Antelope Bitterbrush Flowering, Survival, and Regeneration Following Ponderosa Pine Forest Restoration Treatments

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Abstract: To further understanding of the dynamics of antelope bitterbrush (*Purshia tridentata*) recruitment in a ponderosa pine (*Pinus ponderosa*) forest in western Montana, we measured bitterbrush seed viability and germination, flower numbers in 1997 and 1998, seed depredation, seedling survival between 1994 and 2002, and population changes between 1992 and 2002 on four forest restoration treatments. Treatments included a control, a shelterwood cut, a shelterwood cut followed by a low consumption burn, and a shelterwood cut followed by a high consumption burn. Bitterbrush flower numbers did not differ between treatments, but caged bitterbrush had greater flower numbers ($P < 0.001$) than their uncaged pairs, indicating that browsing reduced flower numbers. Seed depredation by rodents and birds caused a small reduction ($P < 0.050$) in seed crop in 1997. Bitterbrush seed viability and seedling survival (percent) were both high; although, the number of surviving bitterbrush seedlings averaged only 15 plants per treatment between 1994 and 2002. In the control treatment there has been a continual decline in bitterbrush numbers totaling 26 percent between 1992 and 2002; whereas, in the shelterwood cut and burn treatments bitterbrush numbers have stabilized since 1994. If bitterbrush stands are desired as a future part of this landscape, it seems clear that disturbance will be necessary. Failure to allow for disturbances that reduce forest overstory and increase mineral soil coverage may ultimately result in loss of bitterbrush from these stands.

Introduction

Antelope bitterbrush (*Purshia tridentata*) is a wide-ranging western shrub found from New Mexico to British Columbia, and from Montana to California in grasslands and open pine forests. In addition to its intrinsic value as an understory and grassland plant, bitterbrush is often an important winter browse species for mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*). In a study by Austin and Urness (1983), bitterbrush was often the most heavily used browse species even when making up only 3 percent of the plant community. Moose (*Alces alces*), bighorn sheep (*Ovis canadensis*), yellow-pine chipmunk (*Eutamias amoenus*), deermice (*Peromyscus maniculatatus*), chipping sparrow (*Spizella passerina*), and blue grouse (*Dendragapus obscurus*) are among the other species that use bitterbrush for food and cover (Everett and others 1978; Matlock-Cooley 1993; Nord 1965).

During the last five decades, the lack of natural bitterbrush regeneration has become recognized as an increasing problem throughout much of its range (Clements and Young 1996; Fraas 1992; Peek and others 1978; Young and others 1997). For example, in a study of bitterbrush in six forest types in Utah from 1957 to 1980, "*Purshia* population densities declined in all forest types over the study period. Average density loss was 35.9 percent in 20 years. Photographs taken in the initial and the 1978 to 1980 periods demonstrate that many shrub individuals died and left no replacements" (Harper and Buchanan 1983).

Bitterbrush stands in western Montana have shown a similar lack of regeneration (Bunting and others 1985). Studies of the shrub-grass communities at and around the Mount Haggin Wildlife Management Area in southwestern Montana have repeatedly stressed the minimal amount of successful reproduction occurring in that region (Fraas 1992; Guenther 1989; Matlock-Cooley 1993). Such concerns have also been documented in the ponderosa pine forests of the Lick Creek Study Area in the Bitterroot National Forest of western Montana (Ayers 1995; Ayers and others 1999). Mature bitterbrush is an important component of the understory throughout much of this area; however, Ayers (1995) found only eight bitterbrush seedlings in the area during the combined field seasons of 1993 and 1994 raising concerns that seedling recruitment would not replace bitterbrush plants dying of natural causes or associated with forest restoration treatments (Bedunah and others 1999). Therefore, the major objectives of our study were to determine the cause of the low number of bitterbrush seedlings observed by Ayers (1995) at the Lick Creek study site and to monitor long-term changes in bitterbrush populations following ponderosa pine forest restoration treatments. To determine possible causes of the lack of regeneration, we measured (1) bitterbrush

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flower numbers; (2) browsing impacts on flower numbers; (3) seed depredation by ungulates, rodents or birds, and insects; (4) differences in viability and germination between seeds collected from the site and seeds obtained from another local seed source, and (5) seedling survival and population changes between 1994 and 2002. Results from this study clarify factors associated with bitterbrush regeneration and population changes in the Lick Creek Study Area as well as provide information for the development of management prescriptions.

Study Area

Our study site is the Lick Creek Study Area of the Bitterroot National Forest located 21 km southwest of Hamilton, MT. Elevations range from 1,311 to 1,402 m. Mean annual precipitation is 56 cm, with approximately 50 percent in the form of snow. Soils are of granitic till parent material and are shallow to moderately deep, with some poorly drained areas and clay soils at the lowest elevations (Gruell and others 1982). Most of the habitat types (Pfister and others 1977) are Douglas-fir (*Pseudotsuga menziesii*) types. The dominant overstory before treatments was Douglas-fir and ponderosa pine. The potential site indexes for these two species average 16 m tall at age 50 (Gruell and others 1982; Pfister and others 1977). The Lick Creek area is considered an important local winter and spring range for mule deer and elk. White-tail deer and moose also occur but at much smaller numbers.

In 1991, the Bitterroot National Forest and Intermountain Forest Science Fire Laboratory initiated a project to examine the response of a ponderosa pine/Douglas-fir stand to a combination of prescribed fire and shelterwood cutting as ecological restoration management tools. Photographs of the study area in the early 1900s are of an open stand of large ponderosa pine with little shrub understory. Apparently, with fire suppression and subsequent logging practices, the area became dominated by dense stands of small diameter Douglas-fir. In 1992 personnel from the Intermountain Fire Sciences Laboratory divided the study site into 12 approximately equal 4-ha units. Each unit was assigned to one of the following four treatments: (1) a shelterwood cut (no burn), (2) a shelterwood cut and a high consumption burn (high consumption burn), (3) a shelterwood cut and a low consumption burn (low consumption burn), and (4) a control. The shelterwood cut was completed in the fall of 1992. Tree basal area was reduced by 53 percent to 13.1m^2. Before application of the shelterwood cut, the location of all bitterbrush within thirty-six 400-m^2 circular plots established in the control, shelterwood cut, low-consumption burn, and high-consumption burn treatments were permanently recorded. Prescribed burns were conducted in May 1993. Burn conditions and bitterbrush survival 2-years post-treatment are described in Ayers and others (1999).

Methods

Flower Production

In May 1997, fifteen 0.04-ha plots were chosen from each of the forest restoration treatments (five plots/replication) established in 1992 to undergo flower counts and seedling observations. We selected five plots because this was the minimum number of plots per replication that still contained live bitterbrush plants following the burning treatments. For those replicated treatments having more than five plots with live bitterbrush, selection was made by first eliminating plots with less than five remaining live plants, and then randomly selecting from the remaining plots. Bitterbrush flowers were counted for the 1997 and 1998 to determine if forest management treatments significantly affected flower production. Bitterbrush seedling survival and change in bitterbrush numbers between 1998 and 2002 were compared with pretreatment and post-treatment bitterbrush numbers. Flower counts were analyzed both as average number of flowers per hectare and average number of flowers per plant, as plant numbers varied across plots.

In the fall of 1994, previous researchers randomly selected 20 plants from each forest management treatment and paired plants of close proximity and with similar vigor and biomass, caging one plant from each pair in a 1.5-m-high wire cage (Ayers 1995). During May 1997, we located the original caged pairs to determine the difference in flower numbers between caged (unbrowsed) and uncaged (browsed) bitterbrush. Those pairs that had one or both members dead or missing were noted as such, and flower count was obtained only for those pairs, which were still viable during May of 1997 and 1998.

Seed Depredation

At the beginning of July 1997, we reviewed flower count data to identify those plants that produced at least 20 flowers. Of these, 15 plants per treatment were randomly selected for monitoring seed production and seed loss. Three plants per treatment were randomly selected to be caged with large square (4- by 7.5-cm opening) hardware cloth to exclude ungulates, three plants were covered with vexar netting to exclude all seed predators except insects, and three plants/treatments were unprotected (control). Seed count was recorded at the beginning of seed production (late June or early July), and again 3 weeks later (mid to late July), to determine the ratio of remaining seed count to original seed count. This ratio was then used to compare the amount of seed lost before seedfall among the three different sets of plants to assess whether ungulates, rodents and birds, or insects were harvesting or browsing seed before seedfall. In 1998, bitterbrush seeds had already ripened and fallen before our second seed count, likely a result of record high temperatures and extremely low levels of precipitation in July and August. Therefore, seed depredation measurements were not valid for the 1998 growing season and are not reported.

Seed Viability and Germination

Seed was collected from bitterbrush plants immediately outside the study plots during the last 2 weeks of July 1997. The seed were cleaned by hand, removing debris and the remnant flower parts, which contain germination inhibitors (Young and Young 1986). After hulling, black or spotted seeds were removed, as these are usually signs of insect infestation or not viable (Giunta and others 1978). Viability

rates of Lick Creek seed were compared with viability of seed purchased from Bitterroot Restoration, Inc. (BRI). BRI bitterbrush seed was collected during the same season about 8 km south of our study site. The BRI seed had been cleaned and culled in a similar manner to ours and had produced healthy seedlings in previous greenhouse trials done by their seed biologist. Both sets of seeds were placed in dry cold storage (1 °C) until testing in the spring of 1998. Viability of seed was determined using a tetrazolium tests according to procedures of Grabe (1970) and Meyer and Monsen (1989). We used four replications of 30 randomly selected seeds from each seed source.

Germination tests were conducted using procedures of Young and Evans (1983), Young and Young (1986), and Meyer and Monsen (1989). Seeds were stratified in the dark for 6 weeks at 2 to 5 °C. Seeds were initially soaked in a 5-percent bleach solution for 2 minutes to kill bacteria or mold. Each replication of 30 seeds was divided into three equal subsets so that seeds could be spaced on petri dishes to prevent individual seeds contacting each other. Germination percent for each petri dish was determined as the ratio of seeds that germinated to the total number of seeds in that dish.

We also monitored germination and establishment of planted seeds in the control treatment by planting three plots of 10 seed groups in November 1997. The seed groups were planted at a depth of 2.5 cm under mineral soil in groups of five seeds to simulate natural germination conditions in rodent caches (Evans and others 1983; Matlock-Cooley 1993). The artificial caches were unmarked to avoid attracting rodents (Young and others 1997). Sites were inspected biweekly in May and early June 1998 to record the number of germinated seeds. Germination percentages were computed by the percent of seed groups that germinated out of the total number of seed groups. Seedling survival for the growing season was measured as the percentage of seedlings that were surviving in October out of the total number of germinated seedlings.

Data Analyses

All statistical analyses were conducted using SPSS software version 8.0 (SPSS 1997). Data were tested for normality and homogeneity of variances. In most cases, despite attempted transformations, most of the data did not meet assumptions of analysis of variance and necessitated the use of nonparametric tests. Number of flowers per plant and number of flowers per hectare between forest restoration treatments and years were compared using the Kruskal-Wallis test (Ott 1993) and the post-hoc comparisons of Tamhane, Dunnett and Games-Howell (Day and Quinn 1989). Because these tests would not allow a block by year, we also used a Kruskall-Wallis test for each year's data alone (flower counts), both with and without outliers. Flower number per plant was compared with all bitterbrush seedlings (any seedling documented between 1993 and 1998) and caged plants excluded from analyses. Flower count data between caged and uncaged plants and seed depredation treatments were tested with an approximate t-test (Day and Quinn 1989). Seed depredation involved comparing three populations using a two-sample t-test; we compared each one to the others by pairs (that is, big cage versus net; big cage versus no cage; no cage versus net). Comparisons of viability and germination rates between seed sources were conducted using an approximate t-test and the nonparametric Wilcoxon Rank Sum/Mann-Whitney test (Day and Quinn 1989; Norusis 1997) because there were too few data points to clearly ascertain normality. Survival of bitterbrush between treatments and years was tested using a two-way analysis of variance with treatments and years as factors.

Results and Discussion

Flower Numbers

Average flower count per hectare was not statistically different between restoration treatments ($P > 0.800$) or years (approximate t-test $P = 0.255$) (table 1). Average flower numbers per plant also did not differ between treatments ($P > 0.550$), but did differ between years ($P = 0.074$) (fig. 1). In 1997 and 1998, 57 and 44 percent of bitterbrush plants produced no flowers, but plants with several hundred to over 2,000 flowers were also found revealing high plant and plot variability (table 2). We believe the difference in flower production per plant between years was due to variations in climate, but was also affected by browsing pressure.

Flower numbers for caged bitterbrush compared to uncaged pairs were 3.4 and 6 times greater ($P < 0.001$) in 1997 and 1998, respectively. Caged plants had greater ($P < 0.05$) flower numbers than the uncaged plants in all treatments except for the control (fig. 2). The reduced flower numbers on uncaged plants revealed that browsing at the Lick Creek Study Area has a significant impact on flower production. We observed many plants during the late spring and early summer of 1997 that had bark slippage (stem segments stripped of cambium) on shoots 1 and 2 years old. Two-year-old leaders are heavily involved in flower production (Shaw and Monsen 1983). Even caged plants often had considerable twig breakage where ungulates had pushed their heads as far as possible through the

Table 1—Bitterbrush (*Purshia tridentata*) mean flower counts per hectare (95-percent confidence intervals) in 1997 and 1998 for the different forest restoration treatments at the Lick Creek Study Area.

Year	Control	No burn	Low-consumption burn	High-consumption burn
1997	7,064 ± 4,889	28,764 ± 25,125	5,579 ± 4,702	4,158 ± 2,606
1998	27,037 ± 19,278	45,005 ± 41,480	12,668 ± 9,645	12,035 ± 7,532

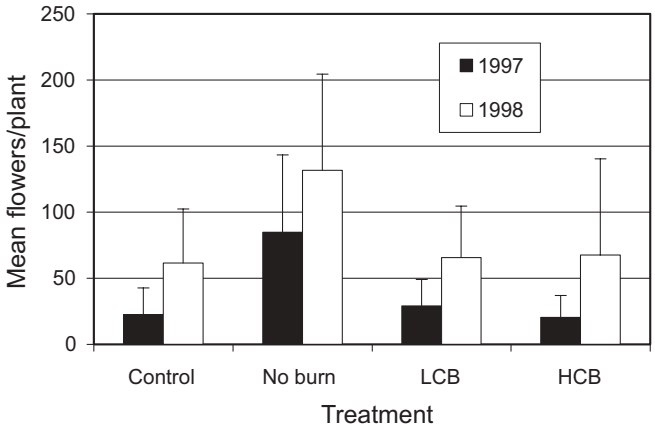

Figure 1—Mean bitterbrush (*Purshia tridentata*) flowers/plants in 1997 and 1998 in the control, no-burn (shelterwood cut only), low-consumption burn (LCB), and high-consumption burn (HCB) treatments at the Lick Creek Study Area.

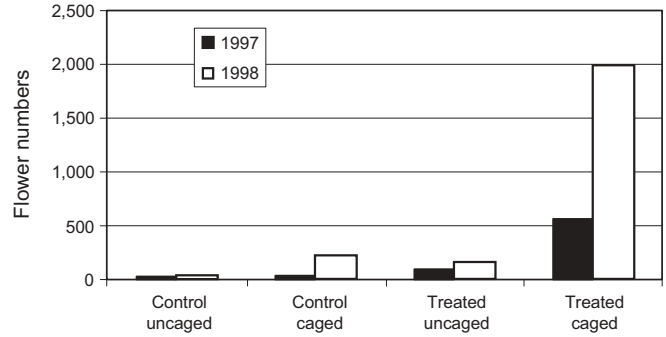

Figure 2—Mean number of bitterbrush (*Purshia tridentata*) flowers/plant for the control and restoration treatments combined for uncaged and caged (protected from browsing) pairs in 1997 and 1998 at the Lick Creek Study Area. Flower counts of caged bitterbrush were significantly different ($P < 0.001$) than uncaged pairs for all treatments except the control. The no burn, low-consumption burn, and high-consumption burn were combined into "treated," as there were no differences between these treatments and all were greater than for the control ($P < 0.01$).

tops of the cages. The lack of difference in flower numbers between caged and uncaged pairs for the control is likely related to low vigor of bitterbrush plants on the control treatment. Other researchers (Buwai and Trlica 1977; Guenther and others 1993) also found that browsing impacted bitterbrush stands, causing decreases in vigor and biomass. However, Tueller and Tower (1979) found a 70-percent reduction in bitterbrush forage production after 2 years of caging. Ferguson and Medin (1983) state that old bitterbrush will reduce leader growth and increase seed production if not browsed. Most caged plants on our study site were three to four times as tall as uncaged plants, and most of them completely filled their cage. These plants had been caged for four growing seasons before our initial flower counts, but were showing none of the reduction in vigor predicted by Tueller and Tower (1979) or Peek and others (1978) for unbrowsed plants. However, as stated previously a number of these caged plants displayed evidence of having been browsed where they extended through the cage at both top and sides. Perhaps this browsing stimulation was enough to keep the plants from becoming senescent. In light of the literature, and the fact that these caged and relatively lightly browsed plants were much more vigorous than the uncaged plants, we conclude that browsing is having a significant negative impact on bitterbrush flower production.

Seed Depredation Ratios of Caged, Netted, and Uncaged Plants

Seed depredation was decreased by netting, but increased by caging plants ($P < 0.05$). Ratios of remaining seeds to initial seeds were 0.75, 0.60, and 0.45 for the netted, uncaged, and large-caged plants, respectively. Apparently, nets kept rodents and birds from consuming seeds, while cages with large openings provided these animals with a safe, relatively predator-free place to feed. We observed a number of caged plants with new chipmunk holes directly under the plant. This bias created by possibly improving rodent habitat with these large cages makes it somewhat difficult to assess possible browsing trends on seed depredation. However, we do not think that ungulate browsing had much effect on these seed count ratios because ungulate populations at this time year are small, as most animals have migrated to their summer ranges. Some sources (Evans and others 1983; Young and Evans 1978) cite high seed depredation levels by ants. We observed

Table 2—Bitterbrush (percent) with no flowers, 1 to 10 flowers, 11 to 100 flowers, 101 to 500 flowers, and greater than 500 flowers in 1997 and 1998 for restoration treatments combined at the Lick Creek Study Area.

	Flower numbers				
Year	None	1 to 10	11 to 100	101 to 500	Greater than 500
	percent				
1997	57.0	14.5	16.9	8.7	3.0
1998	43.7	13.3	19.9	16.0	7.1

minimal ant activity on these plants during our seed count measurements. We conclude that since uncaged plants maintained 60 percent of their seed until seedfall, seed depredation was probably not a significant problem during 1997.

Laboratory Viability and Germination Rates

Comparisons of tetrazolium and laboratory germination test results revealed no difference in percent viability ($P > 0.45$) or germination percentages ($P > 0.55$) between the Lick Creek and Bitterroot Restoration, Inc. seed sources. Viability and germination percentages averaged 91 and 28 percent, and 91 and 33 percent, respectively for the Lick Creek and BRI seed sources. In theory, tetrazolium and laboratory germination tests should yield similar percentages (Grabe 1970; Meyer and Monson 1989; Meyer and others 1986). However, mold is frequently a problem in laboratory stratification and germination, causing some authors to recommend tetrazolium testing only (Grabe 1970; Meyer and others 1986). Once germination testing began we could not bleach or otherwise eliminate mold because the chemicals used would probably also have killed the embryos. This contamination problem is the reason for the lower germination percentages compared to viability. In our field germination trials, 75 percent of the seeds germinated, and 87 percent of these survived through the first growing season.

Seedling Recruitment and Change in Bitterbrush Numbers

Total seedling recruitment, measured as seedlings identified pre-1998 and still present in 2002, was 4, 32, 8 and 4 plants for the control, no burn, low-consumption burn, and high-consumption burn treatments, respectively. Seedling survival was 78 percent across treatments with no difference ($P = 0.69$) between treatments. Thus, the number of bitterbrush seedlings located has been small (and not significantly different between treatments), but survival has been high. The lack of seedlings is a concern in that the initial decrease in bitterbrush numbers following treatments averaged 34, 62, and 65 percent for the no burn, low-consumption burn, and high-consumption burn treatments (fig. 3). Seedling recruitment in these treatments has not been able to add significantly to the population losses caused by the initial treatments, with the no burn, low-consumption burn, and high-consumption burn treatments averaging 103, 106, and 99 percent of bitterbrush numbers found in 1994. However, bitterbrush in the control treatment has declined by 26 percent ($P < 0.05$) since the study began in 1992, showing significant mortality for untreated stands (fig. 3). The decrease in bitterbrush in the control treatment appears to be a relatively continuous decline, with 18-percent mortality between 1994 to 1998, and an additional 8-percent mortality between 1992 to 2002 (fig. 3). We believe this mortality is associated with the poor vigor of bitterbrush in these undisturbed forest stands and illustrates that a "no treatment" option is not a viable option for maintaining bitterbrush in the Lick Creek area.

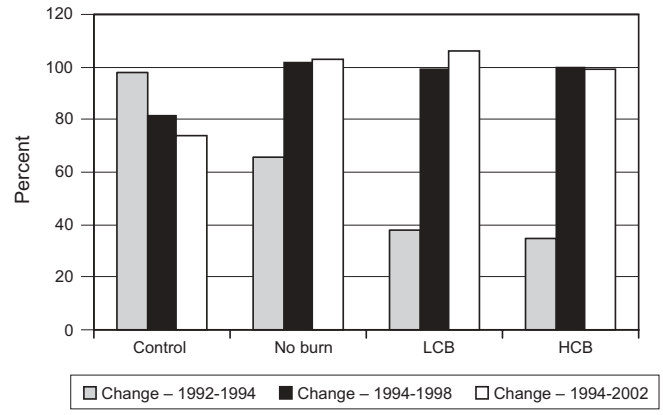

Figure 3—Change (percent) in bitterbrush (*Purshia tridentata*) numbers between 1992 to 1994, 1994 to 1998, and 1994 to 2002 for a control, no burn (shelterwood cut only), low-consumption burn (LCB), and high-consumption burn (HCB) at the Lick Creek Study Area. Pretreatment bitterbrush numbers were 184, 258, 259, and 490 for the control, no burn, low-consumption burn, and high-consumption burn treatments, respectively.

We examined historical photos taken of our study area during the past 90 years (some from Gruell and others 1982, others from the U.S. Forest Service Region 1 Headquarters, Missoula, MT) to determine the historical density and size of bitterbrush on this site. These pictures show mostly small, low-growing bitterbrush at low density for the areas photographed in 1909. These photographs were taken 14 years after the last recorded fire, which is within the 3- to 30-year fire interval for the site (Arno 1976). By the late 1920s, bitterbrush in the photographs are larger and the stands more dense. However, as the forest canopy closes no bitterbrush regeneration is visible, and stands appear less vigorous. When trees are removed in subsequent thinning, the bitterbrush stands appear to regain vigor. Photo interpretation indicates that bitterbrush were present on this site during the era of high-frequency, low-intensity fires although in smaller form and numbers (for example, see photo series accompanying USDA Forest Service photos 87357 and 86480). Therefore, the population levels of bitterbrush now found on the restoration treatments, although lower than before treatments, may represent more natural (pre-1900) levels of bitterbrush.

Summary and Management Implications

The primary goal of this study was to understand bitterbrush regeneration and survival following forest restoration treatments at the Lick Creek Study Area. The restoration treatments were designed to restore the area to an open ponderosa pine stand, similar to conditions prior to European settlement. Previous studies have shown high bitterbrush mortality on all treatments except the control and noted almost no bitterbrush flower production or seedlings

2 and 3-years post-treatment. We found no significant problems in bitterbrush seed viability, field germination, or seedling survival. Netting plants significantly reduced seed depredation; however, depredation of seeds on unprotected plants was only 40 percent and does not appear to be a major factor for the low seedling recruitment. Much higher flower numbers for caged bitterbrush compared to uncaged pairs shows that browsing by ungulates impacts flower numbers. It seems likely that more bitterbrush regeneration would occur if browsing pressure was reduced, especially where there is not a buildup of undecomposed organic matter and suitable sites for rodent caching and seed germination. Several studies have shown that a buildup of undecomposed organic matter reduces suitable sites for rodent caching and seed germination (Evans and others 1983; Ferguson and Medin 1983; Fraas 1992; Matlock-Cooley 1993).

The no burn, low-consumption burn, and high-consumption burn treatments resulted in 34, 62, and 65 percent bitterbrush mortality, respectively, following treatments (1992 to 1994). Bitterbrush mortality was found to be significantly related to mechanical damage class and burn severity (Ayers and others 1999). Since 1994, bitterbrush numbers have stabilized for these treatments, with the low consumption burn and no burn treatments having small increases in total plants (although not significantly different); however, for the control (no treatment) bitterbrush numbers decreased by 26 percent. Therefore, it is apparent that a "no treatment" is not a viable option for maintaining bitterbrush in the Lick Creek area. In addition, the potential of a high-intensity wildfire is much greater in stands with no treatment as compared to forest restoration treated stands. A high-intensity wildfire would likely result in extreme mortality of bitterbrush in this area. Land managers may want to consider a mosaic of different treatments on the landscape as a simulation of mosaics created by fires in the past. Such mosaics provide more diversity of habitat and species, both flora and fauna, and less potential for landscape-scale forest stand replacement by insects, disease, or fire (Camp and others 1996). A shelterwood cut with no burning would result in less bitterbrush plant loss compared to a treatment with understory burning. However, disturbances mimicking natural events, such as forest stand thinning and low-intensity burns, which maintain open ponderosa pine stands, should allow for bitterbrush maintenance and further reduce the potential of wildfires. The type of treatment chosen will depend on the specific management objectives for a given area, both in terms of bitterbrush stand condition and in terms of timber and other interests. However, it is apparent that if bitterbrush stands are desired as a future part of this landscape, some type of disturbance will be necessary to reduce forest overstory and increase mineral soil coverage on at least a portion of the landscape. Failure to provide or allow for these disturbances may ultimately result in long-term loss of bitterbrush from these stands, and for other species that also depend on disturbance for regeneration and maintenance.

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