A comparison of burned and unburned big sagebrush communities in southwest Montana
by Kendal Scott Walhof

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Range Science
Montana State University

Abstract:
Big sagebrush (Artemisia tridentata Nutt.), an important shrub for numerous wildlife populations, does not sprout and is killed by fire. Responses of mountain big sagebrush (A.t. ssp. vaseyena [Rydb.] Beetle) and Wyoming big sagebrush (A.t. ssp. wyomengensis Beetle and Young) communities from fire are not completely understood. Recovery of big sagebrush communities was studied at 13 sites in southwest Montana. Environmentally paired burned and unburned treatments were located within each site. Sites were burned between 2 and 32 growing seasons prior to sampling. Big sagebrush canopy cover, density, and winter forage production, along with herbaceous understory cover were measured in each treatment. Twenty live and 20 dead big sagebrush plants were aged in each treatment. Fire reduced mountain big sagebrush canopy cover and adult density at all sites dominated by mountain big sagebrush($P<0.001$). Two of 3 sites dominated by Wyoming big sagebrush showed no difference ($P<0.36$) in big sagebrush canopy cover between burned and unburned treatments. Of the three sites dominated by Wyoming big sagebrush, adult density was greater in 1 burned treatment ($P<0.0006$), lower in 1 burned treatment ($P<0.01$), and was similar between treatments at the final site. Mountain big sagebrush juvenile density was greater in unburned treatments at 7 of 10 sites ($P<0.002$) while Wyoming big sagebrush juvenile density was variable. Big sagebrush winter forage production was greater ($P< 0.05$) in all unburned treatments. Big sagebrush plants that re-established did so soon after fire disturbance. Ages of dead and live big sagebrush in unburned treatments were similar. This indicates that a variety of factors may kill big sagebrush before it has obtained maximum longevity. Litter cover was greater in unburned treatments ($P<0.05$). Soil and rock exposed was greater in burned treatments ($P<0.0005$). Idaho fescue (Fastuca idahoansis Elmer) cover, total perennial grass cover, and perennial forb cover increased in some burned treatments and decreased in others. Fire disturbance can affect big sagebrush communities for several decades. This shrub component used so extensively by wildlife populations can take longer than 30 years to establish pre-burn conditions with little or no benefit to grasses or forbs.

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APPROVAL

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Kendal Scott Walhof

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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Date 4-15-97

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ABSTRACT

Big sagebrush (*Artemisia tridentata* Nutt.), an important shrub for numerous wildlife populations, does not sprout and is killed by fire. Responses of mountain big sagebrush (*A.t.* ssp. *vaseyena* [Rydb.] Beetle) and Wyoming big sagebrush (*A.t.* ssp. *wyomengensis* Beetle and Young) communities from fire are not completely understood. Recovery of big sagebrush communities was studied at 13 sites in southwest Montana. Environmentally paired burned and unburned treatments were located within each site. Sites were burned between 2 and 32 growing seasons prior to sampling. Big sagebrush canopy cover, density, and winter forage production, along with herbaceous understory cover were measured in each treatment. Twenty live and 20 dead big sagebrush plants were aged in each treatment. Fire reduced mountain big sagebrush canopy cover and adult density at all sites dominated by mountain big sagebrush($P<0.001$). Two of 3 sites dominated by Wyoming big sagebrush showed no difference ($P<0.36$) in big sagebrush canopy cover between burned and unburned treatments. Of the three sites dominated by Wyoming big sagebrush, adult density was greater in 1 burned treatment ($P<0.0006$), lower in 1 burned treatment ($P<0.01$), and was similar between treatments at the final site. Mountain big sagebrush juvenile density was greater in unburned treatments at 7 of 10 sites ($P<0.002$) while Wyoming big sagebrush juvenile density was variable. Big sagebrush winter forage production was greater ($P< 0.05$) in all unburned treatments. Big sagebrush plants that re-established did so soon after fire disturbance. Ages of dead and live big sagebrush in unburned treatments were similar. This indicates that a variety of factors may kill big sagebrush before it has obtained maximum longevity. Litter cover was greater in unburned treatments ($P<0.05$). Soil and rock exposed was greater in burned treatments ($P<0.0005$). Idaho fescue (*Festuca idahoensis* Elmer) cover, total perennial grass cover, and perennial forb cover increased in some burned treatments and decreased in others. Fire disturbance can affect big sagebrush communities for several decades. This shrub component used so extensively by wildlife populations can take longer than 30 years to establish pre-burn conditions with little or no benefit to grasses or forbs.

INTRODUCTION

Big sagebrush (*Artemisia tridentata* Nutt.) is an important component of many plant communities throughout the western United States. Big sagebrush communities provide a variety of amenities for numerous wildlife populations. Big sagebrush maintains a crude protein level nearly 3 to 4 times higher than grasses during winter and provides important winter forage for browsers (Welch and McArthur 1979). Big sagebrush may also provide display areas, birthing areas, nesting sites, and thermal and security cover. Laycock (1979) maintained that "the sagebrush habitat type has a greater potential for increasing red meat production than any other range vegetation in the western United States."

Given the importance of big sagebrush, range and wildlife managers are interested in the short and long-term effects of fire in big sagebrush communities. Managers currently have little information on the effects of burning on big sagebrush and herbaceous understory, or its effects on big sagebrush re-establishment following fire. Few studies have monitored the long-term response of big sagebrush communities to fire in southwest Montana. Research is needed in southwest Montana to determine the effects of burning on big sagebrush and herbaceous understory. Likewise, species composition shifts can occur following fire. These shifts have not been monitored in southwest Montana.

Range managers, wildlife managers, and livestock producers can use this information to monitor range following fire and to determine if future burning is necessary. Managers may have different goals, but they are all interested in range vegetation. Big sagebrush re-establishment and understory response to fire are important to each of them. Depending on management goals, results of this study may influence the manager's decision whether to perform prescribed burning or prevent burning.

The objective of this study was to examine the short and long-term effects of burning within big sagebrush habitat types in southwest Montana. I hypothesized that burned and unburned big sagebrush communities are not equal in winter production, canopy coverage, plant density, and age. I also hypothesized that burned and unburned big sagebrush communities are similar in herbaceous understory cover.

LITERATURE REVIEW

History

Beetle (1960) suggested that big sagebrush occupies over 60 million ha in the Western United States. In much of the Western United States, fire plays a valuable role in ecosystem-level processes. Wright and Bailey (1982) suggested fires burned most sagebrush grasslands every 50 years and every 100 years in Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomengensis* Beetle and Young) grasslands. Houston (1973) conjectured burning occurred every 32-70 years in sagebrush grasslands in northern Yellowstone. Based on fire scars in old-growth conifer forests near Dillon, Montana, Arno and Gruell (1983) maintained mean fire intervals at *Pseudotsuga* forest-grassland ecotones were between 35 and 40 years. Whisenant (1989) suggested fire intervals in Idaho sagebrush-steppe historically occurred every 60 to 110 years.

Response of Big Sagebrush and Bitterbrush to Fire

Big sagebrush is non-sprouting and eliminated by fire in the short term. Following fire in Utah, sagebrush canopy cover was reduced to 0 percent 1 year after burning (West and Hassan 1985). No shrub seedlings established the first season after burning big sagebrush grasslands in Nevada, probably due to lack of shrub seed reserves in litter and soil, and to plant destruction by burning (Young and Evans 1978). Wyoming big sagebrush was removed from the site for the first 2 years following fire (West and Hassan 1985). Eight years after fire in southwest Montana, mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana* [Rydb.] Beetle) failed to recover due to high initial mortality and lack of seedling establishment (Fraas et al. 1992). However, big sagebrush seedlings appeared by the second year after a fire in Idaho (Ratzlaff and Anderson 1995). Harniss and Murray (1973) showed big sagebrush yields (production) and density were approximately the same in burned and unburned plots in southeast Idaho after 30 years. Watts and Wambolt (1996) showed canopy coverage of big sagebrush in burned plots required 30 years before it was equal to control plots. In grazed Wyoming ranges following herbicide treatment, big sagebrush density was similar in sprayed and unsprayed sites 14 years after treatment (Johnson 1969). In ungrazed ranges at the same site, big sagebrush density was similar in each treatment after 17 years. Bartolome and Heady (1978) determined big sagebrush re-establishment began immediately after treatment and that most re-establishment occurred in years immediately following treatment.

Fire can also damage bitterbrush (*Purshia tridentata* (Pursh) DC), an important winter forage for wildlife (Cook et al. 1994, Fraas et al. 1992). However, bitterbrush appears to be much more resistant to browsing damage than big sagebrush (Bilbrough and Richards 1993). Spring burning can minimize bitterbrush and perennial forb damage and minimize annual species invasion. Following spring burning in southcentral Wyoming, bitterbrush survival ranged from 34-56% while summer burning nearly eliminated the stand (Cook et al. 1994).

In contrast to big sagebrush and bitterbrush, rubber rabbitbrush (*Chrysothamnus nauseosus* (Pallas ex Pursh) Britt) and grey horsebrush (*Tetradymia canescens* D.C.) readily sprout from roots following fire and can further increase density by seed dispersal. These unfavorable plants can dominate disturbed big sagebrush communities following fire by root sprouting and abundant achene production (Harniss and Murray 1973, Young and Evans 1974, Young and Evans 1978).

Seed Production

An important aspect of the sagebrush life cycle is its ability to establish seedlings after fire (Ratzlaff and Anderson 1995). Abundant seed production of big sagebrush is possibly the species' foremost genetic adaptation to rapid re-establishment following fire. In western Nevada, Young et al. (1989) showed that average stands of big sagebrush were capable of producing 50 million seeds per ha. Plant characteristics most clearly correlated with seed production were leaf weight, canopy density, and root crown diameter. Older stands were capable of producing more seeds than younger stands. Plants with the highest average seed production had the lowest woody biomass accumulation rate, suggesting these plants were allocating resources to seed production rather than plant biomass accumulation. Young et al. (1989) suggested that big sagebrush was a very "fecund" plant and that 2 year old seedlings to 100 year old senescent plants can be "prolific seed producers." Big sagebrush can live over 200 years (Ferguson 1964).

Because big sagebrush as young as 2 years old can produce abundant amounts of seed, seedlings missed by herbicide control or fire can rapidly re-colonize the area. If fires burn in a mosaic pattern, plants that remain unharmed by fire in unburned areas can serve as a seed bank for re-establishment in burned areas. Johnson and Payne (1969) concluded that unkilled sagebrush remained the major cause of re-establishment. They also suggested that wind-born seed was of no practical importance in sagebrush re-establishment. Plants can also sprout from seed already present in the soil at the time of treatment if the seeds are not damaged by the fire.

Climate

Severe winters lead to longer seed dormancy in big sagebrush and slower germination rates than mild winters (Meyer and Monson 1992). Collections from severe winter sites (1° C) required up to 113 days for 50% germination while mild winter sites (15° C) required as few as 6 days. Seedlings typically emerge in early spring soon after snowmelt (Meyer and Monson 1992). Seeds germinate following spring warming (Johnson and Payne 1969). Severe winter may affect seedling establishment because moisture and nutrients are more limiting later in the growing season, a time when big sagebrush seedlings may have to compete for these resources with grasses and forbs. Seed dormancy during extreme cold with excess snowpack may be a physiological adaption to climatic stress (Meyer and Monson 1992). Delayed germination in severe winter may prevent premature germination under snowpack. Germination in mild sites may promote winter germination in which they have their greatest chance for survival.

Miller et al. (1994) suggested that climate may play a role in woody plant encroachment in the West. He suggested that during the last 2,000 years climate has been moving toward increasing aridity with a greater proportion of winter precipitation. With warmer, milder climates, germination rates of big sagebrush may increase, leading to greater seedling density. Once established, big sagebrush can survive warmer climates due to deep root penetration and efficient resource extraction.

Big sagebrush in mature stands have deeper roots than grass in mature stands, and have access to water and nutrients unavailable to grasses (Harniss and Murray 1973). Thus, big sagebrush has potential to yield abundant foliage. Frequently, estimates of forage production or biomass production per unit area does not take the shrub component into account. This is likely due to cattle of avoidance of this species for consumption. However, maximum vegetation yields result when big sagebrush is present and included in these forage measurements (Harniss and Murray 1973).

Drought may be important in increasing big sagebrush dominance (Miller et al. 1994). Beetle (1960) suggested that grasses may kill big sagebrush seedlings by shading and that drought gives big sagebrush advantage over perennial grasses. Adequate precipitation favors grasses over big sagebrush.

Burning may lead to greater production of perennial grasses and total vegetative production in the short-term (Wambolt and Payne 1986). However, reducing big sagebrush cover may not result in additional herbaceous understory production (Fraas et al. 1992, Peek et al. 1979, McNeal 1984, Wambolt and Payne 1986, Watts and Wambolt 1996.) Burning may also lead to "unplanned shifts" in plant community composition with decreases in grass, forb, and shrub production (Fraas et al. 1992). This is partly why many prescribed burning recommendations call for burning during plant dormancy (Wright 1974).

Big sagebrush is well-adapted to arid habitats (Shultz 1984). With increasing aridity, amount of water-conducting tissue increases, amount of air spaces or internal cuticle layer increases, vessel diameter increases, palisade length/width ratios increase, and epidermal walls thicken. Shultz (1984) maintained that big sagebrush has a "flexible genetic program" and has the ability to adapt to unfavorable conditions. This contributed to its "rapid evolution" and "extensive colonization" in the West.

Hall et al. (1995) examined the effects of understory competition on native shrub recruitment in Utah. They suggested that some other factor or combination of factors influenced shrub recruitment success to a greater extent than understory competition. They concluded that shrub recruitment was "episodical" occuring only when certain environmental factors combine to favor seed production. Conditions must also be favorable for seedling germination and survival in subsequent years.

Soils

Soil-types and their responses to fire can affect seedling establishment (Brown et al. 1985). Soil texture may be important in big sagebrush re-establishment (Johnson and Payne 1969). In southwest Montana, soil texture was related to big sagebrush re-establishment on 2 of 7 sites where soils varied. In these sites, silty soils had the highest rate of big sagebrush re-establishment. Erosion severity was not related to sagebrush re-establishment. Burning may decrease infiltration and increased sediment transport (Brown et al. 1985). This may be due to a buildup of a water repellent layer and poor regrowth of vegetation in this area.

The actual temperature of fires are variable and depend on the amount of fuel, dryness, initial temperature, direction of spread, slope, and wind direction (Daubenmire 1968). Campbell et al. (1995) suggested that heat from fire can be transported down more quickly in moist soils. However, the evaporation of water will not allow a moist soil to exceed 95° C until moisture content becomes very low. In a dry soil, temperature rises more rapidly, but moisture in the soil air prevents rapid soil temperature rise above 90° C. This "buffer" may prevent eradication of big sagebrush seed reserves in the soil. An extremely hot fire with dry soils will eliminate seed reserves in the soil while "cooler" fires with moist soils may prevent seed kill and allow rapid re-establishment. Average soil temperatures remain higher 1 year after the burn, primarily due to the dark surface, lack of litter and cover, and low water levels (Antos et al. 1983).

The root system of big sagebrush contains a deep taproot with shallow, diffuse roots extending from this taproot. Sturges (1983) suggested that soil water depletion in soil 0.9 to 1.8 m deep was less on sprayed areas compared to unsprayed. However, except for the year of spraying, water use in the upper 0.9 m of soil was not reduced by spraying. Twenty years after treatment, Sturges (1993) found that big sagebrush removal reduced water depletion 9% to a soil depth of 1.8m. However, depletion from the surface 0.9 m of soil under the grass vegetation was greater than under the big sagebrush dominated vegetation. Richards and Caldwell (1987) suggested that the deep tap root of big sagebrush can absorb water from moist soils and transport water to drier upper soil layers where it can be used by grasses and forbs.

Christiansen (1996) found that fire can influence litter invertebrate communities in big sagebrush habitat. Litter invertebrates influence nutrient cycling, organic matter decomposition, plant reproduction and growth, and seed dispersal (Christiansen 1996). Big sagebrush density was positively correlated with litter invertebrate density. Following the fires of 1988 in Yellowstone National Park, big sagebrush litter invertebrate diversity declined 90% while density declined 94% in severely burned areas. Neither of these variables had increased two years after the fire.

Grazing

Overgrazing can lead to dense stands of sagebrush with little herbaceous understory (Laycock 1979). Miller et al. (1994) suggested that overgrazing in sagebrush steppe can increase dominance of native woody species and introduced annuals at the expense of native herbaceous species. Fire followed by overgrazing can reduce sagebrush and perennial grasses and lead to cheatgrass (*Bromus tectorum* L.) invasion (Conrad and Poulton 1966, Daubenmire 1968).

Grazing may increase sagebrush mortality and decrease seedling survival due to trampling (Owens and Norton 1992). Exclosures in Yellowstone National Park have greater sagebrush canopy cover, density, and production inside than outside due to heavy grazing by large herbivores (Peterson 1995). Likewise, sagebrush can form a "protective barrier" against trampling and protect grasses growing around sagebrush.

Wambolt and Watts (1996) showed that heavy stocking rates can reduce Wyoming big sagebrush cover. They suggested this reduction was due primarily to trampling or mechanical damage. Browsing probably played a minor role. They also found that reductions in Wyoming big sagebrush canopy cover from high stocking rates did not result in increased herbaceous understory production.

Other Big Sagebrush Mortality Agents

A variety of other mortality agents can regulate big sagebrush populations. Allen et al. (1987) showed that in wet years with high snowfall in Utah, big sagebrush survival and production decreased due to reduced mycorrhizal reproduction and a high incidence of snow mold. In Wyoming, big sagebrush was killed by long periods of soil saturation (Sturges 1989). A leaf-defoliating moth (*Aroga websteri,* Clark) killed 10-15,000 acres of big sagebrush in Oregon in 1962. Twelve million acres of big sagebrush in Oregon have been reduced to some degree by this moth, and older stands were the most heavily damaged (Gates 1964). Leaf beetles (*Trirhabde pilosa*) have caused significant mortality in sagebrush (Pringle 1960). Voles (*Microtus* spp.) girdle and kill large areas of dense big sagebrush (Frischknecht and Baker 1972). A rust fungus or black stem rust (*Puccinia tanaceti,* DC) can greatly reduce big sagebrush seed production (Welch and Nelson 1995). This rust has been collected on big sagebrush in all western states except Arizona. Big sagebrush mortality has increased in communities exposed to successive seasons of heavy browsing (McArthur et al. 1988).

Effect of Fire on Grasses and Forbs

Humphrey (1984) proposed a mechanism of succession after fire on sagebrush-grasslands in southeastern Idaho. He suggested perennial grasses and forbs are the first to dominate a site following fire. Sprouting shrubs, such as green rabbitbrush and grey horsebrush, generally dominate by the sixth year. Shrubs relying on dispersal, such as big sagebrush, become "co-dominants" in later stages. The author maintained this pattern will differ due to variation among plant species present at different sites. If no big sagebrush seed reserves are left after treatment or wildfires, sprouting shrubs may dominate a site for many years.

Most grasses and forbs react negatively during the same year as the burn. Many studies show sagebrush removal results in short-term overall increases in grass and forb production after the initial burn year. However, burning can be detrimental to certain grasses. Slow, smoldering burns in northeast Oregon caused high mortality in Idaho fescue (*Festuca idahoensis* Elmer) while this type of burn did not damage bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn.) (Conrad and Poulton 1966). Idaho fescue was damaged because of the compact root crown and budding zone in a very small area near ground surface. However, Harniss and Murray (1973) suggested Idaho fescue was damaged severely in the short-term, but nearly recovered completely 30 years after a burn in Idaho. They showed that 30 years after burning, production of grasses was near preburn levels. Blaisdell et al. (1982) suggested non-sprouting shrubs and fine bunchgrasses with densely clustered culms are severely damaged by fire. Course bunchgrasses and fine bunchgrasses with loosely clustered culms are only slightly affected, while sprouting shrubs, rhizomatous grasses, and rhizomatous forbs are benefited. Antos et al. (1983) suggested mature stands of rough fescue (*Festuca scabrella* Torrey ex Hook) are severely damaged by fire. They suggested that litter cover on the burned areas was only 36% of unburned while total forb cover decreased in burned areas. They also suggested that mosses and lichens were almost completely eliminated by the fire. Three years later, the mosses and lichens had recovered, but the species composition had changed. Fraas et al. (1992) found total herbaceous canopy coverage did not differ between burned and unburned sites 8 years after burning near Butte, Montana. Likewise, Bartolome and Heady (1978) suggested that "sagebrush-grass ranges may contain a high proportion of big sagebrush before grass production will be significantly decreased." They suggest managers maintain a balance between perennial grasses and big sagebrush.

Burning Effects on Wildlife

Big sagebrush can provide a variety of amenities for numerous wildlife populations. It provides food for mule deer (*Odocoileus hemionus hemionus*), Rocky Mountain elk (*Cervus elaphus nelsoni*), pygmy rabbit (*Brachlagus idahoensis*), pronghorn antelope (*Antilocapra americana*), mountain sheep (*Ovis canadensis*), and sage grouse (*Centrocercus urophasianus*) in southwest Montana (Willms and McLean 1978, Green and Flinders 1980, Kufeld 1973, Bayless 1969, Spowart and Hobbs 1985, Peek et al. 1979, Bentz and Woodard 1988). Big sagebrush is particularly important to ungulates during harsh winter months when deep snow prevents foraging of grasses and forbs.

Burning big sagebrush communities can harm canopy- and ground-nesting birds (Wright and Bailey 1982). When big sagebrush is eliminated by fire, long-term reductions have been observed in populations of Brewer's sparrow (*Spizella breweri*), sage thrasher (*Oreoscoptes montanus*), and sage grouse (Castrale 1982, Klebenow 1970, Braun 1977, Crowley and Connelly 1996). Likewise, burning can be detrimental to small mammal populations. Burning has caused decreases in white-footed deer mice (*Peromyscus maniculatus*), shrews (*Sorex* spp.), and voles (*Microtus* spp.) (Cook 1959, Crowner and Barrett 1979, Wright and Bailey 1982).

Given the importance of big sagebrush to wildlife, it is important that managers understand that this shrub needs maintenance rather than eradication. Therefore, it is important to understand the long-term dynamics of big sagebrush communities following fire.

METHODS

Study Sites

Selection

Study sites were chosen to represent typical mountain and Wyoming big sagebrush grassland communities in southwestern Montana. Sites contained environmentally paired burned and unburned areas. Different age burns were selected for sampling. Each of the areas studied was a part of or near big game winter ranges.

Paired burned and unburned big sagebrush communities were analyzed. In both communities, I determined herbaceous understory cover. Big sagebrush winter forage productivity, canopy coverage, density, and age were determined in each treatment.

Sites differed in either season of burn, slope, aspect, soil type, elevation, or years following burning. Thirteen sites were studied and were dominated by either mountain big sagebrush or Wyoming big sagebrush. The unburned and burned areas were similar in slope, aspect, elevation, soils (texture and depth), and vegetation. Likewise, there was a well-defined burn edge, high internal homogeneity, and lack of outside disturbance (i.e. spraying, seeding, fertilization).

Description

The 13 study sites were located throughout the extreme southwest corner of Montana, with the majority being in the Wise River and Wisdom areas of Montana (Fig. 1). Legal descriptions of each site, along with date of burning and date of sampling are in Table 1.

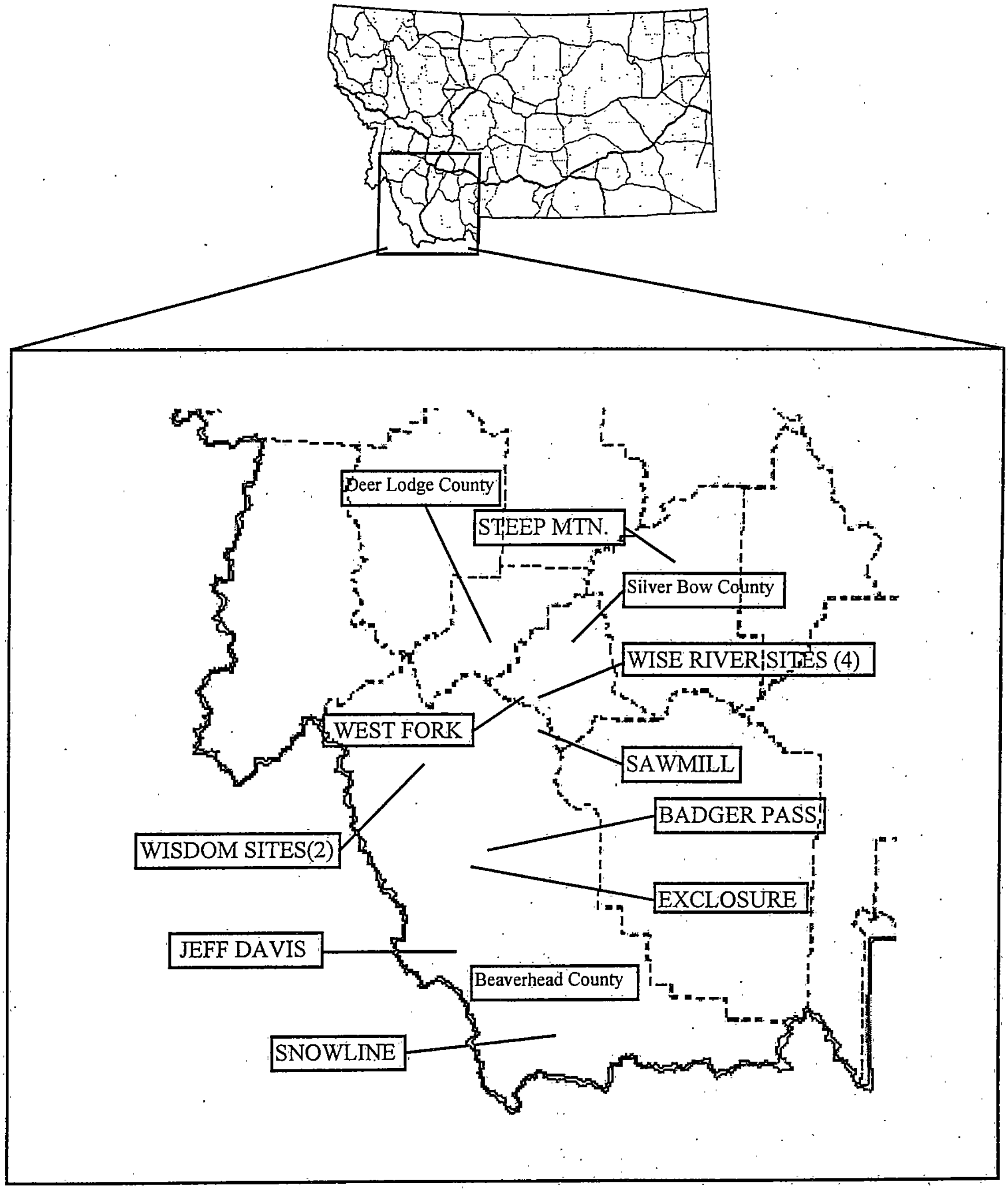


Figure 1. Map of 13 study sites in southwest Montana. Number in parentheses indicates number of sites at that location. Outlined section in state map enlarged in lower figure.

Table 1. Legal descriptions, burning, and sampling dates at 13 sites.

SITE	Legal Description	Date of Burn	Date Sampled	Growing Seasons
Wise River South	T1N, R11W, S24, SW	Apr. 1989	June, 1995	7
Wise River West	T1N, R11W, S24, SW	26 Oct. 1987	June, 1995	8
Wise River North	T1N, R11W, S25, NE	26 Oct. 1987	June, 1995	8
Wise River East	T1N, R11W, S24, SE	26 Oct. 1987	July, 1995	8
Wisdom Flat	T2S, R15W, S2, NW	6 Apr. 1987	July, 1995	9
Wisdom Slope	T2S, R15W, S2, SE	6 Apr. 1987	July, 1995	9
Sawmill Gulch	T1S, R10W, S22, NE	19 Apr. 1989	July, 1995	7
West Fork	T1N, R11W, S22, SW	March/April 1994	July, 1995	2
Badger Pass	T7S, R11W, S9, NE	1 Oct. 1981	August, 1995	14
Snowline	T14S, R8W, S25, NE	1985	August, 1995	11
Exclosure	T7S, R11W, S19	4 Sept. 1964	July, 1996	32
Steep Mountain	T4N, R8W, S27, SE	3 Nov. 1981	July, 1996	15
Jeff Davis	T11S, R13W, S10	29 Sept. 1980	August, 1996	16

Mountain big sagebrush was the dominant shrub at all sites except the Wisdom sites and Exclosure site. Wyoming big sagebrush was present as a minor shrub component and was growing with the mountain big sagebrush at the West Fork, Sawmill Creek, Badger Pass, and 4 Wise

River sites. Topographic characteristics of each site are presented in Table 2.

Table 2. Topographic characteristics of all study areas.

SITE	PERCENT SLOPE	ASPECT	ELEVATION (m)
Wise River South	3	175	2000
Wise River West	6	270	2000
Wise River North	6	330	2000
Wise River East	5	30	2000
Wisdom Flat	0	0	1830
Wisdom Slope	4	20	1840
Sawmill Creek	16	90	2220
West Fork	7	70	1950
Badger Pass	8	310	2090
Snowline	4	30	2040
Exclosure	2	330	1890
Steep Mountain[1]	burn-21 unburn-24	burn-220 unburn-180	1950
Jeff Davis	20	140	2290

[1] From Fraas et al. (1992)

<u>Wise River South Site</u>. This site is located 4.5 km northeast of Wise River, in Silver Bow County. The area is near the border of the Deer Lodge National Forest and is administered by the Butte District, Bureau of Land Management. Total precipitation at Wise River during 1994 was 326 mm while during 1993 it was 392 mm (NOAA 1993-1994). Average annual temperature in this area is 3.3° C (Caprio et al. 1994). Soils in the area are silt loams. The area is part of a cattle grazing allotment with a rotational grazing system with. Seven

hundred eighty-eight cow/calf pairs graze the allotment 4-6 weeks in the summer. The burn was conducted when air temperature was 18°C, relative humidity was 19%, and wind speed was 10 km/hr. Vegetation in unburned treatments at all Wise River study sites indicates a mountain big sagebrush-Idaho fescue habitat type (Mueggler and Stewart 1980).

Wise River West Site. This site is located 4 km northeast of Wise River, Montana. This site had similar precipitation, grazing history, temperature, elevation, habitat type, and big sagebrush composition as the Wise River South site. Soils in the area are loams. This burn was conducted with an air temperature of 10° C, a southwest wind 8-18 km per hour, and a relative humidity of 30%.

Wise River North and East Sites. These 2 sites differed from Wise River West in soil type, slope, and aspect (Table 2). These sites had silt loam soils. All other variables, including burn conditions, were similar to the Wise River West site.

Wisdom Flat Site. This site is located approximately 9 km north of Wisdom, Montana in Beaverhead County. The site is east of State Highway 43, near its junction with McVey Creek. This land is administered by the Department of State Lands in Dillon, Montana. Wisdom's annual precipitation in 1993 was 376 mm, in 1994, 262 mm, and in 1995, 380 mm (NOAA 1993-1995). Average annual temperature for this area is 2.11° C (Caprio et al. 1994). This site has loam soils. The dominant shrub at this site was Wyoming big sagebrush. Vegetation in unburned treatments at the 2 Wisdom sites indicates a Wyoming big sagebrush-Idaho fescue habitat type (Mueggler and Stewart 1980).

Wisdom Slope Site. This site is located approximately 1 km southeast of the Wisdom Flat site. This site was on an east facing slope, had clay loam soils, and was approximately 30 m higher in elevation. All other characteristics were similar to the Wisdom Flat site.

Sawmill Gulch Site. This site is located 7 km west of Divide, Montana on a southeast-facing slope of Sawmill Gulch. This site borders the Beaverhead National Forest, and is administered by the U.S. Forest Service in Wise River, Montana. Mean annual precipitation at Divide is 321 mm while mean annual temperature is 4.9° C (NOAA 1995). Soils at this site are silt loams. The burn was conducted when air temperature was 13-21° C with a southwest wind 17-25 km per hour and a relative humidity of 25-35%. This area has been part of a 4 pasture rotational grazing system since the 1960's. However, it has been grazed only 2 of the last 7 years due to changes in permit holders of grazing allotments. Vegetation in unburned treatments indicates a mountain big sagebrush-bluebunch wheatgrass habitat type (Mueggler and Stewart 1980).

West Fork Site. This site is located approximately 2.5 km north of Wise River. The land is administered by the BLM, and borders the Deer Lodge National Forest in Silver Bow County. Average precipitation, temperature, habitat types, and big sagebrush composition are similar to the Wise River sites. Soils in this area are silt loams and is part of the same grazing allotment as the Wise River sites. Wind speed was 19 km/hr. Relative humidity was 20% at an air temperature of 14° C.

Badger Pass Site. This site is located approximately 25 km west of Dillon on State Highway 278. It is part of the Beaverhead National Forest in Beaverhead county and is administered by the U.S. Forest

Service in Dillon, Montana. Mean annual precipitation in this area is 310 mm (Wambolt and Payne 1986). Average temperature is 2.8° C (Caprio et al. 1994). Soils at this site are silty clay loams. Cattle grazing in the area follows a four pasture rotational grazing system with 435 total A.U.M.s. Vegetation in unburned treatments indicates a mountain big sagebrush- bluebunch wheatgrass habitat type (Mueggler and Stewart 1980).

Snowline Site. This site is located approximately 8 km southeast of Lima, Montana. It is administered by the BLM in Dillon, Montana and is in Beaverhead County. Mean annual precipitation in Lima is 310 mm while mean annual temperature is 1.7° C (NOAA 1995). Soils at this site are fine silty. Vegetation in unburned treatments indicates mountain big sagebrush- Idaho fescue habitat type (Mueggler and Stewart 1980).

Exclosure Site. This site is located approximately 30 km west of Dillon, MT. The land is administered by the BLM in Dillon, Montana, and is in Beaverhead county. Mean annual precipitation is 310 mm (Wambolt and Payne 1986). Mean annual temperature is 2.8° C (Caprio et al. 1994). The primary shrub component at this site in Wyoming big sagebrush. Soils at this site are clay loams with a significant calcareous horizon (Wambolt and Payne 1986). Low fuel loads were present at the time of the burn, requiring some burning of individual plants (Wambolt and Payne 1986). This site has been in an exclosure since May, 1963. Vegetation in unburned treatments indicates a Wyoming big-sagebrush-bluebunch wheatgrass habitat type (Mueggler and Stewart 1980).

Steep Mountain Site. This site is located approximately 6 km northwest of Walkerville, Montana. The area is administered by the U.S.

Forest Service in Butte, Montana, and is part of the Deerlodge National Forest. Mean annual precipitation at this site is 400-450 mm per year (Ross and Hunter 1976). Mean annual temperature at the Butte FAA airport is 3.9 ° C (NOAA 1995). Soils in the area were classified as shallow cryochrepts with decomposing parent material and sandy loam texture (Fraas et al. 1992). Conditions at the time of the burn were 11° C , 37% relative humidity, with south winds 17-29 m per second (Fraas et al. 1992). The area is part of a cattle-grazing allotment with 125 cow/calf pairs grazing the allotment for 1-2 months each summer in a 4-pasture rotational system (Fraas et al. 1992). Vegetation in unburned treatments shows a bitterbrush-mountain big sagebrush-bluebunch wheatgrass habitat type (Mueggler and Stewart 1980).

Jeff Davis Creek Site. This site is located approximately 13 km northeast of the Bannock Pass in the extreme southwest corner of the state of Montana. The area is administered by the U.S. Forest Service in Dillon, Montana. Mean annual precipitation in this area ranges from 500-760 mm (Caprio et al. 1994). Soils in the area are sandy loams. Burn conditions were 17-22° C, 16-32% relative humidity, and a wind of 9-13 km per hour. This area is part of a 4 pasture rotational grazing system. The pastures are grazed 2-3 months per year, generally over the summer, with 344 cow/calf pairs. Vegetation in unburned treatments indicates a mountain big sagebrush-Idaho fescue habitat type (Mueggler and Stewart 1980).

Procedures

Canopy Cover

Within the burned and unburned treatments at each study site, mountain and Wyoming big sagebrush canopy coverage was measured using the line interception method (Canfield 1941). This parameter is one way to measure a plant's contribution to the community (Daubenmire 1959). It is also a relatively easy method of measurement. Canopy coverage was measured along 6 stratified 30 m transect lines with a buffer strip of at least 4 m between burned and unburned treatments. Distance between transect lines was approximately 5 m. Visual determinations were made of the cm of actively growing tissue found underneath the tape. The total number of cm underneath the tape was totaled to determine percent cover. Only live, actively growing tissue (perennial leaves, current growth, reproductive stalks) was measured.

Density

Density of each big sagebrush subspecies was determined using 6 stratified belt transects 2 m wide, centered on the 30 m transect lines in each treatment, thus sampling 360 m^2 in each burned and unburned treatments. The same transect lines used for canopy cover were used for density measurements. For plant density, juvenile and adult sagebrush were differentiated. The major axis (maximum horizontal distance across the live plant crown), the minor axis (perpendicular to major axis), and 2 additional perpendicular axes at 45° to the intersection of the major and minor axes were measured to determine age classification. Those plants that had an average of the four measurements less than 15 cm were termed juveniles (Wambolt et al. 1994).

Big Sagebrush Winter Forage Production

Winter forage production of big sagebrush was estimated for big sagebrush by using subspecies and browse form class (Wambolt et al. 1994). Big sagebrush that had been heavily browsed produced shorter, branched crowns, giving the plant a dense, club-like appearance. Lightly browsed plants had a bushy appearance and were less branched than those heavily browsed (Cook and Stoddart 1960, Personius et al. 1987, Striby et al. 1987, Creamer 1991). Thus, form class was determined in the field by the appearance of the shrub.

The major axis (maximum horizontal distance across the live plant crown), the minor axis (perpendicular to major axis), and 2 additional perpendicular axes at 45° to the intersection of the major and minor axes were measured on 60 randomly selected plants in each treatment (Wambolt et al. 1994). Ten plants were selected on each of 6 transect lines, the same lines used for canopy cover and density measurements. The big sagebrush plant closest to the tape measure at the 2 m mark was the first selected. The remaining plants were chosen at 3 m intervals (5m, 8m, 11m,...), with the closest plant to the interval being selected for production measurement. Photosynthetic tissue was the beginning and end points for each of these measurements. However, dead crown and canopy openings were included for ease of measurement and data analysis. These measurements provided canopy coverage of each plant (Canfield 1941). The minimum average of the four measurements of each plant was 14.6 cm. This ensured that the plants were established. Crown height and overall height of each sagebrush plant were measured. Production per plant was determined by using the models of Wambolt et al. (1994). Using density measurements, the number of adult big sagebrush plants per ha was calculated. Given both the number of plants per ha and the production per adult big sagebrush, winter forage production per ha was calculated.

Age

Twenty live big sagebrush plants were selected in each treatment for age classification. Five plants were selected on 4 of the 30 m transect lines used in the canopy cover, density, and production measurements. Transect lines 1,3,4,and 6 were used in all treatments at all sites. The big sagebrush plant closest to the 2 m mark was selected for aging on each transect line. The remaining plants were selected at 6 m intervals (2m, 8m, 14m,...), with the plant closest to the tape being sampled. Twenty dead plants were selected in the same manner within each unburned treatment where dead plants were present. Ages were determined by counting the annual growth rings from basal stem segments(Ferguson 1964). The big sagebrush plants were cut as close to the ground as possible. Annual growth rings were counted in the field.

Understory Cover

Grass and forb canopy cover were estimated by species using the canopy-coverage method of vegetation analysis (Daubenmire 1959). Thirty 20 X 50 cm plots were selected in each treatment along the same 30m transects as previous measurements. Ten of these plots were located along transect lines 2,4, and 6. The first plot of each transect line was chosen by centering the base of the Daubenmire plot on the 2 m mark beginning on the right side of the tape. The next plot was located at the 5 m mark on the opposite side of the measuring tape. The remaining plots were located at 3m intervals on alternating sides of the tape. Each species was placed in 1 of 6 canopy cover classes based on visual estimates of percent cover according to Daubenmire (1959). The 6 canopy cover classes were 0-5%, 5-25%, 25-50%, 50-75%, 75-95%, and 95-100%. The midpoint of each class was used for data analysis. Canopy cover was estimated for each herbaceous species, total perennial grasses, total perennial forbs, bare ground/rock cover, and litter cover.

Statistical Analyses

Statistical differences in parameters were tested between burned and unburned treatments at each site. Means of each parameter were calculated. Differences between burned and unburned treatments in big sagebrush canopy coverage, density, age, and herbaceous understory canopy coverage were tested using the Student's *t*-test. For canopy cover and density at each site, the means of the 6 transect lines in the unburned treatment were compared with the means of the 6 transect lines in the burned treatment. Within each site where age was measured, the ages of 20 plants in the burned treatment were compared with the ages of 20 plants in the unburned treatment. Within each site the means of the herbaceous understory species were compared between burned and unburned plots. Differences were considered significant at $P<0.05$.

Given that each site was physiographically different from each other in some respect, overall comparisons were made between burned and unburned treatments among all sites. Big sagebrush canopy cover, big sagebrush density, Idaho fescue, total perennial grasses, total perennial forbs, litter cover, and soil exposed were tested for differences in means between burned and unburned treatments at each site. Differences were tested against the null hypothesis that the mean difference between burned and unburned treatments is 0. A paired *t*-test was used. This gave us an overall *P* value that indicated whether burned and unburned treatments in southwest Montana were statistically different. Differences were considered significant at $P < 0.05$. In summary, an overall paired *t*-test was used to compare all sites and then individual site comparisons were made using the Student's *t*-test.

RESULTS AND DISCUSSION

Big Sagebrush Canopy Cover

Analysis of the overall comparison between burned and unburned treatments using the paired *t*-test indicates that mountain big sagebrush canopy cover was reduced by burning ($P<0.001$). Mountain big sagebrush was greater ($P<0.05$) in unburned treatments at every site dominated by mountain big sagebrush regardless of the time since burning occurred (Fig. 2). This provides strong evidence that burning decreases big sagebrush canopy cover for long periods of time.

Fraas (1992) reported mountain big sagebrush canopy cover in the burned treatment at the Steep Mountain site was 0% in 1990 and 1.0% in 1991. In 1996, I found canopy cover was 0.47%. This suggests big sagebrush is not re-establishing at this site following burning. Fraas (1992) reported mountain big sagebrush canopy cover in unburned treatments was 7.0% in 1990 and 7.2% in 1991. In 1996, I found mountain big sagebrush canopy cover was 12.9%. This suggests mountain big sagebrush cover has increased in the last 5 years in unburned treatments.

Two sites dominated by Wyoming big sagebrush in the Wisdom area showed no difference ($P<0.38$) in canopy cover between burned and unburned treatments (Fig. 3). The Exclosure site dominated by Wyoming big sagebrush had greater canopy cover ($P<0.045$) in unburned treatments 32 growing seasons after burning. Harniss and Murray (1973) and Watts and Wambolt (1996) suggested big sagebrush required 30 years before canopy cover was not different from control plots. Data from the Exclosure site suggests greater than 30 years may be required for recovery.

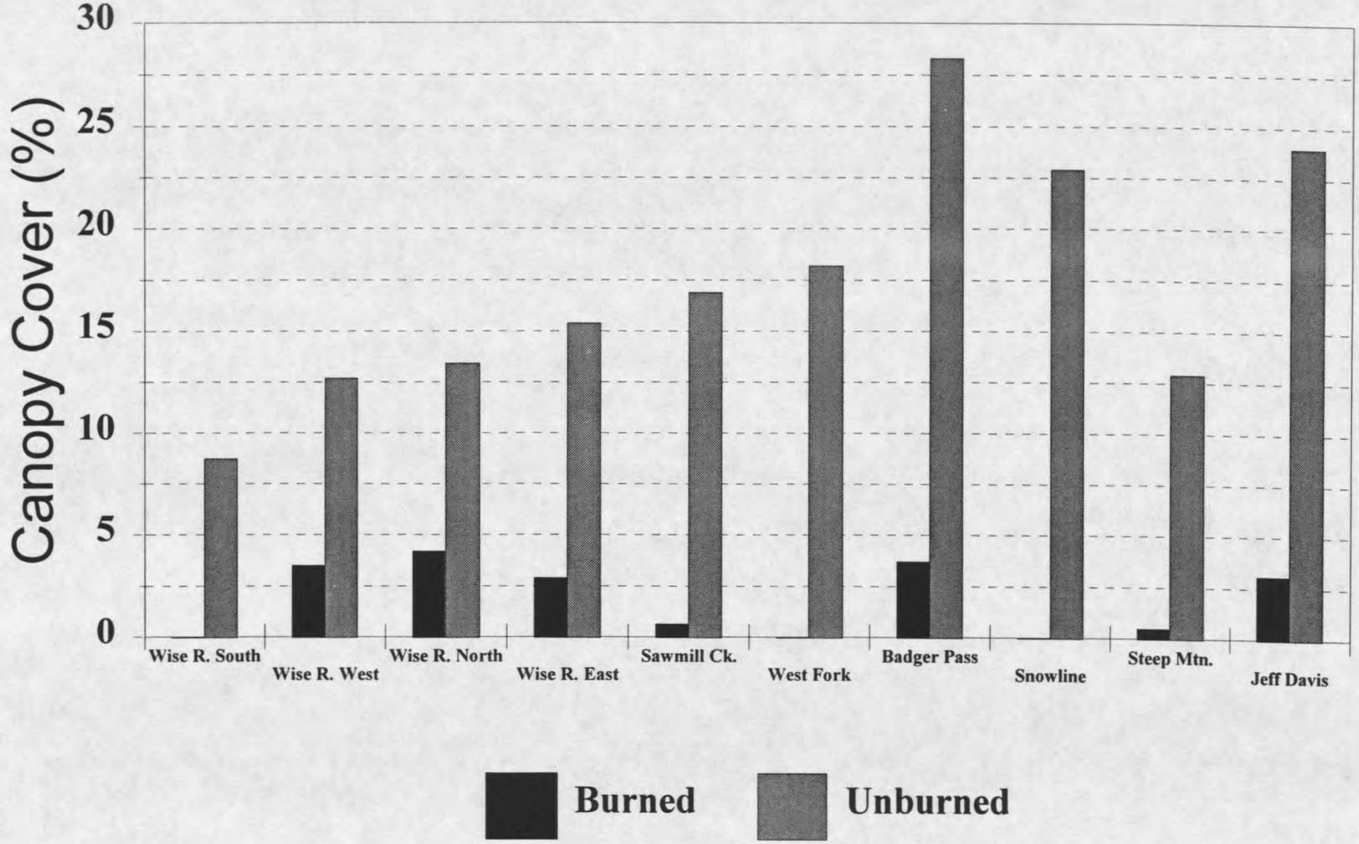


Figure 2. Average (n=6) mountain big sagebrush canopy cover (%) in burned and unburned treatments. Treatments at all sites are significantly different at $P < 0.05$.

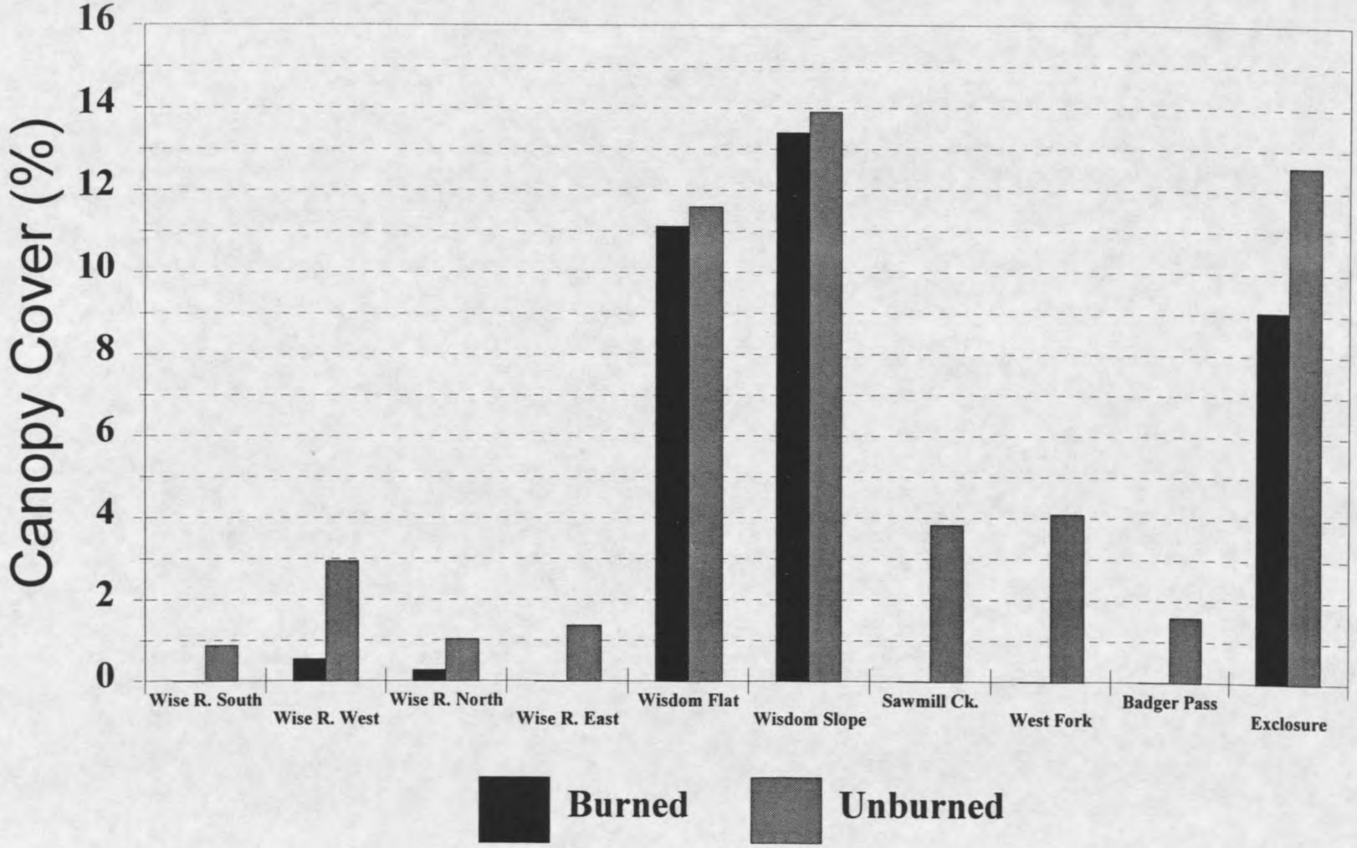


Figure 3. Average (n=6) Wyoming big sagebrush canopy cover (%) in burned and unburned treatments. Wyoming big sagebrush is the dominant shrub at the Wisdom sites and Exclosure site. Treatments at all sites except the Wisdom sites are significantly different at P<0.05.

Although canopy cover was reduced by burning in both Wisdom sites, neither treatment was significantly different. Both of these sites were dominated by Wyoming big sagebrush. This circumstance is somewhat peculiar because Wyoming big sagebrush generally takes longer to recover following fire (Wambolt and Payne 1986, Watts and Wambolt 1995). Canopy cover was reduced for both mountain and Wyoming big sagebrush in the Sawmill Gulch, West Fork, Badger Pass, and Snowline sites.

Canopy Cover Of Other Shrubs

Several sites had important shrubs besides mountain or Wyoming big sagebrush. Three-tip sagebrush (*Artemisia tripartita* Rydb.) was reduced in cover from 4.77% to 1.32% at the Snowline site 9 growing seasons following fire ($P<0.0035$). Green rabbitbrush (*Chrysothamnus viscidiflorus* (Hook.) Nutt.) was not affected by fire at this site while grey horsebrush increased in burned treatments from 2.34% to 7.15% ($P< 0.0003$). Canopy cover of green rabbitbrush increased from 0.47% in the unburned treatment to 1.74% in the burned treatment at the Steep Mountain site 15 growing seasons after the burn ($P<0.014$). Green rabbitbrush canopy cover increased slightly from 0% in the unburned treatment to 0.56% in the burned treatment 16 growing seasons after burning at the Jeff Davis site ($P<0.168$).

The Steep Mountain site contained significant bitterbrush cover. Bitterbrush cover was reduced by fire from 4.59% in unburned treatments to 3.14% in burned treatments after 15 complete growing seasons ($P<0.091$). Fraas (1992) reported bitterbrush canopy cover in burned treatments was 5.3% in 1990 and 4.6% in 1991. Bitterbrush canopy cover in unburned treatments was 13.8% in 1990 and 11.2 % in 1991. I found bitterbrush canopy cover in 1996 was 4.59% in unburned treatments and

3.14 % in burned treatments. Bitterbrush canopy cover has drastically decreased since 1990 in unburned treatments and slightly decreased in burned treatments. This may be due to excess browsing by ungulates. Nearly every bitterbrush plant in the area appeared to be heavily browsed. It is possible that the loss of bitterbrush in burned treatments has caused excess browsing of bitterbrush in unburned areas and harmed the bitterbrush population. While Bilbrough and Richards (1993) suggested bitterbrush was quite resistant to browsing, my data indicate excess browsing can severely damage bitterbrush.

Big Sagebrush Density

Analysis of the overall comparison between burned and unburned treatments using the paired *t*-test indicates that adult mountain big sagebrush density was reduced by burning ($P < 0.0000001$). At all sites where mountain big sagebrush dominated, density of adults was greater in unburned treatments than burned treatments ($P<0.0002$) (Fig. 4).

Differences between treatments were less in the juvenile size class (Fig. 5). Analysis of the overall comparison between burned and unburned treatments using the paired *t*-test indicates that there was no significant difference ($P<0.116$) between mountain juvenile plants in burned and unburned treatments. In all but 2 sites dominated by mountain big sagebrush, juvenile density was greater in unburned treatments versus burned treatments, and different in all but 1 of these ($P<0.007$). The Wise River North and Wise River East sites each had greater density in the burned treatment than the unburned. Only the Wise River East site had greater density in the burned treatment ($P<.0002$).

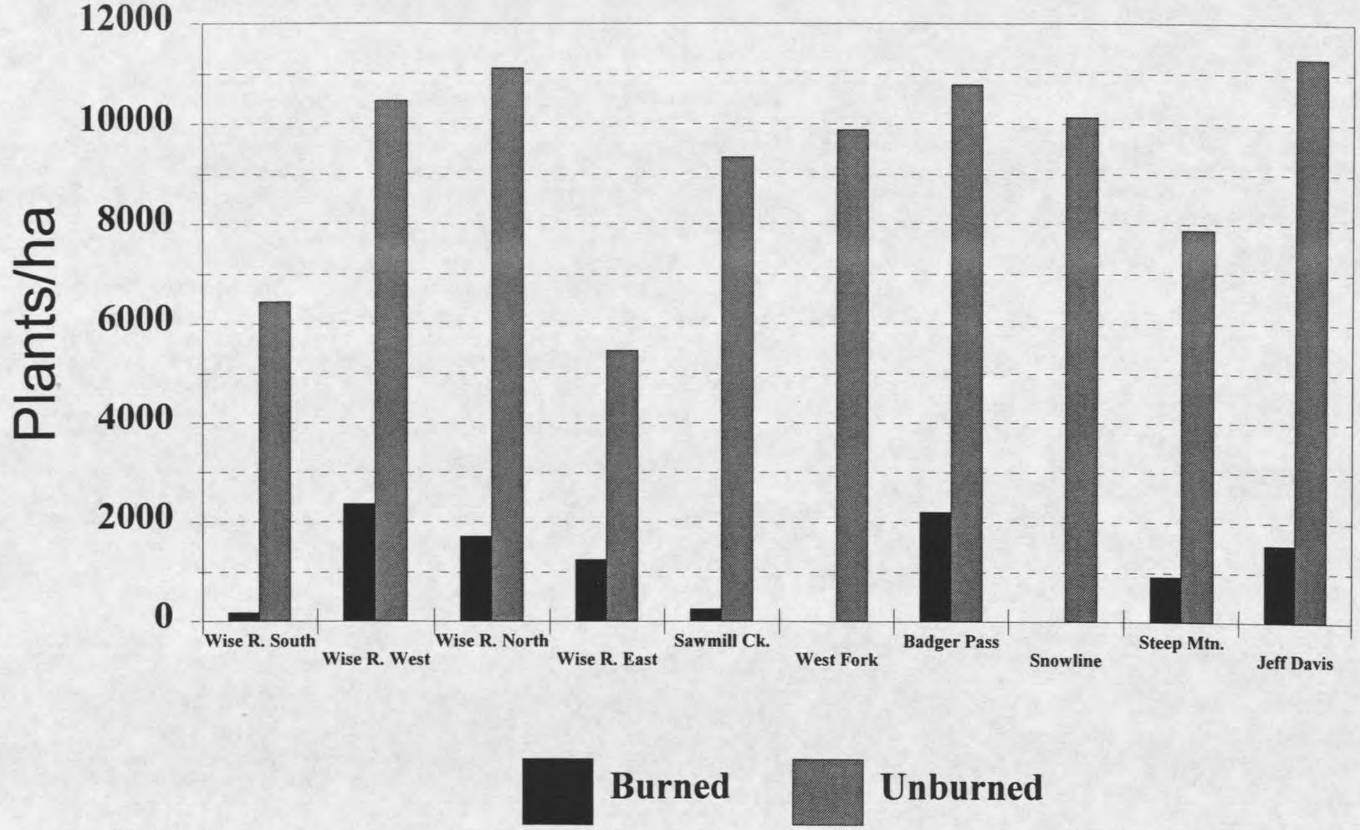


Figure 4. Average (n=6) density (plants per ha) of mountain big sagebrush adults in burned and unburned treatments. Plants were considered adults if the average of the long axis, short axis, and both perpendiculars was greater than 15 cm (Wambolt et al. 1994). Treatments at all sites are significantly different at P<0.001.

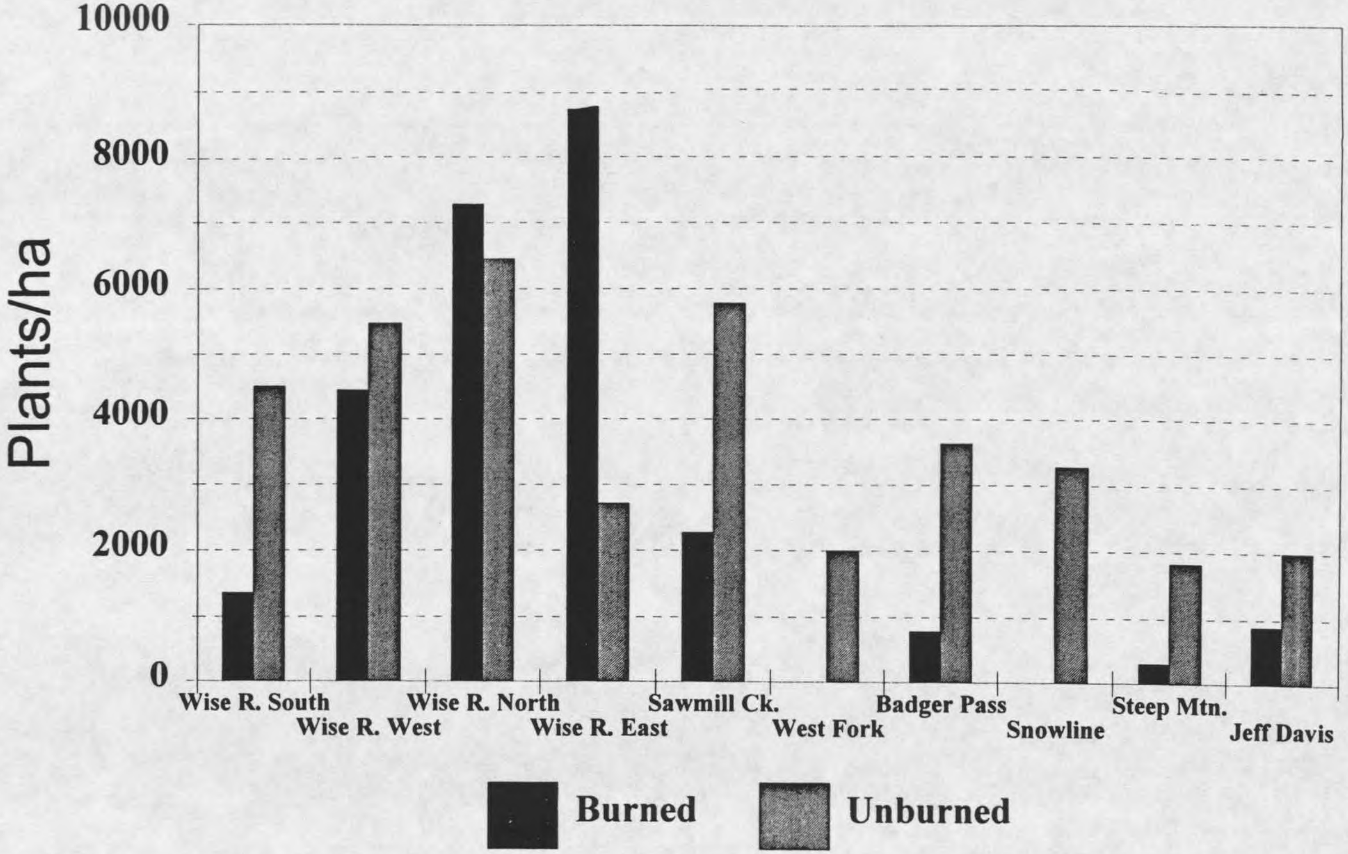


Figure 5. Average (n=6) density (plants per ha) of mountain big sagebrush juveniles. Plants were considered juveniles if the average of the major axis, minor axis, and both perpendiculars was less than 15 cm (Wambolt et al. 1994). Treatments at all sites except Wise River West and Wise River North are significantly different at $P<0.05$.

These data indicate that adult mountain big sagebrush is reduced by fire. However, given a viable seed bank nearby, juveniles do establish in the burned areas. The juvenile size class does slowly recover. However, the burning effects are still seen 16 growing seasons after fire in the Jeff Davis site.

In the overall comparison among all sites, the paired *t*-test showed that adult Wyoming big sagebrush density in burned treatments was not different ($P<0.264$) from unburned treatments.

The Wisdom Flat site had greater ($P<0.01$) adult Wyoming big sagebrush density in the unburned treatment while the Wisdom Slope site had greater ($P<0.0006$) adult density in the burned treatment (Fig. 6). Treatments at the Exclosure site were not different ($P<0.24$). In all other sites where Wyoming big sagebrush was not dominant, adult density was greater in unburned treatments ($P<0.052$).

In the overall comparison of juvenile Wyoming big sagebrush among all sites using the paired *t*-test, my data showed that there was no difference ($P<0.165$) between burned and unburned treatments (Fig. 7). In sites dominated by Wyoming big sagebrush juvenile density between treatments was nearly identical in 2 out of 3 sites. Density was greater ($P<0.0001$) in burned treatments at the Wisdom Slope site while burned and unburned treatments were nearly identical at the Exclosure and Wisdom Flat sites ($P<0.5$ and $P<0.46$ respectively).

My results for Wyoming big sagebrush indicate it is difficult to predict the affects of burning on the taxon in southwest Montana. It seems that the Wisdom site that has a greater slope (4%) and faces northeast had greater big sagebrush recovery than the flat Wisdom site. The Exclosure site, with a 2% slope and northwest exposure, had an intermediate response. Both Wisdom sites were burned 9 growing seasons

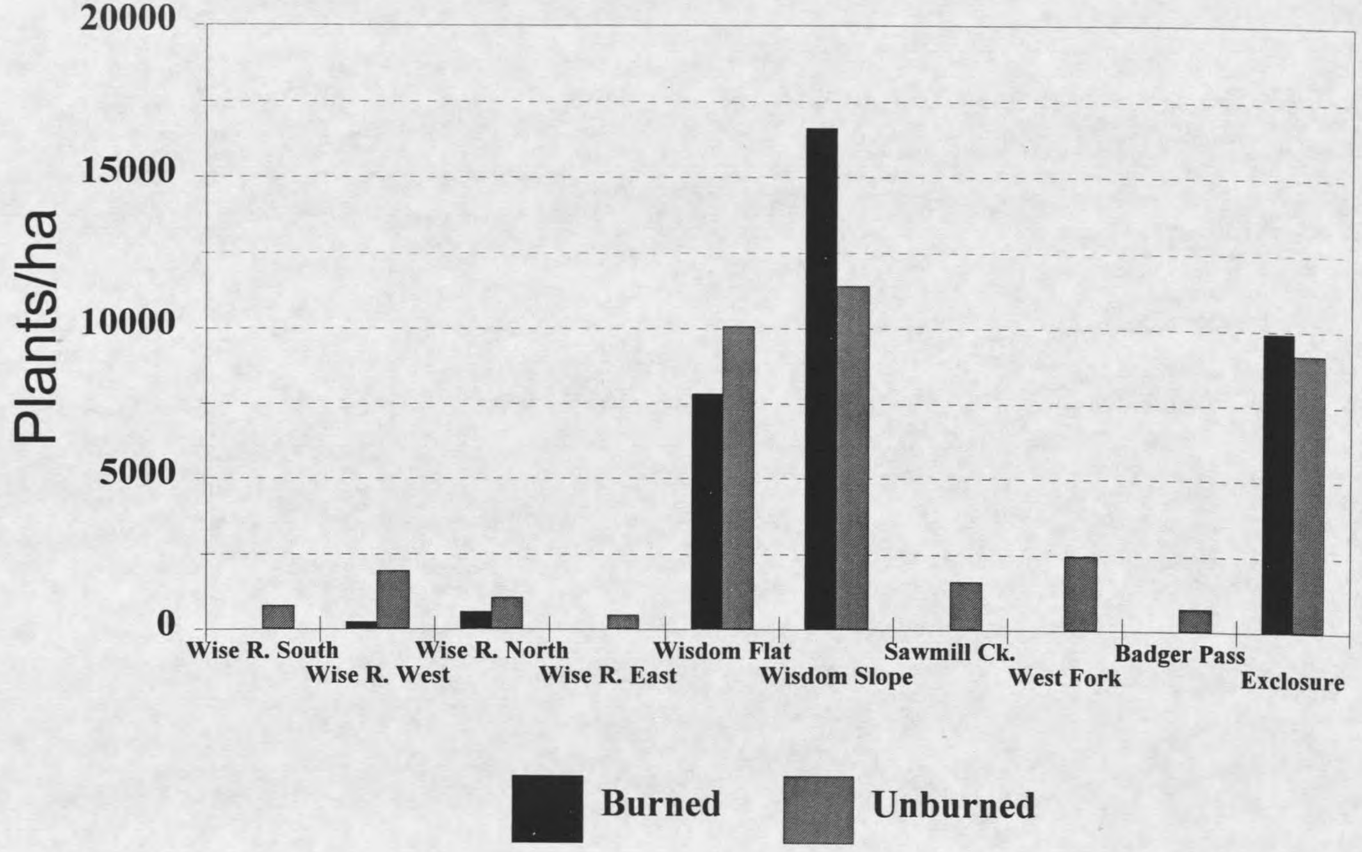


Figure 6. Average (n=6) density (plants per ha) of Wyoming big sagebrush adults. Plants were considered adults if the average of the major axis, minor axis, and both perpenciculars was greater than 15 cm (Wambolt et al. 1994). Treatments at all sites except the Exclosure site are significantly different (P<0.05).

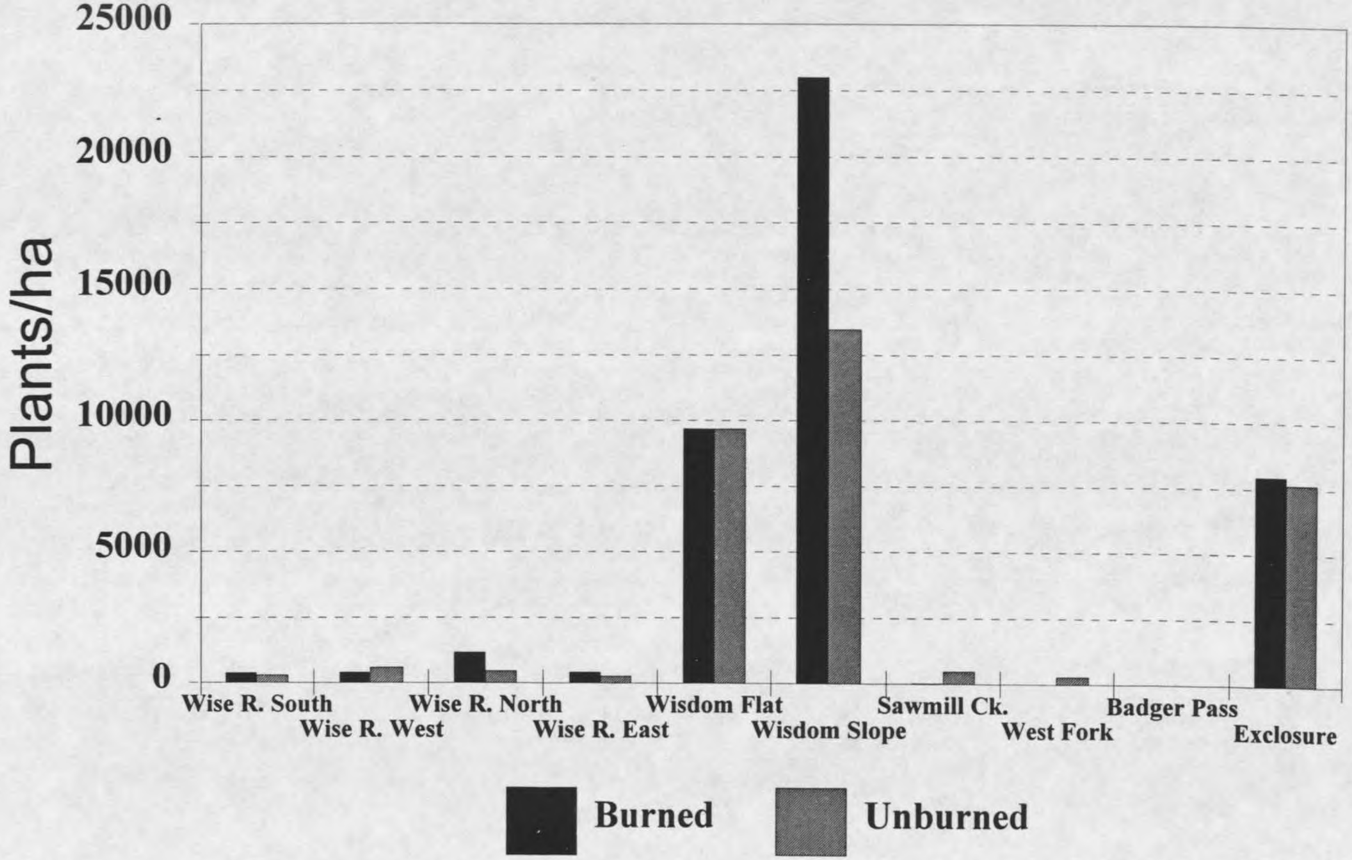


Figure 7. Average (n=6) density (plants per ha) of Wyoming big sagebrush juveniles. Plants were considered juveniles if the average of major axis, minor axis, and both perpendiculars was less than 15 cm (Wambolt et al. 1994). The burned treatment in the Wisdom Slope site had significantly greater density than the unburned treatment ($P<0.05$). All others were not significantly different.

prior to sampling while the Exclosure site was burned 32 growing seasons prior to sampling.

Density of Other Shrubs

Adult three-tip sagebrush density was greater ($P<0.008$) in the unburned treatments at the Snowline site 11 growing seasons following fire. Likewise, juvenile three-tip sagebrush density was greater ($P<0.09$) in the unburned treatments. Green rabbitbrush density was not different between treatments while grey horsebrush density increased from 0.45 plants/m^2 to 1.28 plants/m^2 in burned treatments($P<0.000001$).

At the Steep Mountain site, bitterbrush density was not different between treatments 15 growing seasons following fire ($P<.5$). Total bitterbrush density was 18.7 plants/ 60 m^2 in unburned treatments and 17.8 plants/ 60 m^2 in burned treatments. Fraas (1992) reported no significant difference in bitterbrush density between treatments at this site in 1990. Green rabbitbrush density in unburned treatments was 0.095 plants/m^2 while density in burned treatments was 0.233 plants/m^2 ($P<0.0008$). At the Jeff Davis site, green rabbitbrush was greater in burned treatments 16 growing seasons after burning ($P<0.0016$).

Big Sagebrush Winter Forage Production

Winter forage production at each site is shown in Fig. 8. The regression models of Wambolt et al. (1994) were developed in the Gardiner, Montana area where ungulate concentrations and usage of big sagebrush plants were likely greater than in the Wise River, Dillon, Butte, and Wisdom areas. However, this model can still provide a reasonably accurate estimate of big sagebrush winter forage production in other areas of southwest Montana since the models allow for estimates

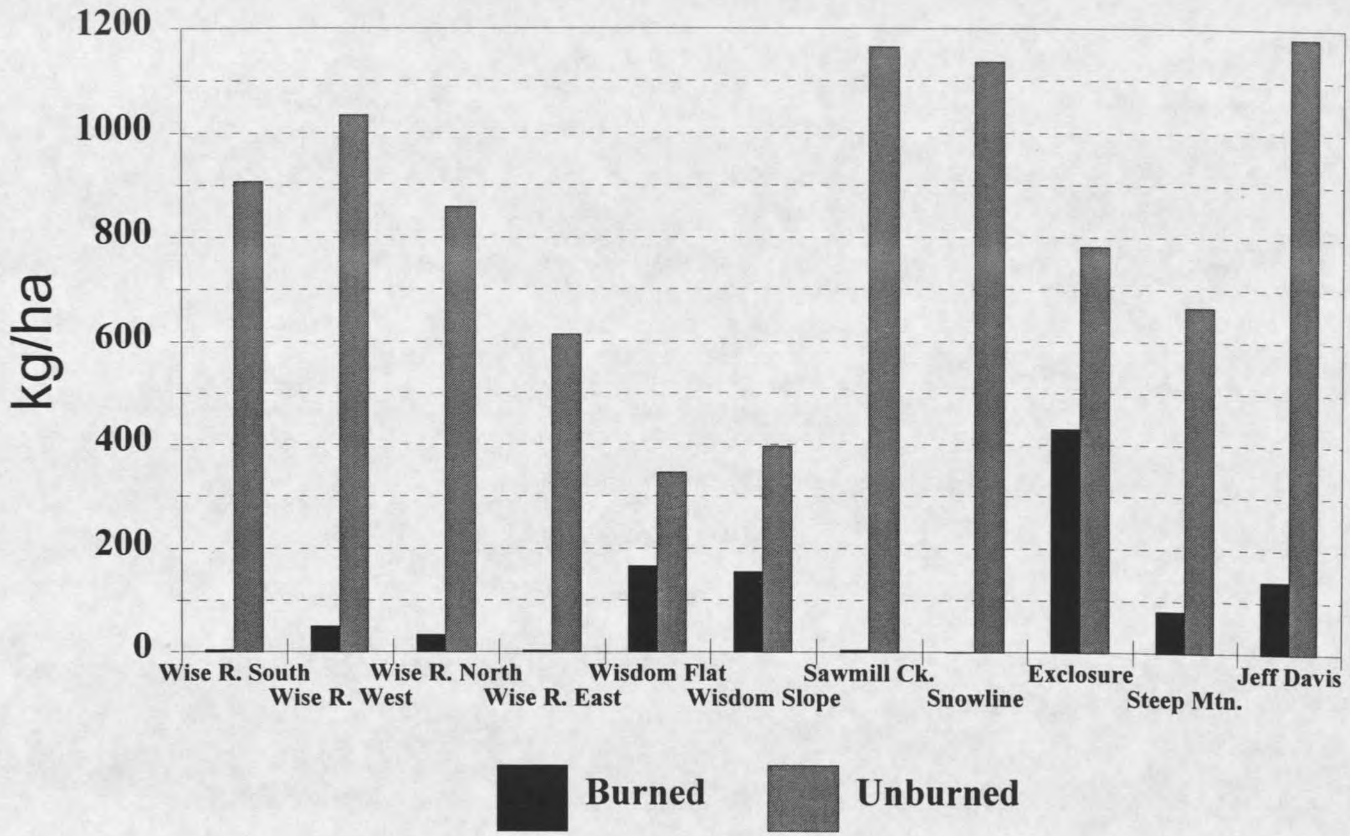


Figure 8. Average big sagebrush winter forage production (kg per ha) including both mountain and Wyoming big sagebrush. Established plants with the average of major axis, minor axis, and both perpendiculars greater than 15 cm were measured for winter forage production estimates. Subspecies and browse form class (Wambolt et al. 1994) along with density measurements were used in estimations. Treatments at all sites are significantly different at $P<0.05$.

of low-use plants as well.

Estimates of winter forage production obtained on the West Fork and Badger Pass sites were not feasible. However, because the West Fork site had no big sagebrush present in the burned treatment one growing season after burning (Fig. 2), winter forage production was obviously greater in the unburned treatment. The Badger Pass site had enormous heavy-use big sagebrush plants. It was common to observe the plants having average crown cover between 130 and 140 cm. The model seemed to over-estimate production in unburned treatments. Big sagebrush plants in the unburned treatments produced ($P<0.05$) more forage than the burned treatments. It is interesting to consider the Wyoming big sagebrush winter forage production at the 2 Wisdom sites. Although the burned and unburned treatments at each site did not differ in canopy cover or density (see Fig. 4 and Fig. 7), the unburned treatment had over twice the winter forage production of the burned treatments. This can be attributed to the larger size of the plants in the unburned treatment. It is also interesting to note that the burned treatments at the Exclosure site, 32 growing seasons after treatment, had less ($P<0.05$) Wyoming big sagebrush forage production than the unburned treatments. When land managers decide to burn big sagebrush communities, they must include the long-term effects of burning in their decision-making. The big sagebrush may not recover after 30 years. Possible short-term increases in herbaceous production may be overshadowed by the long-term reduction in big-game habitat.

In the overall comparison among all sites, the difference in means analysis with each site serving as a replicate shows that the unburned treatments produced more ($P<0.00001$) big sagebrush forage than burned treatments after excluding the West Fork and Badger Pass sites from analysis.

Big Sagebrush Ages

Table 3 summarizes big sagebrush stand ages. No big sagebrush were present for aging in burned treatments at the West Fork and Snowline sites. No dead big sagebrush were present in unburned treatments at the Badger Pass, Snowline, or Jeff Davis sites. Big sagebrush were not sampled at the Exclosure or Steep Mountain sites due to potential for future research in these areas.

Big sagebrush plants that re-established did so relatively soon after the burning treatment (Fig. 9). At sites where plants were measured in burned treatments, peak re-establishment occurred in all sites within the first 4 growing seasons after the burn. Four of the 9 sites sampled had peak re-establishment in either the year of treatment or the year following treatment. Bartolome and Heady (1978) reported similar results. They showed that in 3 of 6 study sites, big sagebrush plants that established the first year following treatment formed the largest age class. Thus, they suggested "reinvasion begins immediately after treatment." This may indicate that big sagebrush taxa are particularly suited for these areas and that environmental conditions are favorable. Programs aimed at big sagebrush eradication may not be feasible or economical (Watts and Wambolt 1989).

Ages of dead and live big sagebrush plants in unburned treatments were quite similar. (Fig. 10). Likewise, the dead plants were quite young. This may indicate that the big sagebrush plants die due to some other mortality agent. Big sagebrush plants in these

Table 3. Big sagebrush stand ages at 11 sites in southwest Montana.

Site*	Unburned					Burned					
	n	range	mean	median	sd	n	range	mean	median	sd	P <
Wise R. South (6)	20	8-41	22.5	20.5	9.12	20	3-8	4.85	5	1.2	0.0001
Wise R. West (7)	20	9-42	26.3	22.5	7.71	20	2-6	4.3	4	0.86	0.0001
Wise R. North (7)	20	6-46	24.3	24	10.4	20	2-8	5.9	6.5	1.86	0.0001
Wise R. East (7)	20	8-43	27.7	30.5	11.4	20	3-6	4.55	4.5	1.1	0.0001
Wisdom Flat (8)	20	13-54	27.2	24.5	9.5	20	3-8	5.85	6	1.73	0.0001
Wisdom Slope (8)	20	9-58	29.5	29	12.3	20	5-7	5.65	6	0.67	0.0001
Sawmill Ck. (6)	20	9-42	19.1	14	10.41	20	3-6	5.15	5.5	1.04	0.0001
West Fork (1)	20	15-67	32.5	30.5	13	no plants present					
Badger Pass (15)	20	9-28	18.8	18	5.59	20	7-14	11.5	12	1.96	0.0001
Snowline (9)	20	10-41	24.2	24	8.21	no plants present					
Jeff Davis (16)	20	10-28	16.7	14	5.86	20	8-15	11.7	12	1.74	0.0008

* ( ) indicates growing seasons between burning and sampling.

Site	Dead				
	n	range	mean	median	sd
Wise R. South	20	16-42	29.5	27.5	7.55
Wise R. West	20	10-46	23.2	21.5	9.5
Wise R. North	20	12-33	22	22	5.78
Wise R. East	20	11-56	30.3	31	11.8
Wisdom Flat	20	7-48	23.8	19	11.5
Wisdom Slope	20	14-49	30.2	29.5	9.5
Sawmill Ck.	20	15-43	27.8	26	8.75
West Fork	20	15-56	31	30	12.4
Badger Pass	no dead plants present				
Snowline	no dead plants present				
Jeff Davis	no dead plants present				

*Both Wisdom sites are dominated by Wyoming big sagebrush. All other sites are dominated by mountain big sagebrush.
*Exclosure and Steep Mountain sites excluded from age analysis due to potential for future research.

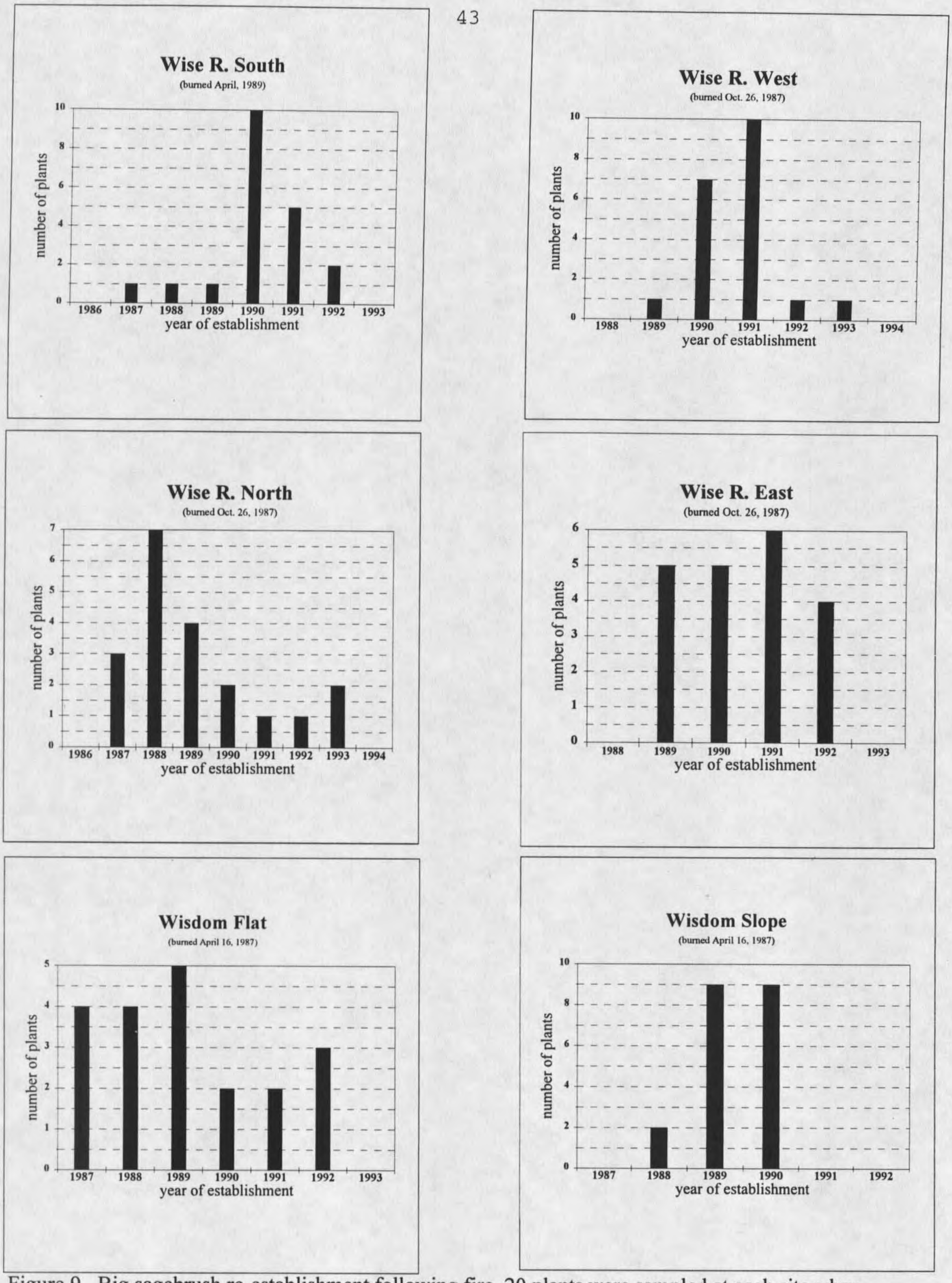
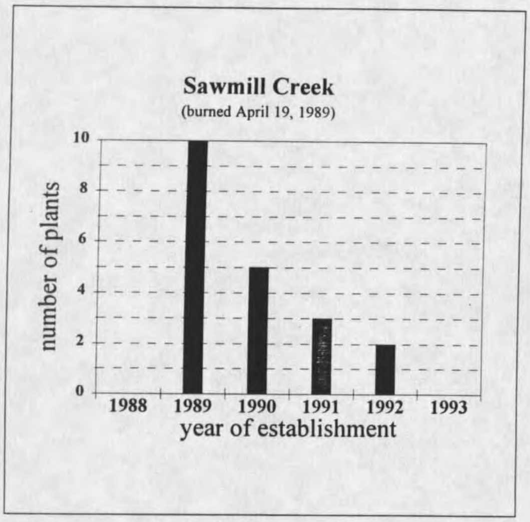
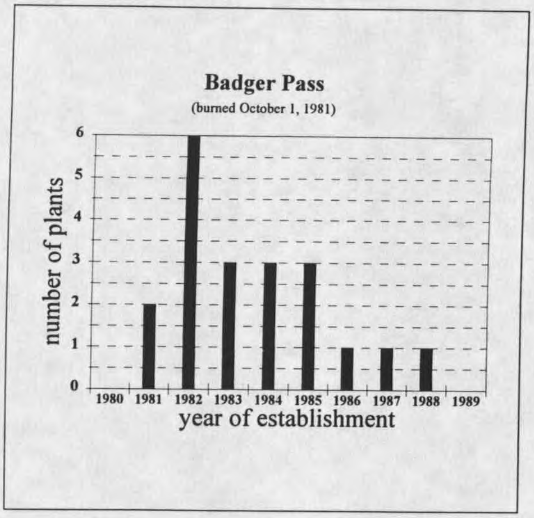


Figure 9. Big sagebrush re-establishment following fire. 20 plants were sampled at each site when present in burned treatments. The West Fork and Snowline sites had no plants present in burned treatments. The Steep Mtn. and Exclosure sites were not sampled due to potential future research. Both Wisdom sites dominated by Wyoming big sagebrush. All others dominated by mountain big sagebrush.





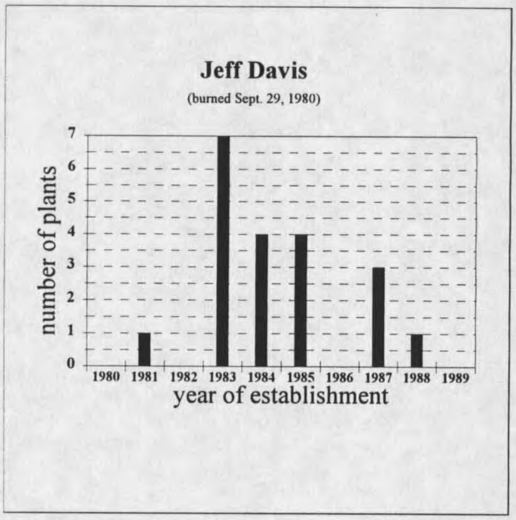


Figure 9 (cont). Big sagebrush re-establishment following fire. 20 plants were sampled at each site when present in burned treatments. The West Fork and Snowline sites had no plants present in burned treatments. The Steep Mtn. and Exclosure sites were not sampled due to potential future research. Both Wisdom sites dominated by Wyoming big sagebrush. All others dominated by mountain big sagebrush.

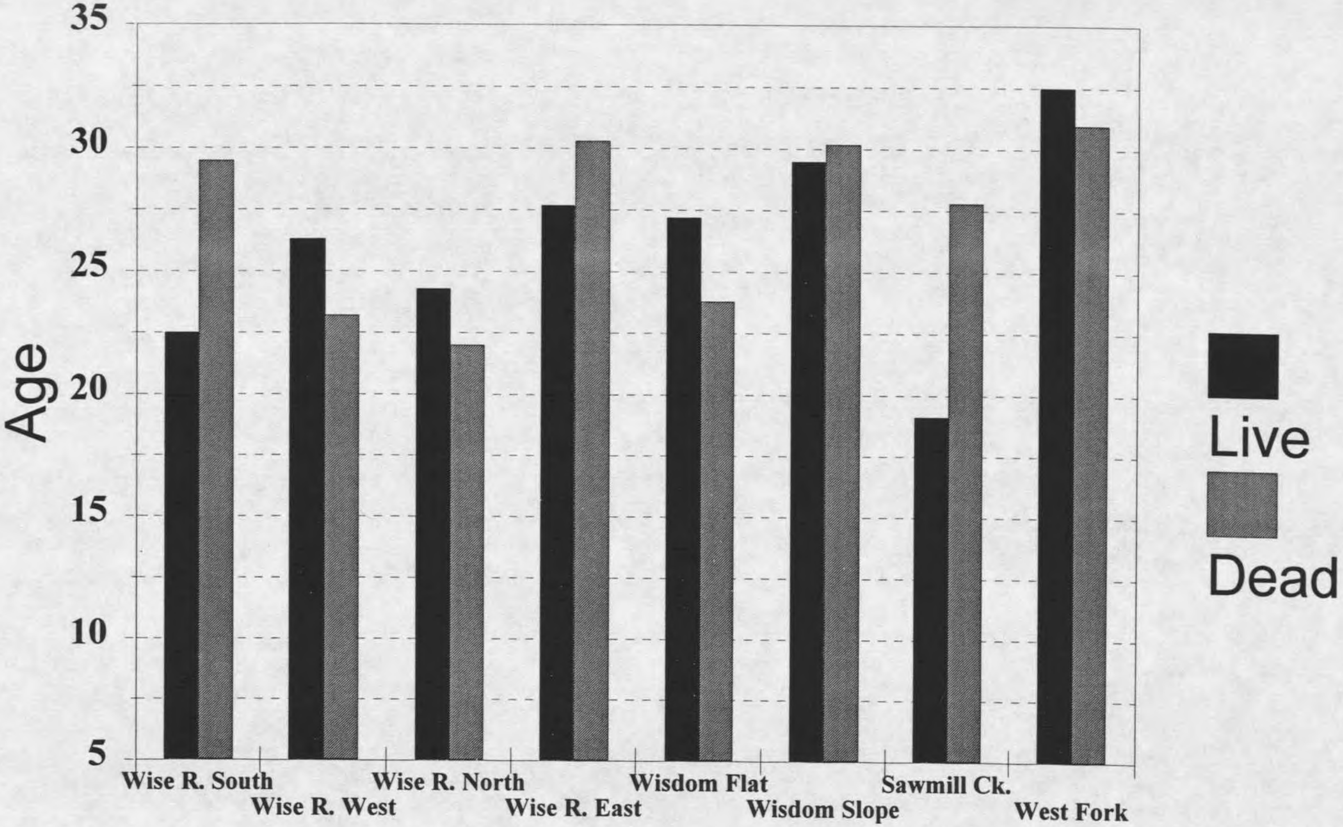


Figure 10. Average (n=20) ages of dead and live big sagebrush at each site. Sites included in analysis are those where both dead and live big sagebrush plants were present in unburned treatments. The Wisdom Flat and Wisdom Slope sites were dominated by Wyoming big sagebrush. All others were dominated by mountain big sagebrush. Treatments at the Wise R. South and Sawmill Creek sites are significantly different ($P<0.05$).

areas do not require a disturbance such as fire to kill the plant or to re-start succession in these communities.

Herbaceous Understory Cover

Idaho fescue

Analysis of the overall comparison between burned and unburned treatments using the paired *t*-test indicates that Idaho fescue canopy cover was not significantly reduced by burning ($P < 0.09$).

Harniss and Murray (1973) suggested Idaho fescue was damaged severely in the short-term, but nearly recovered 30 years after burning in Idaho. In the current study 4 out of 13 sites had significantly greater ($P<0.05$) canopy cover of Idaho fescue in unburned treatments (Fig. 11). The Badger Pass site and Jeff Davis sites were burned 14 and 16 growing seasons prior to sampling, respectively, and burning reduced Idaho fescue canopy cover. This shows that areas burned under extremely, hot, dry conditions can harm Idaho fescue. It is interesting to note that the site data most similar to the Harniss and Murray (1973) results were from the Jeff Davis site. This site is the closest geographically to where Harniss and Murray (1973) worked in Dubois, Idaho. Idaho fescue was significantly greater in the burned treatments in the Wise River South site. The remaining 8 sites showed no difference between burned and unburned treatments. No clear relationship was observed between burn age and Idaho fescue recovery. My data would not support Harniss and Murray (1973). Idaho fescue may or may not be damaged by fire. Idaho fescue can recover much faster than 30 years. The degree of damage likely depends on site-specific burn conditions.

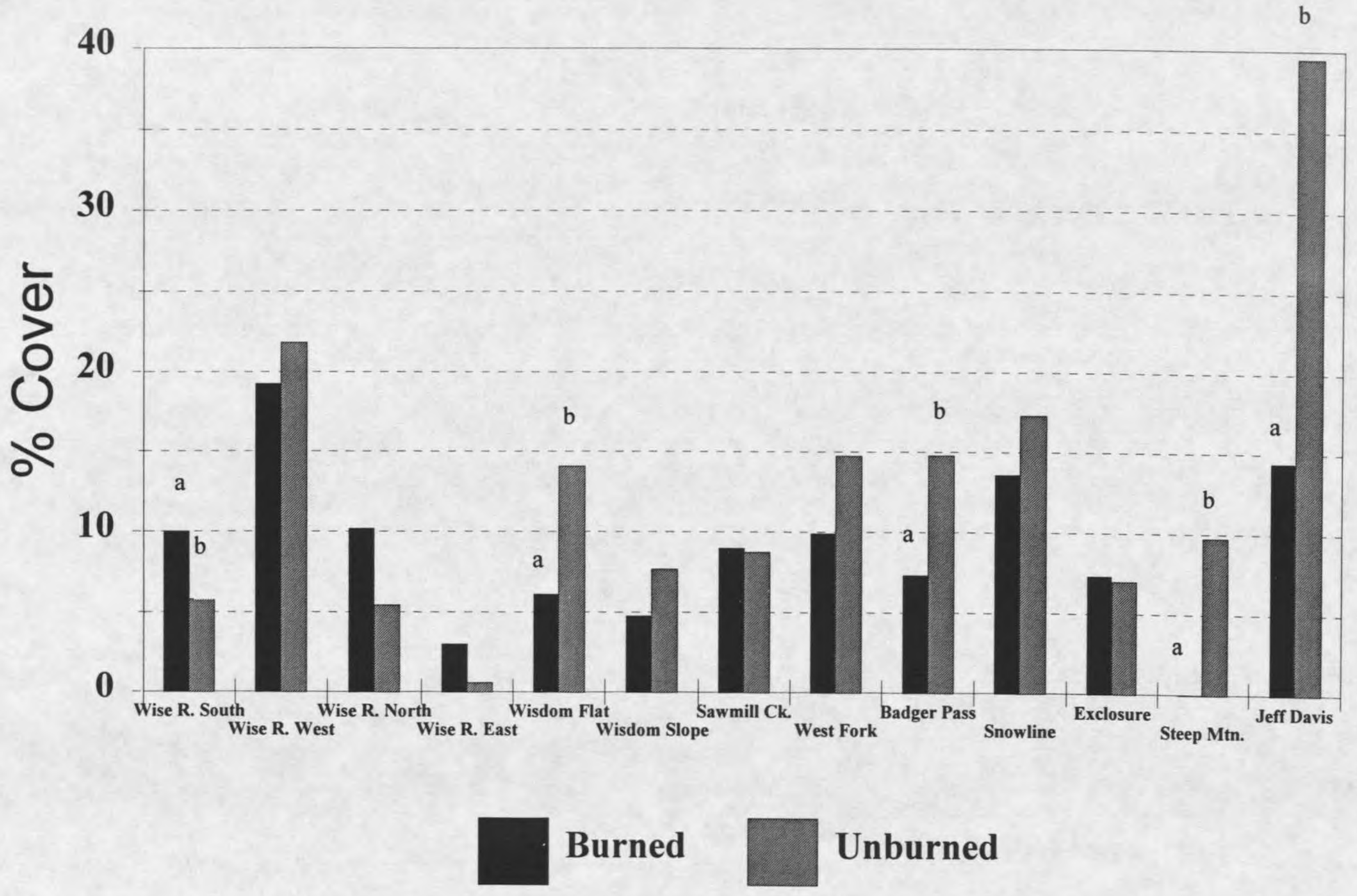


Figure 11. Average (n=30) canopy cover (%) of Idaho fescue in burned and unburned treatments. Pairs of bars at a site with unlike letters are significantly different (P<0.05).

Vegetation Cover/Soil Exposed

Analysis of the overall comparison between burned and unburned treatments using the paired *t*-test indicates that soil and rock exposed were greater in burned treatments ($P < 0.09$).

All burned treatments had greater soil exposed than in unburned treatments (Fig. 12). The difference was significant in 8 of the 13 sites ($P < 0.05$). This response is expected in the short-term. However, the Badger Pass, Steep Mountain, and Jeff Davis sites had significantly ($P<0.05$) greater exposed soil in the burned treatments. These sites were burned 14, 15, and 16 growing seasons before sampling, respectively. Burned and unburned areas were not different at the Exclosure site 32 growing seasons following fire.

Exposed soil is more susceptible to sediment transport (Brown et al. 1985). My data indicates that burned areas may have high erosion potential up to 16 growing seasons following fire.

Litter Cover

Analysis of the overall comparison between burned and unburned treatments using the paired *t*-test indicates that unburned treatments have significantly greater litter cover than burned treatments ($P < 0.025$).

Litter cover was greater in unburned treatments in 11 out of 13 sites (Fig. 13). Cover was significantly greater ($P<0.05$) in six of these sites. Litter cover was significantly greater ($P<0.05$) in burned treatments at the Wise River East and Sawmill Creek sites ($P<0.05$). This response was expected given the combustion of litter by fire. However, the Badger Pass, Steep Mountain, and Jeff Davis sites had significantly greater litter cover in unburned treatments as

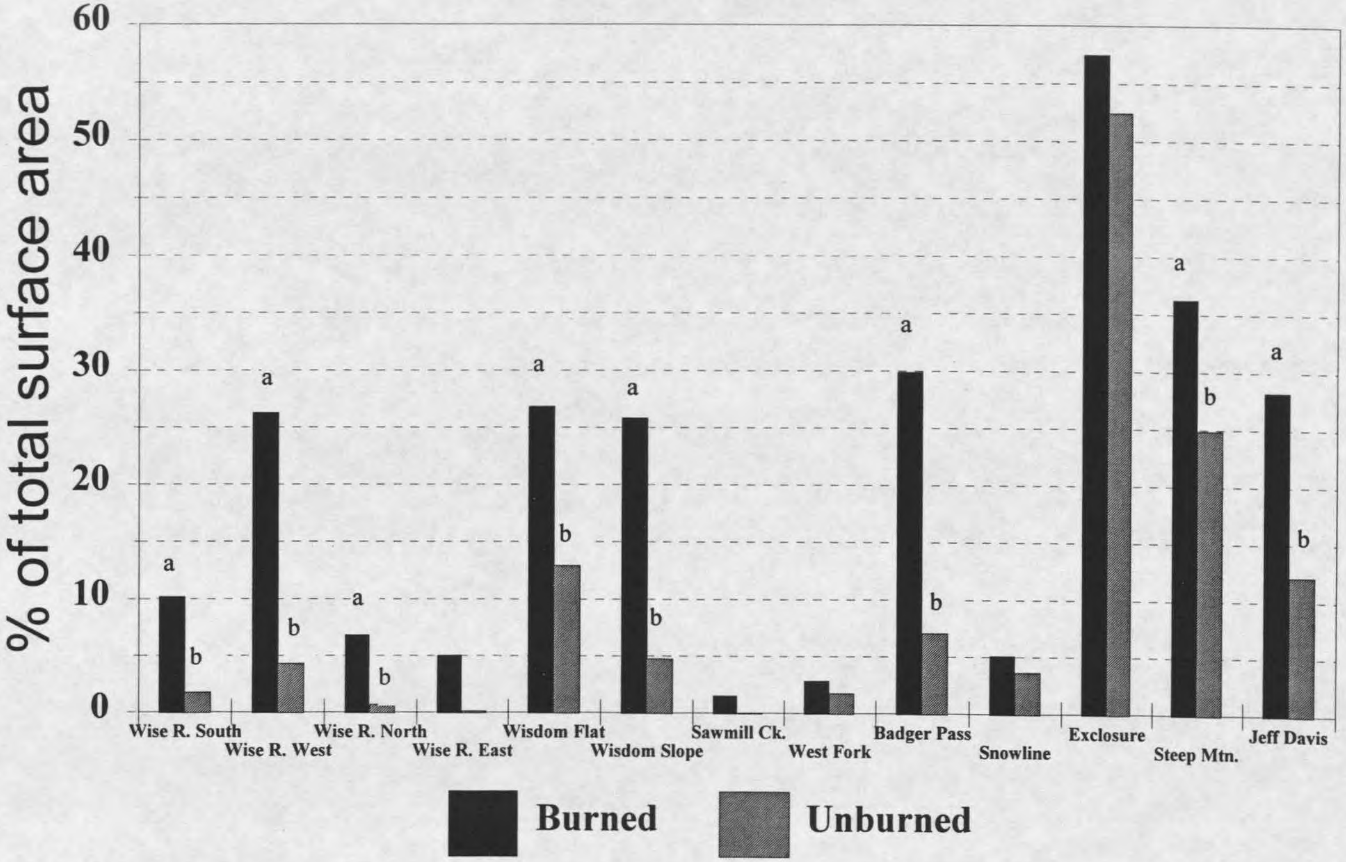


Figure 12. Average (n=30) soil exposed (% of total surface area) in burned and unburned treatments. Pairs of bars at a site with unlike letters are significantly different (P<0.05).

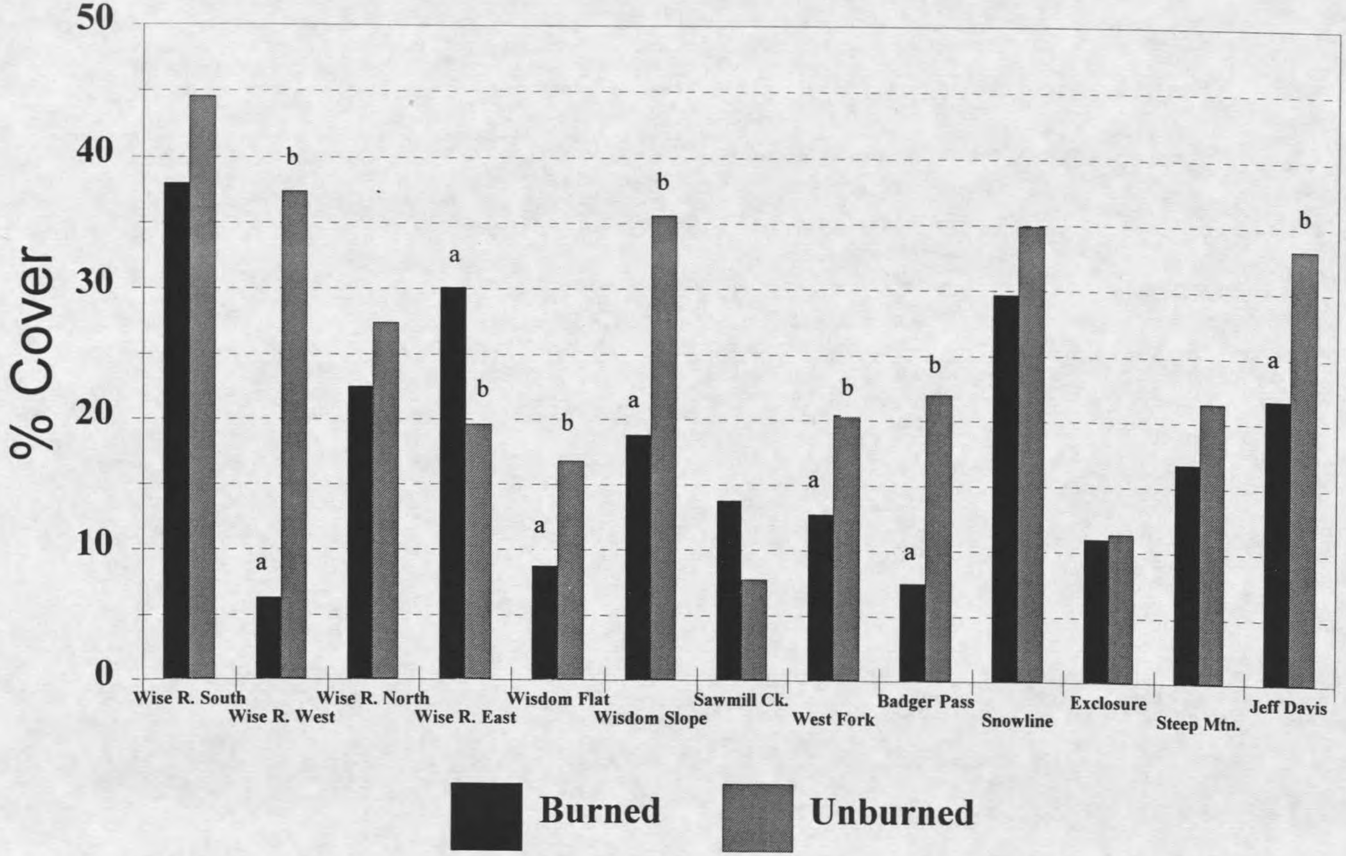


Figure 13. Average (n=30) canopy cover (%) of litter in burned and unburned treatments. Pairs of bars at a site with unlike letters are significantly different (P<0.05).

well. This response was noticable 14, 15, and 16 growing seasons after the burn, respectively. Litter cover was very similar in the 32 growing seasons after fire at the Exclosure site (11.4% unburned vs. 11.0% burned).

Litter invertebrate communities can be signficantly reduced by fire in big sagebrush habitat (Christianson 1996). My study did not look at the litter invertebrate community. However, given the decline in litter cover in burned areas, we would expect the litter invertebrate community to decline as well. This may affect long-term nutrient cycling and organic matter decomposition (Christianson 1996).

Perennial Grasses

Analysis of the overall comparison using the paired *t*-test indicates that perennial grass canopy cover was not different between burned and unburned treatments ($P<0.91$).

Perennial grass response to fire was quite variable. Perennial grass canopy cover was greater in unburned treatments at 7 sites while cover was greater in burned treatments at 6 of the sites (Fig. 14). Only the Wise River North site had a significant difference between burned and unburned treatments. The burned treatment had significantly greater ($P<0.04$) perennial grass cover than the unburned treatment. The West Fork site had no difference ($P<0.42$) between burned and unburned treatments 2 growing seasons after the fire (47% cover in unburned vs. 50% in burned). This is the only site where the burned treatment was expected to produce significantly more perennial grasses than the unburned treatment because most herbaceous responses to burning are in the first few years following fire (Harniss and Murray 1973). The Exclosure burn had very similar canopy cover

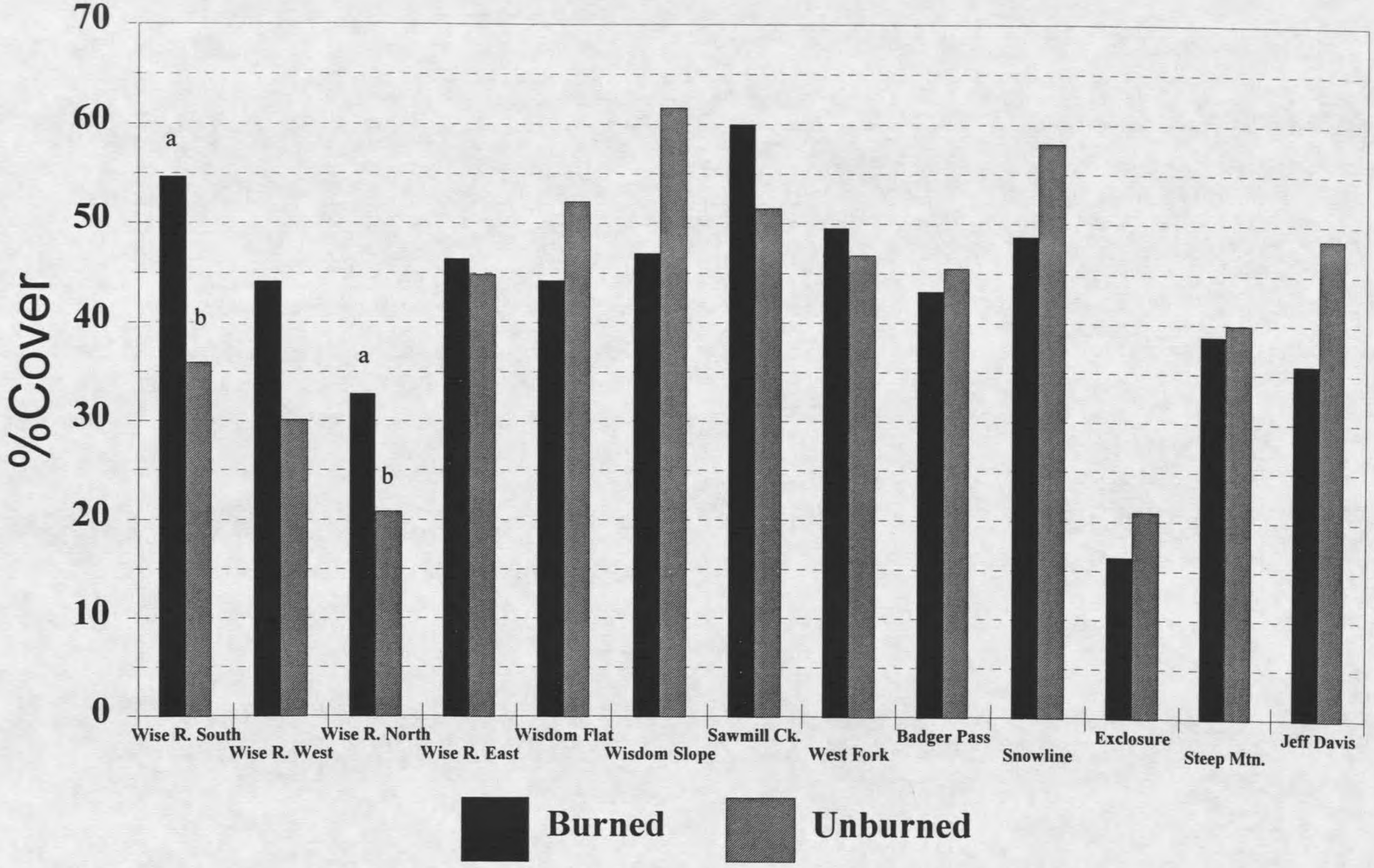


Figure 14. Average (n=30) canopy cover (%) of perennial grasses in burned and unburned treatments. Pairs of bars at a site with unlike letters are significantly different ($P<0.05$).

between burned and unburned treatments (40% in unburned vs. 39% in burned). This data supports the claim that reducing big sagebrush cover may not result in additional herbaceous understory production (Fraas et al. 1992, Peek et al. 1979, McNeal 1984, Wambolt and Payne 1986, Watts and Wambolt 1996.) Perennial grass responses to fire are quite variable and dependent on site conditions. Burning may not increase perennial grass production for livestock or wildlife forage.

Table 4 shows the canopy cover and frequency of individual plant taxa in burned and unburned treatments. Richardson's needlegrass (*Stipa richardsonii* Link.) was the dominant perennial grass at the Wise River South and Wise River East sites. This species was present in 97% of burned plots and 93% of unburned treatments and had 36% canopy cover in the burned treatment and 28% in the unburned treatment at the Wise River South site ($P<0.08$). However, the exact opposite was true at the Wise River East site, with the burned treatment having 28% cover and the unburned treatment having 38% cover ($P<0.05$). This grass was present in 90% of plots in the unburned treatment and 87% in the burned treatment at this site.

Rough fescue was a major component of understory cover at the Wise R. North and Wise R. East sites. Cover was greater in burned treatments ($P<0.05$) only at the Wise R. North site. Bluebunch wheatgrass was a dominant understory species at the Sawmill Creek, Snowline, Exclosure, Steep Mountain, and Jeff Davis sites. Cover was greater ($P<0.05$) in burned treatments only at the Sawmill Creek and Jeff Davis sites.

At the Steep Mountain site, Fraas (1992) reported perennial grass canopy cover in burned treatments at 15.4% in 1990 and 28.1% in 1992. I found perennial grass canopy cover in burned areas sampled in

Table 4. Comparisons of Canopy Coverage (%) and Frequency (% Occurence) of Plant Taxa in Burned and Unburned Treatments.

Taxa	Location (Complete Growing Seasons Since Burn)									
	Wise R. South(7)		Wise R. West(8)		Wise R. North(8)		Wise R. East(8)		West Fork (2)	
	B	U	B	U	B	U	B	U	B	U
Stipa richardsonii	36/97	28/93					28.5/87	38.5/90		
Carex filifolia			14.5/53*	01/10					32/90	23/87
Festuca idahoensis	10/60	6/33	19/87	22/87	10/63	5.5/37			10/66	15/77
Festuca scabrella					17/60*	7/40	10/63	5.5/40		
Poa pratensis									01/07	07/20
Juncus balticus					5.5/37	03/20				
Geum triflorum							3/17*	17.5/63		
Achillea millefolium					08/23	7/43	6/63	7/77	9.5/63	7.5/57
Antennaria microphylla					6/40	2.5/17				
Lupinus spp.			12.5/83	11/73	16.5/73*	6/50			10/37	7.5/50
Arnica diversifolia			7/53*	0.5/10	8/63*	3.5/40			5/40	10/63
Arenaria conjesta			6/53*	0.08/3	5.5/47*	2/37				
Astragalus spp.			1/13*	8.5/43						

taxa with < 5% Canopy cover in either treatment not included in table
* indicates significant difference at P<0.05
B=burned, U=unburned
measured using method of Daubenmire (1959) with 30 plots/treatment

Table 4 (cont). Comparisons of Canopy Coverage (%) and Frequency (% Occurence) of Plant Taxa in Burned and Unburned Treatments.

Taxa	Location (Complete Growing Seasons Since Burn)									
	Wisdom Flat(9)		Wisdom Slope(9)		Exclosure (32)		Sawmill Ck(7)		Badger P. (14)	
	B	U	B	U	B	U	B	U	B	U
Agropyron spicatum					9/83*	14/97	46/97*	24.5/87	6.5/63	3/33
Carex filifolia	23/97	30/97	29/97	25.5/93					29/100	29/100
Festuca idahoensis	6/43*	14/90	5/60	7.5/60	7/77	7/63	9/60	9/50	7.5/60*	15/87
Koeleria cristata	9.5/83*	4/66	9.5/83	7/66						
Stipa comata			4/23*	19.5/83						
Poa pratensis							4.5/20*	18.5/77		
Antennaria microphylla	05/30	7/40							05/27	01/07
Lupinus spp.	11.5/73	18.5/90					15/66	10/40	2.5/10*	22/83
Arnica diversifolia							7.5/57*	3.5/27		
Arenaria conjesta			5.5/33*	1.5/13						
Geranium viscosissimum							1/13*	8/47		
Astragalus spp.									8.5/77*	01/07
Lycopodium spp.					11/63	10/80				
Taraxacum spp.							2.5/80	6/53		

taxa with <5% Canopy cover in either treatment not included in table
* indicates significant difference at P<0.05
B=burned, U=unburned
measured using method of Daubenmire (1959) with 30 plots/treatment

Table 4 (cont). Comparisons of Canopy Coverage (%) and Frequency (% Occurence) of Plant Taxa in Burned and Unburned Treatments.

Taxa	Location (Complete Growing Seasons Since Burn)					
	Snowline (11)		Steep Mountain (15)		Jeff Davis Creek (16)	
	B	U	B	U	B	U
Agropyron spicatum			28/90	21.5/87	21.5/83*	2/30
Carex filifolia	16.5/80	20/77			0/0*	7/43
Festuca idahoensis	13.5/83	17.5/90	0/0*	9.5/53	14.5/77*	39.5/100
Poa pratensis	7/43	9/40	6.5/40	3.5/37		
Juncus balticus						
Bromus tectorum					10.5/40*	0/0
Lupinus spp.	8/57	5/60				

Taxa with <5% Canopy cover in either treatment not included in table
* indicates significant difference at $P<0.05$
B=burned, U=unburned
measured using method of Daubenmire (1959) with 30 plots/treatment

1996 was 38.8%. Likewise, Fraas (1992) reported perennial grass cover in unburned areas was 12.6% in 1990 and 20.0% in 1991. I found canopy cover in unburned areas in 1996 was 40.0%. This response is likely due to favorable growing conditions in 1995 and 1996 along with differences in time of sampling.

Conrad and Poulton (1966) and Daubenmire (1968) suggested fire followed by grazing can reduce big sagebrush, harm Idaho fescue, improve bluebunch wheatgrass, and lead to cheatgrass (*Bromus tectorum* L.) invasion. Results from the Jeff Davis site supports this. Cheatgrass canopy cover was 10.5% in burned plots and occurred in 40% of plots sampled. Cheatgrass was not present in unburned plots. Bluebunch wheatgrass canopy cover was 21.5% in burned plots and 2% in unburned plots. Idaho fescue was severely damaged by the fire and was significantly reduced ($P<0.05$) from 39.5% cover in unburned plots to 14.5% in burned plots. Burning occurred at this site under hot and dry conditions in the fall (burned Sept. 29, 1980, air temperature 17-22°C, relative humidity 16-32%, wind 9-13 km/hr). Likewise, the soils in the area are sandy loams. These soils likely get very hot due to their inability to hold much moisture. These factors may have contributed to the Idaho fescue damage and cheatgrass establishment at this site. The cheatgrass invasion may have come from significant soil movement following the fire. The fire burned up a 20% slope. This factor, along with a relatively sandy soil, probably caused soil to move downhill and significantly alter the vegetation.

Perennial Forbs

Analysis of the overall comparison between burned and unburned treatments using the paired *t*-test indicates that perennial forb responses to burning are quite variable with no difference between burned and unburned treatments (*P*<0.49).

No clear trend in perennial forb cover was evident between burned and unburned treatments. Forb cover was greater (*P*<0.05) in the burned treatment at the Wisdom Slope site (Fig. 15). Forb cover was greater (*P*<0.05) in unburned treatments at the Wise River East and Jeff Davis sites. Treatments at the remaining 10 sites were not significantly different.

Prairie smoke (*Geum triflorum* Pursh) was significantly greater in unburned treatments at the Wise River East site (*P*<0.05). Lupine (*Lupinus* ssp.) cover was greater in burned treatments in 5 of 7 sites where this plant was a major component, but significantly greater at only 1 site. Lupine cover was significantly greater in the unburned treatments at the Badger Pass site. Sandwort (*Arenaria conjesta* Nutt.) was significantly greater in burned treatments at the 3 sites where it was a major component. Sticky geranium (*Geranium viscosissimum* Fisch. and Meyer ex Meyer) was significantly greater in the unburned treatments at the Sawmill Creek site. Club moss (*Lycopodium* spp.) cover was not affected by treatment 32 growing seasons after burning at the Exclosure site.

This data indicates that burning does not increase forb production. Given that forbs compose a major portion of the summer diet of mule deer and shrubs compose a major portion of winter diets, burning likely does not benefit mule deer. Burning does not improve forb canopy cover while burning decreases big sagebrush canopy cover. Thus, burning may cause decreases in mule deer forage.

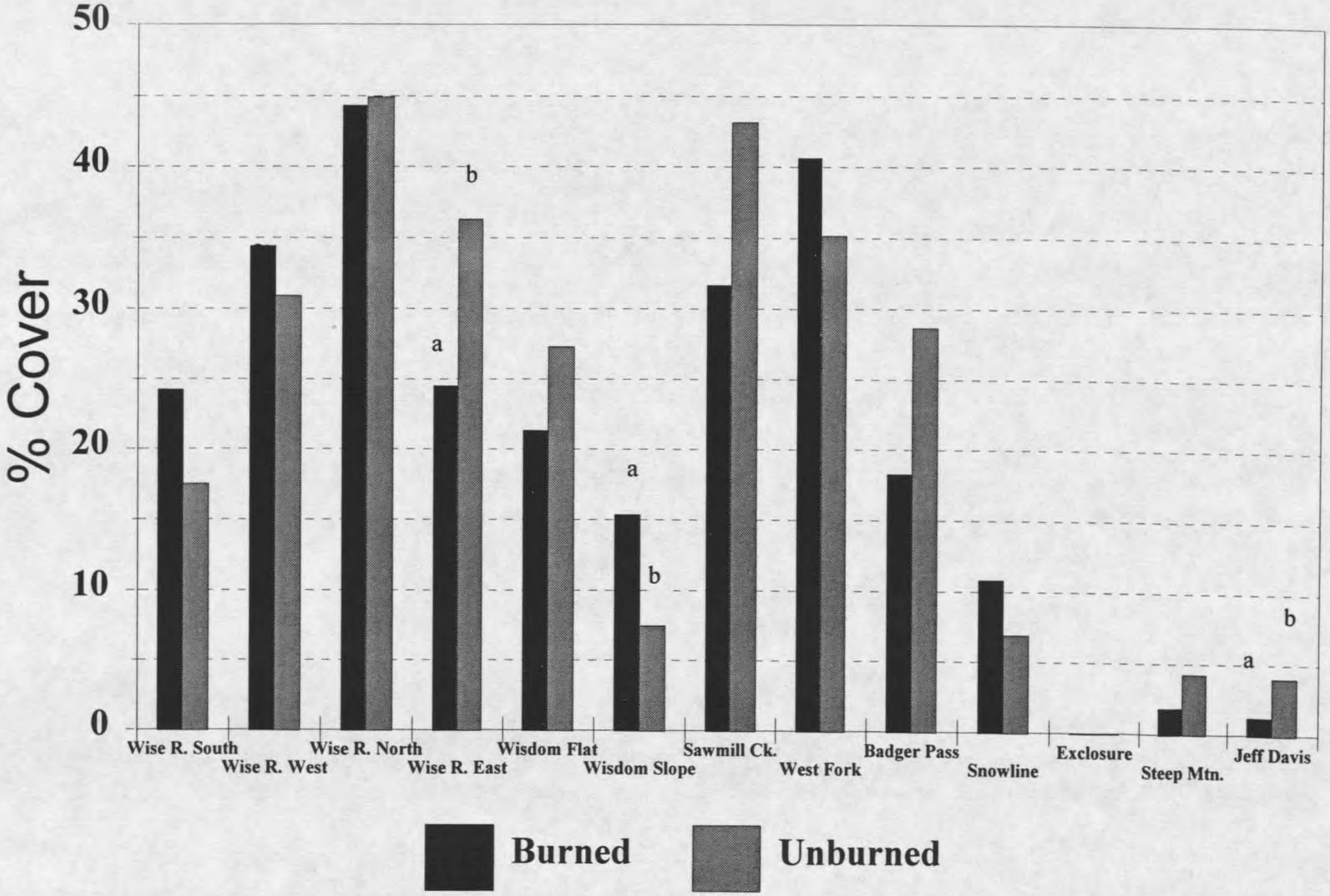


Figure 15. Average (n=30) canopy cover (%) of perennial forbs in burned and unburned treatments. Pairs of bars at as site with unlike letters are significantly different (P<0.05).

SUMMARY AND CONCLUSIONS

I examined big sagebrush population responses and herbaceous understory responses to fire at 13 sites in southwest Montana. Big sagebrush is an important dietary component for many wildlife species. It is nutritious and can be critical for winter survival of many ungulates. Fire can eliminate or reduce big sagebrush stands for many years. Fire can alter big sagebrush canopy cover, density, production, stand age, and herbaceous understory cover. Measurements and *P* values are presented in the Appendix, Tables 5-18.

Big Sagebrush Canopy Cover

Fire significantly reduced big sagebrush canopy cover, with all sites dominated by mountain big sagebrush showing a decrease ($P<0.05$) in canopy cover in burned treatments. Canopy cover ranged from 8.7% to 28.2% in unburned mountain big sagebrush treatments while canopy cover ranged from 0% to 4.2% in burned mountain big sagebrush treatments. Two of 3 sites where Wyoming big sagebrush dominated showed no significant difference between burned and unburned treatments. In these 3 sites dominated by Wyoming big sagebrush, canopy cover ranged from 11.6% to 13.9% in unburned treatments and 9.1% to 13.4% in burned treatments. Additional Wyoming big sagebrush sites should be analyzed before anything conclusive could be said about this habitat type. These 2 sites may be atypical, and their responses are clearly not similar to other published data on Wyoming big sagebrush recruitment following fire (Wambolt and Payne 1986, Watts and Wambolt 1995).

Big Sagebrush Density

Adult mountain big sagebrush density was reduced ($P<0.05$) in all burned treatments. Density ranged from 0.55 to 1.14 plants/m^2 in unburned treatments and 0 to 0.23 plants/m^2 in burned treatments. Juveniles seemed to be re-establishing in some sites, while juvenile density in most unburned treatments was still significantly higher. Density ranged from 0.18 to 0.65 plants/m^2 in unburned treatments and 0 to 0.73 plants/m^2 in burned treatments. In sites dominated with Wyoming big sagebrush, adults were significantly greater in burned treatments in 1 of 3 sites. Adult density ranged from 0.05 to 1.14 plants/m^2 in unburned treatments and 0 to 1.66 plants/m^2 in burned treatments. Likewise, density of juveniles was significantly greater in only 1 of these 3 sites. Juvenile density ranged from 0 to 1.35 plants/m^2 in unburned treatments and 0 to 0.97 plants/m^2 in burned treatments. In general, it appears that fire reduces big sagebrush density. Differences between burned and unburned treatments can be detected in mountain big sagebrush up to 16 growing seasons following fire.

Big Sagebrush Winter Forage Production

Fire significantly reduced ($P<0.05$) big sagebrush production. Production in burned treatments ranged from 0 to 431 kg/ha while production in unburned treatments ranged from 346 to 1182 kg/ha. This decrease in production following fire was evident up to 32 growing seasons following fire. It is interesting that the Wyoming big sagebrush-dominated site that had significantly greater canopy cover and density in burned treatments still had lower production in burned treatments.

Herbaceous Understory Cover

Herbaceous understory responses to fire were quite variable and site specific. Idaho fescue was greater in some burned treatments and greater in some unburned treatments. This is likely related to burn intensity. Perennial grass canopy cover was similar in burned and unburned treatments. This supports the claim that perennial grass' increase following fire is generally short-lived. Both the 2-growing season burn and 32 growing season burn had very similar perennial grass canopy cover in burned and unburned treatments. Likewise, perennial forb cover was similar between burned and unburned treatments.

Soil and rock cover was significantly greater ($P<0.05$) in burned treatments. Burned treatments at all 13 sites had more soil and rock exposed to weathering. This suggests that burning can have long-term impacts not only on the vegetation but also on the soil. Soils that have no cover may be more susceptible to erosion. Litter cover was significantly greater in unburned treatments. This was expected given the combustion of surface litter following fire. This difference in litter cover was still evident 16 growing seasons after burning.

Conclusions

I studied the population dynamics of big sagebrush communities at 13 different sites in southwest Montana. With each site having an environmentally paired burned and unburned treatment, comparisons were made between treatments. Burning decreased mountain big sagebrush canopy cover, density, and production. Burning decreased Wyoming big sagebrush canopy cover and production while density was variable. Burning decreased litter accumulation, increased soil and rock exposed, and had few long-term effects on Idaho fescue, perennial grasses, or perennial forbs.

Historically, burning has been prescribed for its short-term benefits, with little long-term monitoring of the plant community ever occurring. My results show that the shrub component used so extensively by wildlife populations can take longer than 30 years to establish pre-burn conditions with. No short or long-term benefits to grasses or forbs were evident. Managers must clearly define their management goals prior to burning, determine what species the management action is aimed at, and clearly outline the long-term costs and benefits.

LITERATURE CITED

References Cited

Allen, M.F., E.B. Allen, and N.E. West. 1987. Influence of parasitic and mutualistic fungi on *Artemisia tridentata* during high precipitation years. Bull. Torrey Bot. Club. 114: 272-279.

Antos, J.A., B. McCune, and C. Bara. 1983. The effect of fire on an ungrazed western Montana grassland. The American Midland Naturalist. 110: 354-364.

Arno, S.F., and G.A. Gruell. 1983. Fire history at the forest-grassland ecotone in southwest Montana. J. Range Manage. 36: 332-336.

Arno, S.F., and G.A. Gruell. 1986. Douglas fir encroachment into mountain grasslands in southwest Montana. J. Range Manage. 39: 272-276.

Bartolome, J.W., and H.F. Heady. 1978. Ages of big sagebrush following brush control. J. Range Manage. 31: 403-406.

Bayless, S.R. 1969. Winter food habits, range use, and home range of antelope in Montana. J. Wildl. Manage. 33: 538-551.

Beetle, A.A. 1960. A study of sagebrush- section Tridentatae of *Artemisia*. Wyo. Agr. Exp. Sta. Bull. 368. 83 p.

Bentz, J.A., and P.M. Woodard. 1988. Vegetation characteristics and bighorn sheep use on burned and unburned areas in Alberta. Wildl. Soc. bull. 16: 186-192.

Billbrough, C.J., and J.H. Richards. 1993. Growth of sagebrush and bitterbrush following simulated winter browsing: mechanisms of tolerance. Ecology. 74: 481-492.

Blaisdell, J.P., R.B. Murray, and E.D. McArthur. 1982. Managing intermountain rangelands- sagebrush grass ranges. USDA Forest Serv. Gen Tech. Rep. INT-134.

Booth, G.D., B.L. Welch, and T.L.C. Jacobson. 1990. Seedling growth rate of three subspecies of big sagebrush. J. Range Manage. 43: 432-436.

Braun, C.E., T. Britt, and R.O. Wallestad. 1977. Guidelines for maintenance of sage grouse habitats. Wildl. Soc. Bull. 5: 99-106.

Brown, J.C., R.A. Evans, and J.A. Young. 1985. Effects of sagebrush control methods and seeding on runoff and erosion. J. Range Manage. 38: 195-199.

Campbell, G.S., J.D. Jungbaver Jr., K.L. Bristow, and R.D. Hungerford. 1995. Soil temperature and water content beneath a surface fire. Soil Science. 159: 363-373.

Canfield, R.H. 1941. Application of the line interception method in sampling range vegetation. J. of Forestry. 39: 388-394.

Caprio, J.M., D.I. Cooksey, J.S. Jacobsen, G.A. Nielsen, and R.R. Roche. 1994. MAPS Atlas- A land and climate information system. Extension Bull. 125, Montana State University, Bozeman.

Castrale, J.S. 1982. Effects of two sagebrush control methods on non-game birds. J. Wildl. Manage. 46: 945-952.

Christiansen, T.A. 1996. Terrestrial litter invertebrate communities in Yellowstone National Park. Yellowstone Sci. 2-3.

Conrad, C.E., and C.E. Poulton. 1966. Effects of a wildfire on Idaho fescue and bluebunch wheatgrass. J. Range Manage. 19: 138-141.

Cook, C.W., and L. A. Stoddart. 1960. Physiological responses of big sagebrush to different types of herbage removed. J. Range Manage. 13: 14-16.

Cook, J.G., T.J. Hershey, and L.L. Irwin. 1994. Vegetative response to burning on Wyoming mountain-shrub big game ranges. J. Range Manage. 47: 296-302.

Cook, S.F., Jr. 1959. The effects of fire on a population of small rodents. Ecology. 40: 102-108.

Creamer, W.H. 1991. Prediction of available forage production of big sagebrush. M.S. Thesis. Montana State University, Bozeman. 73 pp.

Crowley, C.M., and J.W. Connelly. 1996. Sage grouse population and habitat trends in southeastern Idaho and southwestern Montana. Idaho Dept. of Fish and Game, Pocatello.

Crowner, A.W., and G.W. Barrett. 1979. Effects of fire on the small mammal component of an experimental grassland community. J. Mammal. 60: 803-813.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science. 33: 43-64.

Daubenmire, R. 1968. Ecology of fire in grasslands. Advan. in Ecol. Res. 5: 209-266.

Ferguson, C.W. 1964. Annual rings in big sagebrush (*Artemisia tridentata*). Papers of the lab of tree rings. Res. University of Arizona Press. Tucson. Page 95.

Fraas, W.W., C.L. Wambolt, and M.R. Frisina. 1992. Prescribed fire effects on a bitterbrush-mountain big sagebrush-bluebunch wheatgrass community. *In*: Bedunah, D., Wambolt, C.L., McArthur, E.D., Compilers. Proceedings-Symposium on ecology and management of riparian shrub communities. USDA Forest Service General Technical Report, INT-289. Ogden, UT.

Fraas, W.W. 1991. Bitterbrush growth and reproduction characters in relation to browsing levels in southwest Montana. Master's thesis, Montana State University, Bozeman. 137 pp.

Frischknecht, N.C., and M.F. Baker. 1972. Voles can improve sagebrush rangelands. J. Range Manage. 25: 466-468.

Gates, D.H. 1964. Sagebrush infested by leaf defoliating moth. J. Range Mange. 17: 209-210.

Green, J.S., and J.T. Flinders. 1980. Habitat and dietary relationships of the pygmy rabbit. J. Range Manage. 33: 136-142.

Hall, D.B., S.B. Monson, and V.J. Anderson. 1995. Influence of herbaceous understory on native shrub recruitment. Rangelands. 17: 12-14.

Harniss, R.O., and R.B. Murray. 1973. 30 years of vegetal change following burning of a sagebrush-grass range. J. Range Manage. 26: 322-325.

Houston, D.B. 1973. Wildfires in northern Yellowstone National Park. Ecology. 54: 1111-1117.

Humphrey, L.D. 1984. Patterns and mechanisms of plant succession after fire on *Artemisia*-grass sites in southeastern Idaho. Vegetatio. 57: 91-101.

Johnson, J.R., and G.F. Payne. 1969. Sagebrush reinvasion as affected by some environmental influences. J. Range Manage. 21: 209-213.

Johnson, W.M. 1969. Life expectancy of sagebrush control in central Wyoming. J. Range Manage. 22: 177-182.

Klebenow, D.A. 1970. Sage grouse versus sagebrush control in Idaho. J. Wildl. Manage. 23: 396-400.

Kufeld, R.C. 1973. Foods eaten by the Rocky Mountain elk. J. Range Manage. 26: 106-112.

Laycock, W.A. 1979. Management of sagebrush. Rangelands 1: 207-210.

McArthur, E.D., A.C. Blauer, and S.C. Sanderson. 1988. Mule deer induced mortality of mountain big sagebrush. J. Range Manage. 41: 114-117.

McNeal, A.F. 1984. Site characteristics and effects on elk and mule deer use of the Gardiner winter range, Montana. M.S. thesis. Montana State University, Bozeman. 133 pp.

Meyer, S.E., and S.B. Monsen. 1992. Big sagebrush germination patterns: subspecies and population differences. J. Range Manage. 45: 87-93.

Miller, R.F., T.J. Svejcar, and N.E. West. 1994. Implications of livestock grazing in the Intermountain sagebrush region: plant composition. *In*: Ecological implications of livestock herbivory in the West. ed. Vavra, Laycock, and Pieper. Society for Range Management.

Mueggler, W., and W.L. Stewart. 1980. Grassland and shrubland habitat types of western Montana. USDA Forest Serv. Intermountain Forest and Range Exp. Sta. Gen. Tech. Rep. INT-66, Ogden, Utah.

NOAA. 1993-1995. Climatological data annual summary, Montana. ISSN 0145-0395. Dept. Commerce, National Oceanic and Atmospheric Adm. (NOAA)

Owens, M.K, and B.E. Norton. 1992. Interactions of grazing and plant protection on basin big sagebrush. J. Range Manage. 45: 257-262.

Patten, D.T. 1969. Succession from sagebrush to mixed conifer forest in the Northern Rocky mountains. Amer. Midl. Natur. 82:229-240.

Peek, J.M., R.A. Riggs, and J.L. Lauer. 1979. Evaluation of fall burning on bighorn sheep winter range. J. Range Manage. 32: 430-432.

Personius, T.L., C.L. Wambolt, J.R. Stephens, and R.G. Kelsey. 1987. Crude terpenoid influence on mule deer preference for sagebrush. J. Range Manage. 40: 84-88.

Peterson, J.G. 1995. Ecological implications of sagebrush manipulation. A literature review. MT Dept. Fish, Wildl., Parks. 49 p.

Pringle, W.L. 1960. The effect of a leaf feeding beetle on big sagebrush in British Columbia. J. Range Manage. 13: 139-142.

Ratzlaff, T.D., and J.E. Anderson. 1995. Vegetal recovery following wildfire in seeded and unseeded sagebrush steppe. J. Range Manage. 48: 386-391.

Richards, J.H., and M.M. Caldwell. 1987. Hydraulic lift: substantial nocturnal water transport between soil layers of *Artemisia tridentata* roots. Oecologia. 73: 486-489.

Ross, R.L., and H.E. Hunter. 1976. Climax vegetation of Montana. Bozeman, MT. USDA, Soil Conservation Service. 64 p.

Schultz, L.M. 1984. Comparative leaf anatomy of sagebrush: ecological considerations. *In*: Proceedings- symposium on the biology of *Artemisia* and *Chrysothamnus*. U.S Dept. Agr. For. Ser.

Spowart, R.A., and N.T. Hobbs. 1985. Effects of fire on diet overlap between mule deer and mountain sheep. J. Wildl. Manage. 49: 942-946.

Striby, K.D., C.L. Wambolt, R.G. Kelsey, and K.M. Havstad. 1987. Crude terpenoid influence on in vitro digestibility of sagebrush. J. Range Manage. 40: 244-248.

Sturges, D.L. 1983. Long-term effects of big sagebrush control in vegetation and soil water. J. Range Manage. 36: 760-765.

Sturges, D.L. 1993. Soil-water and vegetation dynamics through twenty years after big sagebrush control. J. Range Manage. 46: 161-169.

Walker, B.H. 1993. Rangeland ecology: understanding and managing change. Ambio. 22: 80-87.

Wambolt, C.L., and G.F. Payne. 1986. An 18 year comparison of control methods for Wyoming big sagebrush in S.W. Montana. J. Range Mange. 39: 314-319.

Wambolt, C.L., W.H. Creamer, and R.J. Rossi. 1994. Predicting big sagebrush winter forage by subspecies and browse form class. J. Range Manage. 47: 231-234.

Wambolt, C.L., and M.J. Watts. 1996. High stocking rate potential for controlling Wyoming big sagebrush. *In* Proceedings: shrubland ecosystem dynamics in a changing environment. Gen. Tech. Rep. INT-GTR-338. U.S. Dept. Agr. For. Ser.

Watts, M.J. and C.L. Wambolt. 1989. Economic evaluation of Wyoming big sagebrush (*Artemisia tridentata*) control methods. Weed Technology. 3: 640-645.

Watts, M.J., and C.L. Wambolt. 1996. Long-term recovery of Wyoming big sagebrush after four treatments. J. Environmental Manage. 46: 95-102.

Welch, B.L., and E.D. McArthur. 1979. Variation in winter levels of crude protein among *Artemisia tridentata* subspecies grown in a uniform garden. J. Range Manage. 32: 467-469.

Welch, B.L., and D.L. Nelson. 1995. Black stem rust reduces big sagebrush seed production. J. Range Manage. 48: 398-401.

West, N.E., and M.A. Hassan. 1985. Recovery of sagebrush-grass vegetation following wildfire. J. Range Mange. 38: 131-134.

Willms, W., and A. McLean. 1976. Spring forage selection by tame mule deer on big sagebrush range, British Columbia. J. Range Manage. 31: 192-198.

Whisenant, S.G. 1989. Changing fire frequencies on Idaho's Snake River Plains: ecological and management implications. *In*: Proceedings- Symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management. April 1989.

Wright, H.A., and A.W. Bailey. 1982. Fire ecology, United States and southern Canada. John Wiley and Sons, Inc. N.Y.

Young, J.A., and R.A. Evans. 1974. Population dynamics of green rabbitbrush in disturbed big sagebrush communities. J. Range Manage. 27: 127-132.

Young, J.A., and R.A. Evans. 1978. Population dynamics after wildfire in sagebrush grasslands. J. Range Manage. 31: 283-289.

Young, J.A., R.A. Evans, and D.E. Palmquist. 1989. Big sagebrush (*Artemisia tridentata*) seed production. Weed Science. 27: 47-53.

APPENDIX

Table 5. Mountain big sagebrush canopy cover (%).

Site	Burned	Unburned	P<x
Wise R. South	0	8.7	0.0001
Wise R. West	3.5	12.7	0.0011
Wise R. North	4.2	13.4	0.0001
Wise R. East	2.9	15.4	0.0001
Sawmill Ck.	0.64	16.9	0.0001
West Fork	0	18.2	0
Badger Pass	3.7	28.3	0.0001
Snowline	0	22.9	0.0002
Steep Mtn.	0.47	12.9	0.0001
Jeff Davis	3.1	24	0.0001

Grouped t-test P<0.000001.

Table 6. Wyoming big sagebrush canopy cover (%).

Site	Burned	Unburned	P<x
Wise R. South	0	0.88	0.016
Wise R. West	0.54	3	0.0002
Wise R. North	0.27	1	0.047
Wise R. East	0	1.4	0.039
Wisdom Flat	11.1	11.6	0.387
Wisdom Slope	13.4	13.9	0.359
Sawmill Ck.	0	3.8	0.001
West Fork	0	4.1	0
Badger Pass	0	1.6	0.025
Exclosure	9.1	12.6	0.045

Grouped t-test P<0.001

Table 7. Total big sagebrush cover (%).

Site	Burned	Unburned
Wise R. South	0	9.6
Wise R. West	4	15.6
Wise R. North	4.5	14.4
Wise R. East	2.9	16.7
Wisdom Flat	11.1	11.6
Wisdom Slope	13.4	13.9
Sawmill Ck.	0.64	20.8
West Fork	0	22.3
Badger Pass	3.7	29.9
Snowline	0	22.9
Exclosure	9.1	12.6
Steep Mtn.	0.47	12.9
Jeff Davis	3.1	24

Table 8. Mountain big sagebrush adult density (plants/m2

Site	Burned	Unburned	P<x
Wise R. South	0.0167	0.645	0.0002
Wise R. West	0.236	1.05	0.0001
Wise R. North	0.172	1.11	0.0001
Wise R. East	0.125	0.547	0.0001
Sawmill Ck.	0.025	0.933	0
West Fork	0	0.988	0.0001
Badger Pass	0.22	1.08	0.0001
Snowline	0	1.01	0.0001
Steep Mtn.	0.0922	0.788	0.0001
Jeff Davis	0.155	1.14	0.0001

Grouped t-test P<.0000001

Table 9. Total big sagebrush density (plants/m2).

Site	Burned	Unburned
Wise R. South	0.189	1.21
Wise R. West	0.74	1.85
Wise R. North	1.08	1.89
Wise R. East	1.04	0.89
Wisdom Flat	1.98	1.75
Wisdom Slope	3.96	2.49
Sawmill Ck.	0.255	1.72
West Fork	0	1.46
Badger Pass	0.298	1.53
Snowline	0.364	1.68
Exclosure	1.79	1.69
Steep Mtn.	0.122	0.972
Jeff Davis	0.244	1.34

Table 10. Mountain big sagebrush juvenile density (pl/m2)

Site	Burned	Unburned	P<x
Wise R. South	0.136	0.45	0.0009
Wise R. West	0.445	0.547	0.1593
Wise R. North	0.728	0.645	0.2508
Wise R. East	0.875	0.272	0.0002
Sawmill Ck.	0.228	0.578	0.0029
West Fork	0	0.2	0
Badger Pass	0.0778	0.363	0.0002
Snowline	0	0.328	0.0001
Steep Mtn.	0.0305	0.183	0.0021
Jeff Davis	0.0888	0.2	0.0078

Grouped t-test P<.1159

Table 11. Wyoming big sagebrush adult density (plants/m2).

Site	Burned	Unburned	P<x
Wise R. South	0	0.08	0.0002
Wise R. West	0.025	0.195	0.0007
Wise R. North	0.0583	0.106	0.0515
Wise R. East	0.00283	0.0472	0.0003
Wisdom Flat	0.783	1.01	0.0106
Wisdom Slope	1.66	1.14	0.0006
Sawmill Ck.	0	0.161	0.001
West Fork	0	0.247	0
Badger Pass	0	0.075	0.0001
Exclosure	0.992	0.92	0.234

Grouped t-test P<.2641

Table 12. Wyoming big sagebrush juvenile density (pl/m2)

Site	Burned	Unburned	P<x
Wise R. South	0.0362	0.0278	0.256
Wise R. West	0.0389	0.0583	0.184
Wise R. North	0.117	0.0445	0.0104
Wise R. East	0.0417	0.025	0.073
Wisdom Flat	0.967	0.967	0.5
Wisdom Slope	2.3	1.35	0.0001
Sawmill Ck.	0.00278	0.0472	0.003
West Fork	0	0.0278	0.0003
Badger Pass	0	0.000185	0.118
Exclosure	0.795	0.766	0.457

Grouped t-test P<.164

Table 13. Big sagebrush winter forage production (kg/ha).

Site	Burned	Unburned
Wise R. South	3.7	907.6
Wise R. West	49.8	1035
Wise R. North	33.2	859.6
Wise R. East	2.34	613.6
Wisdom Flat	165.2	345.8
Wisdom Slope	154.9	396.9
Sawmill Ck.	2.9	1164.9
Snowline	0	1136.5
Exclosure	430.7	783
Steep Mtn.	79.9	666.5
Jeff Davis	139.2	1182

Table 14. Soil and rock exposed (%).

Site	Burned	Unburned	P<x	OverallP<
Wise R. South	10.2	1.75	0.001	0.000522
Wise R. West	26.3	4.31	1E-05	
Wise R. North	6.83	0.67	0.004	
Wise R. East	5.07	0.08	0.11	
Wisdom Flat	26.8	12.9	0.006	
Wisdom Slope	25.8	4.75	3E-06	
Sawmill Ck.	1.5	0	0.083	
West Fork	2.83	1.75	0.521	
Badger Pass	29.9	7.08	2E-07	
Snowline	5.08	3.67	0.53	
Exclosure	57.5	52.5	0.351	
Steep Mtn.	36.3	24.9	0.03	
Jeff Davis	28.3	12.2	5E-05	

Table 15. Litter cover (%).

Site	Burned	Unburned	P<x	Overall P<x
Wise R. South	38	44.6	0.7284	0.02587
Wise R. West	6.33	37.4	3E-09	
Wise R. North	22.5	27.4	0.2654	
Wise R. East	30.1	19.6	0.0135	
Wisdom Flat	8.75	16.8	0.0092	
Wisdom Slope	18.8	35.6	3E-05	
Sawmill Ck.	13.8	7.75	0.0509	
West Fork	12.8	20.4	0.0384	
Badger Pass	7.5	22	7E-07	
Snowline	29.7	34.9	0.143	
Exclosure	11	11.4	0.868	
Steep Mtn.	16.8	21.5	0.16	
Jeff Davis	21.8	33.3	0.003	

Table 16. Idaho fescue canopy cover (%).

Site	Burned	Unburned	P<x	OverallP<
Wise R. South	10	5.82	0.0283	0.0877
Wise R. West	19.3	21.8	0.5411	
Wise R. North	10.2	5.41	0.1119	
Wise R. East	3	0.58	0.2746	
Wisdom Flat	6.08	14.1	0.0008	
Wisdom Slope	4.75	7.67	0.1653	
Sawmill Ck.	9	8.75	0.9315	
West Fork	9.92	14.75	0.103	
Badger Pass	7.33	14.8	0.0011	
Snowline	13.6	17.3	0.1425	
Exclosure	7.33	7	0.855	
Steep Mtn.	0	9.75	0.0001	
Jeff Davis	14.4	39.5	0.0001	

Table 17. Perennial grass canopy cover (%).

Site	Burned	Unburned	P<x	OverallP<
Wise R. South	54.7	36	0.03493	0.9071
Wise R. West	44.2	30.1	0.0906	
Wise R. North	32.7	20.8	0.0358	
Wise R. East	46.5	44.9	0.7085	
Wisdom Flat	44.3	52.2	0.2959	
Wisdom Slope	47	61.7	0.0827	
Sawmill Ck.	59.9	51.6	0.4192	
West Fork	49.6	46.8	0.776	
Badger Pass	43.2	45.5	0.697	
Snowline	48.7	58.1	0.1732	
Exclosure	16.3	20.9	0.143	
Steep Mtn.	38.8	40	0.9584	
Jeff Davis	35.9	48.6	0.135	

Table 18. Perennial forb canopy cover (%).

Site	Burned	Unburned	P<x	OverallP<
Wise R. South	24.2	17.5	0.3945	0.48185
Wise R. West	34.4	30.9	0.7247	
Wise R. North	44.3	44.9	0.9547	
Wise R. East	24.5	36.3	0.0429	
Wisdom Flat	21.3	27.3	0.2985	
Wisdom Slope	15.3	7.49	0.0131	
Sawmill Ck.	31.7	43.2	0.0963	
West Fork	40.7	35.2	0.4461	
Badger Pass	18.2	28.7	0.0874	
Snowline	10.8	6.91	0.147	
Exclosure	0	0	1	
Steep Mtn.	1.83	4.25	0.1112	
Jeff Davis	1.25	4	0.045	