Antelope Bitterbrush and Scouler's Willow Response to a Shelterwood Harvest and Prescribed Burn in Western Montana

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ABSTRACT: *In many western Montana ponderosa pine (*Pinus ponderosa*) stands, fire suppression and past selective logging of large trees have resulted in conditions favoring succession to dense stands of shade-tolerant, but insect- and disease-prone Douglas-fir (*Pseudotsuga menziesii*). Stand thinning and understory prescribed burning have been proposed as surrogates for pre-Euro-American settlement ecological processes and as potential treatments to improve declining forest condition and reduce the probability of severe wildfire. To test the effectiveness of these silvicultural techniques on overstory and understory conditions, research is ongoing in the Lick Creek Demonstration Site in the Bitterroot National Forest, Montana. Our research examined the response (mortality and vigor) of the dominant browse species, antelope bitterbrush (*Purshia tridentata*) and Scouler's willow (*Salix scouleriana*), to a ponderosa pine stand restoration project utilizing four treatments: (1) a shelterwood cut that removed 53% of the tree basal area; (2) a shelterwood cut with a low fuel consumption burn; (3) a shelterwood cut with a high fuel consumption burn; and (4) a control. Prior to the application of treatments, 1,856 bitterbrush and 871 willow were located, and their survival and vigor subsequently monitored for 2 yr posttreatment. The cut and burn treatments resulted in the greatest reduction in antelope bitterbrush and Scouler's willow density averaging 66% and 24% of pretreatment density, respectively. The shelterwood cut reduced bitterbrush and Scouler's willow density by 35% and 14%, respectively. On treatments receiving a shelterwood cut (all treatments but the control), but where antelope bitterbrush and Scouler's willow did not have fire damage, mortality was 45% for bitterbrush and 20% for willow, respectively. For bitterbrush and Scouler's willow plants that received fire damage, mortality was 72% for bitterbrush and 19% for willow. Although the burn and shelterwood harvest treatments resulted in reduced density of antelope bitterbrush and Scouler's willow 2 yr posttreatment, these treatments increased vigor of both species and created mineral seedbeds that may be necessary for establishment of seedlings. West. J. Appl. For. 14(3):137–143.*

Throughout western Montana, more than 80 yr of fire suppression and selective logging have caused dramatic changes in stand structure and species composition of ponderosa pine (*Pinus ponderosa*) forests (Arno 1976). Photographs from the early 1900s provide evidence of more open, park-like stands of primarily large trees yielding an abundant grass and forb understory (Gruell et al. 1982). This open-forest condition was sustained by frequent low-intensity fires at intervals of 1 to 30 yr prior to Euro-American settlement in the mid-1800s (Arno 1988). Since settlement, stand structure has changed to more shade-tolerant species, especially true firs (Larsen 1929, Habeck 1990) and increasing densities of Douglas-fir (*Pseudotsuga menziesii*), as well as second-growth ponderosa pine. In western Montana, Scouler's willow (*Salix scouleriana*) and antelope bitterbrush (*Purshia tridentata*) are two shrubs that may have increased following the elimination of frequent fires and initial opening of stands associated with logging (Gruell, 1986). The subsequent increasing tree densities, however, have increased resource competition between trees and understory species, such as bitterbrush and willow, which are often of low vigor and reproduce poorly in many of these stands. These shrubs often

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supply critical winter/spring browse to wild ungulates such as elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), and moose (*Alces alces*), whose response to changing forest conditions is important to land managers.

Current forest management strategies are focusing on ecological, restorative management approaches that encompass multi-resource values of forest stands (Arno et al. 1995). By reducing stand densities using shelterwood harvesting and reintroducing fire, managers are attempting to simulate pre-1900 ecological processes that were critical components in the life history of many plant species and shaped stand density, structure, and species composition (Fiedler et al. 1992). For example, biomass and vigor of many browse species frequently increase following shelterwood cutting (McConnell and Smith 1970, Stuth and Winward 1976, Edgerton 1983) as well as prescribed burning (Biswell 1973, Driver et al. 1980). For bitterbrush specifically, overstory thinning (McConnell and Smith 1970, Sherman and Chilcote 1972, Stuth and Winward 1976, Edgerton 1983) has generally been more effective than prescribed burning for enhancing browse quality in both rangelands (Clark et al. 1982, Kituku et al. 1992, Cook et al. 1994) and forested areas (Driver et al. 1980). For willow, however, fire effectively promotes vigorous regrowth (Mueggler 1965, Asherin 1973, Leege 1979b, Noste and Bushey 1987). Management of sites with both species may present a dilemma for land managers, given these different responses. Our research examined the response of antelope bitterbrush and Scouler's willow to the combined impacts of prescribed fire and timber harvesting as potentially restorative management treatments of western Montana ponderosa pine forests.

Methods

Study Area

Research was conducted at the Lick Creek Demonstration Area on the Bitterroot National Forest in western Montana. The abiotic conditions of this site, at an elevation of 1300 to 1400 m, typify those of many ponderosa pine stands of western Montana. Mean annual precipitation is 53 cm, with approximately 50% falling as snow (Gruell et al. 1982). November through March temperatures average –2°C and ranged from –28° to 12°C during those months in 1993 and 1994. Mid-May through mid-September temperatures average 20°C and ranged from –2° to 32°C during those months in 1993. The soils are derived from granitic parent materials and are shallow to moderately deep (Gruell et al. 1982). Habitat types (Pfister et al. 1977) on the site include *Pseudotsuga menziesii/Vaccinium caespitosum* on toe slopes and benches and *Pseudotsuga menziesii/Symphoricarpos albus, Agropyron spicatum* phase on drier south-facing slopes.

Ponderosa pine was primarily even-aged, established after a 1906 clearcut (Gruell et al 1982) Over the last 90 yr, the only documented stand entry was a precommercial thinning in 1967. Minimal disturbance in this stand has resulted in an increase of Douglas-fir and increasing competition among dense second-growth pine indicated by reduced annual increment growth and recent bark-beetle induced mortality. The site is managed as an important winter range for white-tailed deer, mule deer, Rocky Mountain elk, and moose by the Bitterroot National Forest. Beginning in 1992, cattle grazing was excluded from the Lick Creek Demonstration Area.

Experimental Approach

The site was divided into 12 units of approximately 3 ha, and each unit was randomly assigned to one of the following four treatments: (1) a shelterwood cut, (2) a shelterwood cut and a high fuel consumption burn, (3) a shelterwood cut and a low fuel consumption burn, and (4) a control. The shelterwood cut was designed to favor ponderosa pine by leaving the largest, healthiest pines and removing Douglas fir and smaller, marketable pines. The intent was to improve productivity of overstory trees and understory grasses and shrubs, increase pathogen resistance of the trees, and along with prescribed burning, reduce the risk of stand-replacing wildfire. Before application of treatments, twelve 400 m^2 circular plots were systematically located in each unit and permanently marked with steel spikes. In the summer of 1992, we recorded the location of all bitterbrush and willow within these plots for a total of 871 willow plants and 1,856 bitterbrush plants. The shelterwood harvest was conducted in the fall of 1992, and log skidding was done with crawler tractors.

Prescribed burns were conducted in May 1993 under two different fuel moisture conditions to contrast the impacts of low and high fuel consumption. Fuels sampled for moisture determination were fresh litter, woody material larger than 7.5 cm in diameter, and the decomposed organic horizon referred to as "duff." Low and high fuel consumption prescriptions differed with respect to fuel moisture contents of large woody fuels and duff (Table 1), but due to unusual weather patterns, air temperatures and relative humidities overlapped for the two burns. Duff depths before and after burning were measured with two spikes placed flush with the top of the duff near the root crowns of 69 willows and 92 bitterbrush plants. Duff consumption (%) was chosen as a measure of fire severity since it is the material that burns immediately above the root crowns.

Plant Response to Treatments

For each treatment, canopy cover (%) of willow and bitterbrush was estimated in thirty-six 33 m^2 circular plots All other measurements were determined from the individual plants located prior to application of treatments in the thirty-

Table 1. Abiotic conditions in 1993 during prescribed burns in the Lick Creek Demonstration Area.

Treatment	Date	Temperature (°C)	Humidity (%)	Moisture content (%) Large fuels	Woody fine fuels	Duff
Low consumption burn	May 13	10–20	46–70	100	9	50
High consumption burn	May 25	13–23	34–77	29	8	16

six 400 m^2 plots per treatment. These plants were monitored to determine survival and vigor. To determine which plant characteristics might influence plant response to the treatments, in the summer of 1992 we measured pretreatment plant characteristics, including height, stem diameter, and vitality. Vitality rating was based on five classes in 20% increments: [1] < 20% of plant dead, to [5] > 80% of plant dead. Immediately after the shelterwood harvest, plants were relocated to determine the degree of mechanical damage and proximate fuel quantity. Mechanical damage was assessed using five classes: [0] no damage, [1] plant with broken branches, main stem still standing (low), [2] plant with all branches broken, main stem damaged (medium), [3] plant with only remains of main stem present (high), and [4] plant removed/skid trail (severe). Proximate fuel quantity was assessed using five classes: [0] no duff, bare mineral soil, [1] < 2 cm duff present, [2] 2 to 6 cm of duff present, [3] 6 to 10 cm of duff present, and [4] harvesting slash or naturally heavy duff, > 10 cm deep. Following prescribed burning in spring 1993, all bitterbrush and willow were relocated to determine level of fire damage, and each plant was placed in one of five burn classes: [0] no evidence of fire on plant, [1] some charring of main stem near ground level (low), [2] main stem and branches charred, no leaves present (medium), [3] only charred main stem stump remaining (high), and [4] plant completely consumed by fire, no evidence of main stem (severe). Each shrub was then monitored in the summers of 1993/1994 to document survival and vigor. Vigor was assessed using methodology similar to that employed by Buwai and Trlica (1977) using three classes based on a proportion of current annual growth (CAG) meeting a minimum twig length of 10 cm for willow and 5 cm for bitterbrush (Lyon 1968): [1] < 33% of CAG (low vigor), [2] 33% to 67% of CAG (medium vigor), and [3] > 67% of CAG (high vigor).

Data Analysis

Differences in pretreatment and posttreatment canopy cover and density of bitterbrush and willow were evaluated using one-way analysis of variance. Assumptions of equal variance and normality were tested and, if necessary, variables were transformed to meet assumptions. We also grouped bitterbrush and willow into categories of burned and unburned, since not all plants within the burned treatments received fire damage, and then used logistic regression to determine which variables were most significant in predicting mortality for each group using the variables of height, diameter, vitality class, mechanical damage, fuel class, and burn class. These variables were also correlated with posttreatment vigor using Kendall-tau nonparametric correlation analysis (Sokal and Rohlf 1995). Differences in vigor and survival among treatments were compared using a X^2 test. Differences were considered significant at $P < 0.05$ for all analyses.

Results

The results are separated into two sections. The first describes the effects of the treatments on overall site conditions. The second describes the response of bitterbrush and willow to the treatments, as well as to pretreatment and posttreatment plant variables.

Site Conditions

The shelterwood cut, applied to all treatments but the control, resulted in a 59% reduction of Douglas-fir, which represented 18% of the preharvest basal area and subsequently 4% of the postharvest basal area. Average tree basal area was reduced from 27 to 11 m^2/ha. Average tree density/ha was reduced from 593 to 277. The harvest operation resulted in 11% of the area as skid trails. Sites most impacted by the harvesting operation were trails over which groups of logs were skidded, often several times. Other less severe mechanical damage was caused by falling trees and pulling single logs over individual willow and bitterbrush plants.

Preburn duff depths around willow root crowns ranged from 4 to 13 cm and averaged 6.2 cm. Duff consumption as percent depth reduction measured adjacent to individually marked willow plants (n = 69) was significantly greater (F = 15.57, P < 0.001) in the high consumption burn ($\bar{x}$ = 91%) than the low consumption burn ($\bar{x}$ = 70%). For individually marked bitterbrush plants (n = 92), duff depths ranged from 0.5 to 9 cm and averaged 2.7 cm. Duff reduction for the high consumption burn ($\bar{x}$ = 71%) did not differ significantly (P > 0.9) from the low consumption burn treatment ($\bar{x}$ = 62%). In the low consumption burn, 66% of bitterbrush and 86% of willow received fire damage; whereas, in the high consumption burn 48% of the bitterbrush and 86% of the willow exhibited fire damage. These treatment differences, however, were not significant (P > 0.05) for either species.

Plant Response

The shelterwood cut and prescribed burn treatments resulted in modest willow mortality, but substantial bitterbrush mortality (Figure 1). There was a concurrent decrease (P < 0.05) in willow and bitterbrush cover (%) compared to the control. Mean canopy cover reductions were 58, 62, 33, and 1% for Scouler's willow and 92, 83, 75, and 2% for bitterbrush in the high burn, low burn, harvest-only, and control treatments, respectively.

The shelterwood cut resulted in mechanical damage to 35% and 59% of the bitterbrush and willow, respectively, within those treatments receiving a shelterwood cut. Mortality of bitterbrush and willow plants not exposed to fire was best explained by the degree of mechanical damage (Table 2). Bitterbrush survival was greater than 81% in the first four damage classes but was only 14% in the severe damage class (Table 2). Of the bitterbrush plants receiving any mechanical damage, almost 69% sustained severe damage. Willow survival was greater than 89%, except for those plants severely damaged on skid trails where survival decreased to 58% (Table 2). Complete top removal of plants due to skidding (severe damage class) accounted for 90% of bitterbrush mortality and 77% of willow mortality.

For willow and bitterbrush that received burn damage, mortality was best explained by the degree of burn sever-

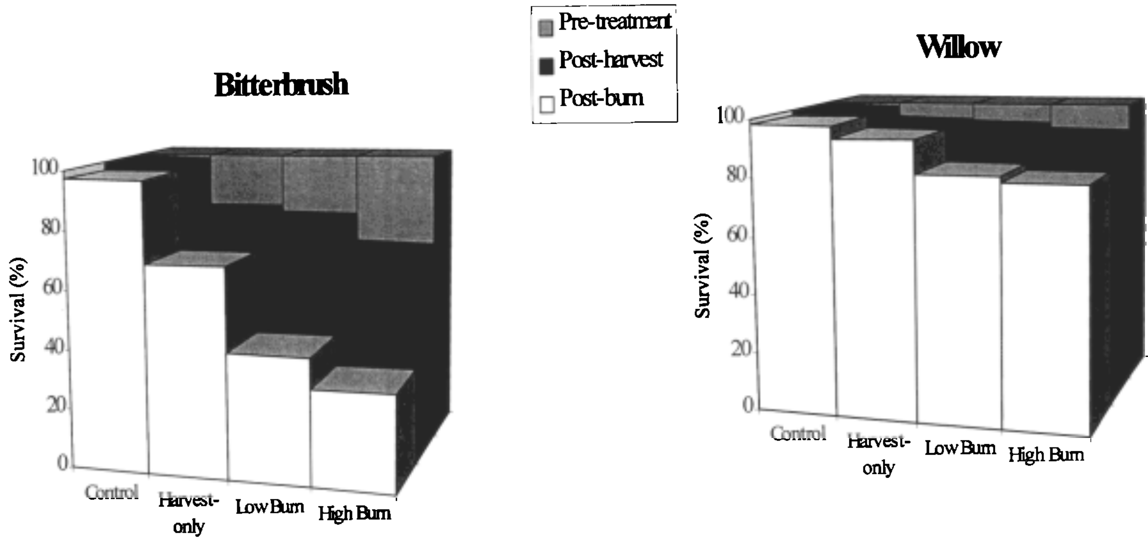

Figure 1. Survival of Scouler's willow (*Salix scouleriana*) and antelope bitterbrush (*Purshia tridentata*) two seasons after harvesting and burn treatments in the Lick Creek Demonstration Area.

ity (burn class) (Figure 2 and Table 3). Bitterbrush was notably impacted by any fire damage, whereas willow was not markedly affected until it suffered deep charring of the root crown (Figure 2). For bitterbrush, mortality was also slightly and positively related to variations in fuel loading and negatively related to vitality class and height (Table 3). Of the 639 bitterbrush plants that received burn damage, only 28% survived, and these were predominantly in the low and medium burn classes (Figure 2). Bitterbrush mortality (%) by burn class was greater ($P < 0.05$) for the high consumption burn compared to the low consumption burn. Of the 337 willow plants that received burn damage, 80% survived, and there was no difference between the burn treatments.

The proportion of bitterbrush and willow in the high vigor class was greater in the burn and the harvest-only treatments than in the control ($P < 0.05$) (Figure 3). For both bitterbrush and willow without fire damage, vigor was positively correlated with mechanical damage and negatively correlated with initial vitality class, but did not correlate well with other pretreatment plant characteristics (Table 4). For plants surviving exposure to fire, no significant correlations were found between vigor and the set of independent variables.

Table 2. Influence of mechanical damage class for the shelterwood cut and burn treatments on survival (%) of Scouler's willow (*Salix scouleriana*) and antelope bitterbrush (*Purshia tridentata*) for plants receiving no burn damage at the Lick Creek Demonstration Area, 1994.

	Mechanical damage class				
Species	None	Low	Medium	High	Severe
	Survival (%)				
Scouler's Willow	89 (66)[1]	95 (42)	94 (51)	94 (34)	58[2] (115)
Antelope Bitterbrush	94 (289)	88 (77)	92 (79)	81 (41)	14[2] (432)

Discussion

The shelterwood harvest resulted in significant shrub injury; however, the mortality of willow (20%) and bitterbrush (45%) associated with mechanical damage was considered relatively low, most likely related to the low amount of severe ground disturbance (11%). Edgerton (1983) reported 72% mortality of bitterbrush following harvesting of a lodgepole pine stand where the tree basal area was reduced by 78% compared to the removal of 53% basal area in this study. More extensive disturbance probably would have contributed to higher shrub mortality, especially for bitterbrush. Indeed, the low-burn treatment with 9% of the area in skid trails had 12% less loss of bitterbrush to skidding than the other two harvested treatments, both of which had 12% of their area in skid trails. In this restoration project, distances between skid trails were maximized to minimize the impact of the skidding operation. Since the tractors could winch trees from 18 m away, skid trails were spaced 36 m apart.

Both shrub species had minimal mortality in the lowest four mechanical damage classes, but in the severe damage class willow mortality was 42% compared to 86% for bitterbrush. Within skid trails, willow plants had greater resilience than bitterbrush; 20% of willow resprouted compared to only 4% of bitterbrush. The difference in mortality (%) and amount of resprouting between bitterbrush and willow subjected to similar mechanical injury is a result of their different morphologies. The deep root system and multistemmed growth of willow allow for higher tolerance to disturbance than that of bitterbrush. Willow often resprouts after surface disturbance from a subterranean root crown (Lyon 1966), whereas bitterbrush can only resprout from a surface caudex (Guinta et al. 1978), which is more easily removed or injured by disturbance.

For bitterbrush and willow with fire damage, burn class was the most significant variable in explaining within

Table 3. Variables explaining significant variation in antelope bitterbrush (*Purshia tridentata*) and Scouler's willow (*Salix scouleriana*) mortality in Lick Creek Demonstration Area, 1995.

Species	Exposure	No. dead (total)	Variable	Variance explained (%)
Bitterbrush	Fire	459 (639)	Burn class	72
			Fuel loading	2
			Vitality class	2
			Height	1
	No fire	425 (1,217)	Mech. damage	91
Willow	Fire	65 (337)	Burn class	84
	No fire	68 (534)	Mech. damage	90

[1] Numbers in parentheses are total numbers by class.
[2] Significantly different ($P < 0.05$) from all other classes.

Table 4. Correlation of antelope bitterbrush (*Purshia tridentata*) and Scouler's willow (*Salix scouleriana*) vigor with independent variables for plants not exposed to fire in Lick Creek Demonstration Area, 1994.

Species	*N*	Variables	Kendall τ
Bitterbrush	792	Mechanical damage	0.23
		Vitality class	–0.10
		Height	–0.09
Willow	466	Mechanical damage	0.39
		Vitality class	–0.07

species variation in mortality (Table 3). Morphology, in turn, explains the difference between bitterbrush and willow in resprouting after fire injury. Bitterbrush response to fire varies with ecotype (Menke and Trlica 1981). The recumbent ecotype can readily sprout after fire (Blaisdell and Mueggler 1956, Driscoll 1963, Wright et al. 1979), whereas the columnar ecotype has a much reduced ability to sprout, relying primarily on seedling regeneration from both onsite and offsite seeds (Wright et al. 1979, Noste and Bushey 1987). Other factors influencing resprouting include variation in fire prescription (Blaisdell and Mueggler 1956, Buwai and Trlica 1977, Driver et al. 1980), fuel loading (Driscoll 1963, Driver et al. 1980), and abiotic conditions (Driscoll 1963, Hobbs and Schimel 1984). Low fuel consumption spring burns tend to enhance sprouting (Blaisdell and Mueggler 1956, Driver et al. 1980, Martin and Driver 1983) and minimize mortality (Wright et al. 1979), whereas higher fuel consumption fall burns increase mortality but produce mineral seedbeds that favor plant regeneration by seed (Fischer and Bradley 1987).

For this study, the combination of a spring burn, above average summer precipitation, and cool temperatures following the burn should have produced favorable conditions for bitterbrush to resprout (Driscoll 1963, Nord 1965, Ferguson 1972). The nearest National Weather Service station at Darby, MT, 8 km to the southwest, received 16 cm of precipitation above normal and was about 2°C cooler than normal for June, July, and August of 1993. Yet, because bitterbrush on this site is of the weak-sprouting columnar ecotype and because duff consumption at the root crowns was relatively high (> 60%), only 9% of the bitterbrush resprouted after 2 yr. Nevertheless, the 72% mortality of bitterbrush that received fire damage is within reported ranges of 30–100% for similar burn treatments (Blaisdell and Mueggler 1956, Clark et al. 1982, Kituku et al. 1992, Cook et al. 1994).

Although fire can cause high mortality of bitterbrush, seed germination of bitterbrush from rodent caches apparently requires almost competition-free, mineral seedbeds, naturally caused by fire (Sherman and Chilcote 1972,

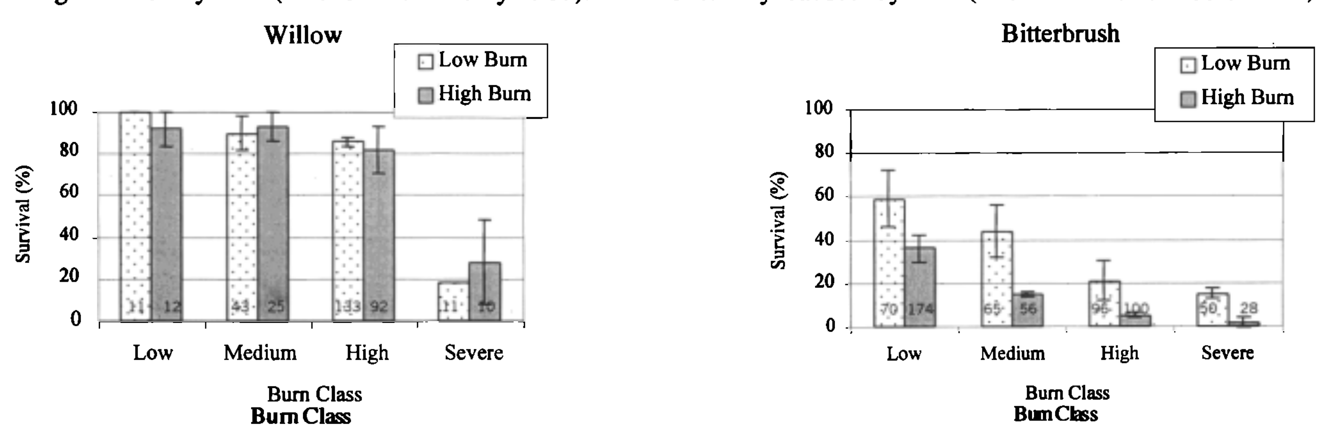

Figure 2. Survival (%) of Scouler's willow (*Salix scouleriana*) and antelope bitterbrush (*Purshia tridentata*) by burn class. Total number of plants in each class are shown.

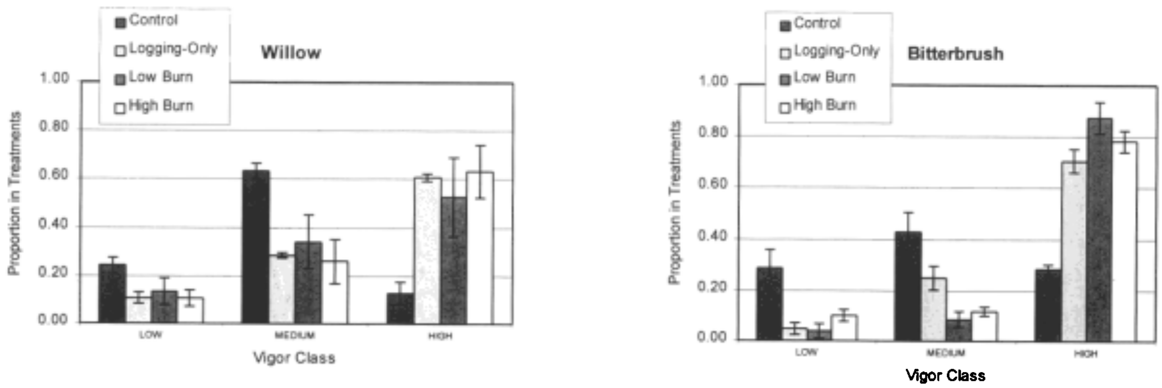

Figure 3. Treatment effects on the proportion (%) of Scouler's willow (*Salix scouleriana*) and antelope bitterbrush (*Purshia tridentata*) in low, medium, and high vigor classes.

Clark et al. 1982). We found only 10 bitterbrush seedlings (< 0.3seedlings/ha) in the 3 yr following the burn applications; however, we hypothesize that the lack of bitterbrush seedlings was a result of low flower/seed production associated with low pretreatment vigor and relatively high posttreatment wild ungulate browsing. The lack of bitterbrush seedlings is a concern, and further research is needed to determine its cause.

In contrast to bitterbrush, willow readily resprouted after burning, resulting in low overall mortality (19%). Vigorous resprouting is consistent with other research (Leege and Hickey 1971, Leege 1979a), and willow has been reported to increase in both biomass and vigor by as much as 100% following a burn (Noste and Bushey 1987, Leege 1969b, Mueggler 1965). Besides sprouting, willow is a seral species, which can colonize rapidly after fire from off-site seed germinating on fire-created mineral seedbeds (Noste and Bushey 1987).

The willow and bitterbrush also responded differently to the two burn treatments. For willow there was no difference in mortality (%) between the low consumption and high consumption burn treatments. Bitterbrush mortality (%) by burn class, however, was greater overall in the high consumption burn treatment. It is our hypothesis that this greater mortality was associated with the phenological development of the bitterbrush. The high consumption burn was conducted 12 days after the low consumption burn allowing for greater spring growth of the bitterbrush and therefore a greater loss of this new growth to the burn.

Vigor increased for both bitterbrush and willow in all treatments compared to the control (Figure 3). In the growing season immediately following the burns, bitterbrush responded most favorably to the shelterwood cut, whereas willow had higher mean vigor within both burned treatments (data not presented). Yet surprisingly, the proportion of high vigor willow plants was not significantly greater in the burn treatments over the harvest-only treatment, 2 yr posttreatment. This is most likely related to heavy browsing in the growing season following the treatments, resulting in loss of new growth and subsequently lower vigor for these plants. Unfortunately, the relatively short duration of this study cannot fully address questions of long-term increases in vigor; however, other research findings have reported an increase in current annual growth of bitterbrush following logging for up to 7 yr after overstory removal (McConnell and Smith 1970, Stuth and Winward 1976, Edgerton 1983) and immediately after spring burning (Demarchi and Lofts 1985, Cook et al. 1994).

Management Implications

Our results show that despite significant bitterbrush mortality and modest willow mortality from overstory removal and prescribed burning, surviving willow and bitterbrush showed a positive increase in vigor following treatments. If one considers the fact that fire is a natural disturbance, then the loss of a proportion of the bitterbrush population to fire may not be ecologically detrimental. Even though the most severe fire treatment caused 68% reduction in bitterbrush, there were still 168 plants/ha of which almost 80% had high vigor. By reducing the negative effects of harvesting by using widely spaced skid trails with low-impact equipment and prescribing low fuel consumption burns with variable fire coverage, plant mortality should be minimized, especially for bitterbrush. With the return of open stand conditions, mineral seedbeds, and more vigorous plants, the potential for natural regeneration to replace fire-killed plants is high (Gruell 1986). Heavy browsing of the vigorous shoots by ungulates, however, could be a possible detriment to flower and seed production.

The current harvesting and prescribed burning treatments appear to have been a positive stimulus to willow productivity. Survival was greater than 75%, and the percentage of high vigor plants increased from 15% pretreatment to 70% posttreatment. With dispersed ungulate browsing, seed production and seedling establishment potential should be greater on the mineral seedbeds in the open stands.

In areas where both willow and bitterbrush occur, resource managers interested in maintaining or enhancing browse need to consider understory composition and species-specific responses to management practices, as well as desired plant characteristics (e.g.. greater density, increased biomass, increased vigor, etc.) before applying treatments. A no entry option would eliminate mortality of individual shrubs caused by the stand entry, but population fitness may decline dramatically as overstory density increases, and the threat of wildfire may increase. A stand-replacing wildfire would be highly destructive to bitterbrush, specifically, and to the forest in general. Alone, this research is valuable in understanding species-specific responses to disturbances. It is most applicable, however, when used in conjunction with results from the other resources assessed in the Lick Creek Demonstration Area. Multiresource assessment must be a requisite for successful restoration management.

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