some mechanism to discourage fertilization or seedling development would be present. In a controlled test, Powers (1971) collected pollen from several bearclover plants on the Challenge Experimental Forest and observed that the grains germinated on the stigmas of other bearclover plants, but did not develop further. It is possible that these plants were all from one clone and were incompatible. Perhaps interclonal pollination is needed. A larger question concerns the size and age of bearclover clones. Are patches or stands made up of one or several individuals? No information is available on this subject.

Knowledge is needed not only on seed, but on rhizomes as well. From the rhizome transect study in central California (McDonald and Fiddler 1999), bearclover rhizomes elongated for 2 years after disturbance, developed very little the third year, and then occupied new territory from deep underground structures the fourth year. From the study in Eldorado County with small mulches (McDonald and Everest 1996), the poor growth of the ponderosa pine seedlings was attributed to the capture of soil moisture by roots and rhizomes located deep in the soil. Connection to rhizomes outside the mulches also was likely.

All of this adds to the confusion on when, where, and how bearclover spreads over the landscape. Distinguishing between mature undisturbed bearclover stands and young disturbed stands could be useful. Numerous observers have noted the remarkable lack of mature bearclover extension into treated areas, and the lack of extension of rhizomes from disturbed areas into undisturbed areas. It is likely that mature bearclover, which is characterized by already-developed dense masses of roots and rhizomes, allocates most of its energy to crown development, and rhizome extension is relegated to only a few inches each year. Mature bearclover has to be damaged before it grows rapidly. In contrast, newly disturbed stands, which are characterized by scattered stems aboveground and an in-place root system belowground, vigorously extend rhizomes from those near the soil surface and from roots located deep in the soil. The sporadic nature of rooting from side nodes of extending rhizomes could be a response to a strategy of first allocating energy to rhizome tips and then to the development of side rhizomes.

Silviculturists have long been intrigued by the idea that damaging competing plants when their food reserves are low is the best time to treat them. Food reserves tend to be lowest at the time of peak growth or at the time of peak flowering. For bearclover, this would be June-July in most instances. If bearclover were treated for three or more successive summers, would the effect of low carbohydrate reserves be compounded to the point that the plant would be seriously affected? Studies by Rundel and others (1981) and Weatherspoon and others (1991) showed that regrowth of bearclover is slowed after successive mid-summer treatments, and after three such treatments, vigor appeared to be low. But low enough to allow conifer seedlings to grow at the potential of the site? Presumably, more successive treatments would lower bearclover reserves even more. Cost could eventually become prohibitive. An additional problem with burning is obtaining enough fuel to carry the fire in successive years.

Because the techniques for treating bearclover are many and the variations and combinations are even more numerous, an at-a-glance table is presented (*table 4*). Of interest is that all of the treatments have broad to moderate application, and every treatment has at least one limitation. No treatment is immune to causing too much disturbance to the environment, or being too costly, or not being socially acceptable, or simply being limited by the steepness of slope or rocky ground. Risk, regulation, lack of fuel for subsequent burns, or creating conditions that will be difficult to manage in the future are additional limitations. However, it is important to note that this is a generalized table and exceptions can occur where local conditions of soil, microclimate, and vegetation occur. Cost also is a wide-ranging variable that could be modified by local conditions.

In spite of the limitations, two treatments stand out as being effective. These are subsoiling and herbicides. A third that has potential for being effective is successive growing-season treatments (burns). All three are based on the fact that to be effective it is necessary to treat the entire plant; above- and below-ground plant parts need to be killed. Just damaging them is not enough.

Additional discussion on some of the treatments, old and new, follows: Most of the mechanical methods are limited by slope, large rocks in the soil, and stumps, boulders, rock outcrops, and residual vegetation that block the path of the machines. This causes a significant portion of each acre to not be treated. Worse,

Table 4—*Summary of treatments on bearclover and their comparative effectiveness*

Treatment and variation	Application	Limitation	Effectiveness[1]
Manual			
Hand grubbing	Broad	Cost	Ineffective
Mulching			
Various materials	Broad	Cost	Ineffective
Mechanical			
Mowing	Broad	Cost, terrain	Ineffective
Dynamiting	Broad	Cost, disturbance	Ineffective
Disking	Moderate	Terrain, disturbance	Moderate[2]
Plowing	Moderate	Terrain, disturbance	Ineffective
Subsoiling	Moderate	Terrain, disturbance	Effective
Terracing	Moderate	Terrain, disturbance, cost, management	Ineffective[2]
Burning			
One growing season	Broad	Cost, risk	Ineffective
Two+ growing seasons	Broad	Cost, risk, adequate fuel	Moderate[3]
Herbicides			
2,4,5-T	Broad	Social pressure, regulation	Effective
Escort	Broad	Social pressure	Effective
Roundup	Broad	Social pressure, grass invasion	Effective
Garlon	Broad	Social pressure	Effective
Velpar	Moderate	Social pressure	Effective

[1]Density of bearclover reduced to the point that conifer seedlings can become established and grow at the potential of the site.

[2]Can be effective on gentle-moderate slopes and coarse-textured soils.

[3]Moderate rating on the basis of promise; not enough trials to be certain.

these untreated areas serve as sources of propagules that eventually reinvade the treated areas.

For terracing, the difficulty of managing the stand in the future may be as much a detractor of the method as are soil disturbance and possible loss in site productivity. Although growth of some conifer seedlings is negatively affected, others reach a size at which they will need to be commercially thinned and eventually harvested. How and where to lay out roads, thin, and harvest could be a major logging and engineering problem in the future. How best to treat terraces covered by bearclover is another challenge.

Just as burning was most effective when performed during mid-summer, so is the application of most of the herbicides. Mid-summer is the time when photosynthesis and internal moisture levels in bearclover are high. Thus, the herbicide is readily absorbed by the plant and transported to the site within the plant where it is active.

Bearclover is notorious for being a strong competitor in young forest plantations. Such plantations occur after various combinations of logging, burning, and site preparation and are characterized by bare mineral soil, planted conifer seedlings, and few competing plants above ground. Below ground, however, the rhizomes of bearclover are mostly unscathed and in position to capture critical soil moisture. Even if fragmented, the rhizomes quickly develop into new plants. In this competition-free environment, site resources are plentiful and bearclover becomes a vigorous competitive species.

Consequently, the species that become associates of the after-disturbance bearclover plant community must be able to compete aggressively for site resources both above and below ground. Few species are able to do this and, as noted at Gold Note and Penmoke, species richness tends to be low almost from the beginning. However, with distance from the heart of bearclover's range, species

Figure 14—At age 2, bearclover is able to grow and dominate in a dense stand of seeded rye grass.

richness increased as noted at Chaix and Challenge. Although the four study areas had a varied and rapidly developing plant assemblage, the composition of the community differed. In addition to bearclover and ponderosa pine seedlings, which were common to all four study areas, the Challenge vegetation consisted of forbs, grasses, shrubs, and hardwoods; Chaix had a similar mix; Gold Note was predominately bearclover, manzanita, and a few forbs; and Penmoke was primarily bearclover, a few forbs, and cheatgrass.

Based on the density and development of the various species in stands that have received both site preparation and release (*tables 2,3*), composition of the typical bearclover community in the near future can be ascertained. Certainly, the main constituents will be bearclover and conifer seedlings, with whiteleaf manzanita a lesser component. The forbs will be few and consist of those species that can persist in a shady, competitive environment. Grasses also will be present, initially in large numbers and then declining as taller vegetation develops.

Almost inevitably, treatments that disturb bearclover cause the density of various grass species to increase. Whether site preparation or release, and regardless of type of treatment, the grasses invade. On the Stanislaus National Forest, a study was designed to specifically test the effect of grasses on bearclover regrowth.[6] The study area burned in a wildfire in late summer 1987 and was seeded to annual rye grass that fall. A vigorous stand of grass became established in 1988, and a myriad of seed was produced. Each of these seeds produced a plant in 1989 (*fig. 14*) and by that fall numbered over 10 million per acre. Thus bearclover had to sprout and regrow at this high level of competition.

Results from the measurement of study plots in fall 1992 showed a dramatic decrease in number of stems of both bearclover and rye grass (*table 5*). Although both species maintained their initial height values, the density of grass actually fell

Table 5—*Average stem density and height of bearclover and annual rye grass, Stanislaus National Forest in 1989 and 1992*

Year	Bearclover				Grass			
	Density		Height		Density		Height	
	Mean	SE[1]	Mean	SE	Mean	SE	Mean	SE
	stems/acre		*ft*		*stems/acre*		*ft*	
1989	339,900	12,200	0.8	0.1	10,489,000	805,000	1.6	0.1
1992	9,867	1,555	0.9	0.1	9,133	1,711	1.6	0.1

[1]SE = Standard error

[6]Study entitled "Effect of herbicides and seeded grass for controlling bearclover in a young ponderosa pine plantation on the Stanislaus National Forest." Philip M. McDonald and Gary O. Fiddler. 1989. On file at Pacific Southwest Research Station, Redding, CA. (Study area destroyed by forest fire in 1996.)

below that of bearclover in 1992, indicating that the grass population was being stressed by the bearclover. This and all the other studies in which grass was monitored, strongly suggest that bearclover is virtually immune to competition from grass, regardless of species or seed origin (natural or artificial seeding). Nevertheless, grass of one species or another will continue to be an associate of bearclover and persist in small openings between the bearclover plants.

In the heart of bearclover's natural range, natural plant succession in disturbed stands is characterized by an onrush of bearclover sprouts, annual grasses from seed, and other shrubs, particularly those of the genera *Arctostaphylos* and *Ceanothus*, from dormant seeds in the soil. Species from these categories capture site resources early and establish dominance at an early age. Such species expand their populations rapidly and cumulate at ages 4 to 7 in very high densities. These high density levels are unsupportable and the number of plants per acre declines, but foliar cover and height increase. Grass density generally decreases first because of pressure from the shrubs (including bearclover). During the longer term, bearclover becomes ever more dominant, and plant species richness declines. Biotic agents and abiotic forces have little effect, and the bearclover community adds new meaning to the word "stable." After 19 years, even ponderosa pine seedlings had no adverse effect on bearclover (Tappeiner and Radosevich 1982).

Given this stability and a much longer timeframe, has bearclover been markedly affected by the activities of humans? Based on extensive observations and inquiries throughout the Eldorado National Forest, Lyons (1913) noted that bearclover has not extended its natural range for many years. However, he noted that a "considerable increase in the density of the stands" has occurred on both private and government lands that have burned over. The extent of bearclover over the landscape probably did not change much until the advent of herbicides in the 1960s. But what about since then? Probably the best answer, is "somewhat," but only temporarily. Not all areas in a plantation are treated, and islands of bearclover remain. In addition, a few deep roots, which escape damage from herbicides, apparently lead to new invaders in a few years. Consequently, bearclover density may be affected locally, but its presence across the landscape remains constant over longer time frames. A large wildfire like the Stanislaus complex of 1987 is an example. It destroyed thousands of acres of pine plantations which converted to vigorous stands of bearclover in a few years.

References

Adams, R.S. 1969. **How to cure mountain misery.** Sacramento: California Division of Forestry; 23 p.

Anderson, M. Kat. 1997. **A study to retrieve the traditional ecological knowledge of Sierran tribes regarding the former uses, management, and fire ecology of bearclover (*Chamaebatia foliolosa*).** Unpublished draft supplied by author.

Anonymous. 1994. **Bearclover (get it before it hibernates)**. Focus Forestry 2(1): 3. DowElanco, Lebanon, OR.

Ballew, Larry. Forestry consultant, Oakhurst, CA. [Personal communication]. September 26, 1989.

Campodonico, Frank. Forest technician, Stanislaus National Forest, CA. [Personal communication]. April, 2002.

Click, Chris; Fiske, John; Macmeeken, Sue; Sherlock, Joseph. 1994. **Alternatives to herbicides in the USDA Forest Service Pacific Southwest Region—the ten-year update.** In: Proceedings of the 15th annual forest vegetation management conference; 1994 January 25-27; Redding, CA. Redding, CA: Forest Vegetation Management Conference; 46-60.

Click, Chris; Fiske, John N.; Sherlock, Joseph; Wescom, Robert. 1989. **Alternatives to herbicides—update based on the five-year herbicide use moratorium in the USDA Forest Service Pacific Southwest Region.** In: Proceedings of the 10th annual forest vegetation management conference; 1988 November 1-3; Eureka, CA. Redding, CA: Forest Vegetation Management Conference; 49-90.

Coombes, D.E.; McHenry, W.B. 1984. **Bear clover herbicide trials.** In: Proceedings of the 5th annual forest vegetation management conference; 1983 November 2-3; Sacramento, CA. Redding, CA: Forest Vegetation Management Conference; 135-137.

Craig, Stewart. Forester, USDA Forest Service, Pioneer, CA [Personal conversation]. September 15, 1989.

Delapp, Jim. 1975. Memoranda dated October 21 and November 4 to culturists on the Stanislaus National Forest on terracing. File designation 2550, Soil Survey. On file at the Pacific Southwest Research Station, Redding, Calif.

Everest, Glen A. Forestry technician, Pacific Southwest Research Station, USDA Forest Service, Redding, CA. [Personal communication]. July 1996.

Fredrickson, Edward A. 1994. **Efficiency of forest vegetation control with herbicides.** Corvallis: Oregon State University; 204 p. M.S. Thesis.

Furman, T.E. 1959. **The structure of the root nodules of *Ceanothus sanguineus* and *Ceanothus velutinus*, with special reference to the endophyte.** American Journal of Botany 46: 698-703.

Gibbens, R.P.; Schultz, A.M. 1963. **Brush manipulation on a deer winter range.** California Fish and Game 49(2): 95-117.

Grime, J.P. 1979. **Plant strategies and vegetation processes.** New York: John Wiley and Sons; 222 p.

Heald, Bob. Forester, Blodgett Experimental Forest, University of California Field Station. [Personal communication]. October 7, 1987.

Heisey, R.M.; Delwiche, C.C.; Virginia, R.A.; Wrona, A.F.; Bryan, B.A. 1980. **A new nitrogen-fixing nonlegume: *Chamaebatia foliolosa* (Rosaceae).** American Journal of Botany 67(3): 429-431.

Hickman, James C., ed. 1993. **The Jepson manual, higher plants of California.** Berkeley: University of California Press; 1,400 p.

Jackson, Nelroy E.; Lemon, Martin D. 1988. **Roundup herbicide for control of bearclover (*Chamaebatia foliolosa*) in California forestry.** In: Proceedings of the 9th annual forest vegetation management conference; 1987 November 3-5; Redding, CA. Redding, CA: Forest Vegetation Management Conference; 59-65.

Johnson, Scott A. 1988. **Pronone herbicide: A granular hexazinone formulation for site preparation and conifer release.** In: Proceedings of the 9th annual forest vegetation management conference; 1987 November 3-5; Redding, CA. Redding, CA: Forest Vegetation Management Conference; 34-42.

Lanini, W.T. 1981. **Seasonal effectiveness of five herbicides on several Sierran brush species.** Davis: University of California; 92 p. M.S. Thesis.

Little, E.L., Jr. 1979. **Checklist of the United States trees (native and naturalized).** Agric. Handb. 541. Washington, DC: Forest Service, U.S. Department of Agriculture ; 375 p.

Lyons, George W. 1913. **Report on bear clover study.** Report to Supervisor, Eldorado National Forest; 15 p.

McDonald, Philip M. 1999. **Diversity, density, and development of early vegetation in a small clearcut environment.** Res. Paper PSW-RP-239. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 22 p.

McDonald, Philip M.; Everest, Glen A. 1996. **Response of young ponderosa pines, shrubs, and grasses to two release treatments.** Res. Note PSW-RN-419. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 7 p.

McDonald, Philip M.; Fiddler, Gary O. 1999. **Recovery of a bearclover (*Chamaebatia foliolosa*) plant community after site preparation and planting of ponderosa pine seedlings.** Res. Note PSW-RN-423. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 7 p.

McDonald, Philip M.; Mori, Sylvia R.; Fiddler, Gary O. 1999. **Outlook for genetically improved ponderosa pine seedlings in forest vegetation management.** In: Proceedings of the 20th annual forest vegetation management conference; 1999 January 19-21; Redding, CA. Redding, CA: Forest Vegetation Management Conference; 64-76.

McHenry, W.B.; Smith, N.L.; Irving, D. 1980. **Bearmat control with five foliage applied herbicides.** In: Proceedings of the 2nd annual forest vegetation management conference; 1980 November; Redding, CA. Redding, CA: Forest Vegetation Management Conference; 86-87.

Munns, E.N. 1922. **Bear clover and forest reproduction.** Journal of Forestry 20(7): 745-754.

Nelson, Duane A. 1990. **Effectiveness of a winged subsoiler for control of bearclover and reduction of soil compaction during site preparation.** In: Proceedings of the 11th annual forest vegetation management conference; 1989 November; Sacramento, CA. Redding, CA: Forest Vegetation Management Conference; 59-64.

Newcomb, W.; Heisey, R.M. 1984. **Ultrastructure of actinorhizal root nodules of *Chamaebatia foliolosa* (Rosaceae).** Canadian Journal of Botany 62: 1697-1707.

Parsons, Annette. Forester, USDA Forest Service, Placerville, CA. [Personal communication]. March 1991.

Potter, D.A. 1976. **Ecology of bear clover.** In: Proceedings of the bear clover conference; 1976 March 17; Sonora, CA; 1-4.

Potter, Donald A. 1985. **Control of bearclover.** In: Proceedings of the 6th annual forest vegetation management conference; 1984 November 1-2; Redding, CA. Redding, CA: Forest Vegetation Management Conference; 144-150.

Potter, Donald A. 1997. **Results of herbicide trials in low-elevation pine plantations of the central and southern Sierra Nevada.** In: Proceedings of the 18th annual forest vegetation management conference; 1997 January 14-16; Sacramento, CA. Redding, CA: Forest Vegetation Management Conference; 21-33.

Powers, Robert F. 1971,1972. Data on file at the Pacific Southwest Research Station, Redding, CA.

Reigel, Gregg. 1991. Data on file at the Pacific Southwest Research Station, Redding, CA.

Rundel, Philip W.; Baker, Gail A.; Parsons, David J. 1981. **Productivity and nutritional responses of *Chamaebatia foliolosa* (*Rosaceae*) to seasonal burning.** In: Margaris, N.S.; Mooney, H.A., eds. Components of productivity of Mediterranean-climate regions— basic and applied aspects. The Hague: Dr W. Junk Publishers; 191-196.

Rutty, Michael. Silviculturist, Stanislaus National Forest, CA. [Personal communication]. October, 2002.

Schubert, Gilbert H. 1955. **Recent trials with 2,4-D and 2,4,5-T to kill brush in the Sierra Nevada in California.** Res. Note 102. Berkeley, CA: California Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 7 p.

Stowell, M.D.; Lloyd, L.D. 1935. **Reforestation of bearclover areas.** Preliminary summary for field use and preparation of progress reports, Stanislaus Branch, California Forest and Range Experiment Station; 32 p.

Tappeiner, John C., II, Professor, Oregon State University, Corvallis, OR. [Personal communication]. May 4, 1989.

Tappeiner, John C., II; Helms, John A. 1971. **Natural regeneration of Douglas-fir and white fir on exposed sites in the Sierra Nevada of California.** American Midland Naturalist 86(2): 358-370.

Tappeiner, John C., II; Radosevich, Steven R. 1982. **Effect of bearmat (*Chamaebatia foliolosa*) on soil moisture and ponderosa pine (*Pinus ponderosa*) growth.** Weed Science 30: 98-101.

Weatherspoon, C. Phillip. Research Forester, Pacific Southwest Research Station, Redding, CA. [Personal communication]. July 1989, May 2002.

Weatherspoon, C. Phillip; Skinner, Carl N.; Simpson, Celeste S. 1991. **Reducing bearclover by repeated growing-season prescribed burns: Preliminary test results.** In: Proceedings of the 12th annual forest vegetation management conference; 1991 May 14-16; Redding, CA. Redding, CA: Forest Vegetation Management Conference; 1-9.

Wulff, J. 1914. **Bearclover.** Stanislaus National Forest; 12 p.

The Forest Service, U.S. Department of Agriculture, is responsible for Federal leadership in forestry. It carries out this role through four main activities:

- Protection and management of resources on 191 million acres of National Forest System lands;
- Cooperation with State and local governments, forest industries, and private landowners to help protect and manage non-Federal forest and associated range and watershed lands;
- Participation with other agencies in human resource and community assistance programs to improve living conditions in rural areas; and
- Research on all aspects of forestry, rangeland management, and forest resources utilization.

The Pacific Southwest Research Station

- Represents the research branch of the Forest Service in California, Hawaii, American Samoa, and the western Pacific.

United States
Department
of Agriculture

Forest Service

Pacific Southwest
Research Station

General Technical Paper
PSW-GTR-190

Ecology and Manipulation of Bearclover (*Chamaebatia foliolosa*) in Northern and Central California: The Status of Our Knowledge