

THE INFLUENCE OF DOUGLAS-FIR AND ROCKY MOUNTAIN JUNIPER
ON WYOMING AND MOUNTAIN BIG SAGEBRUSH COVER IN
SOUTHWEST MONTANA

by

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ABSTRACT

Expansion of conifers into sagebrush steppe is a management concern, since conifers reduce sagebrush cover for wildlife. The primary objective of this research was to examine the relationship between the conifers, Douglas-fir (*Pseudotsuga menziesii*) and Rocky Mountain juniper (*Juniperus scopulorum*), and two subspecies of big sagebrush, Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*) and mountain big sagebrush (*Artemisia tridentata* spp. *vaseyana*), in southwest Montana using a best-fit model. A secondary objective was to determine whether either of the two conifer species have a greater influence on sagebrush cover.

Percent cover of both conifers and sagebrush was recorded at 40 Wyoming and 40 mountain big sagebrush plots at each of three study sites in southwest Montana ($n = 240$). The best-fit model utilizes the terms site, sagebrush subspecies, $\sqrt{\text{conifer cover}}$ and site by sagebrush subspecies as the independent variables, with $\sqrt{\text{sagebrush cover}}$ as the dependent variable. The model ($\sqrt{\text{sagebrush cover}} = a_i - 0.401\sqrt{\text{conifer cover}}$; $r^2 = 0.61$) found a negative relationship between conifer cover and sagebrush cover and indicates that there is no difference between the two sagebrush subspecies and across all three sites in the study area. The best-fit model was validated within the 95 % confidence interval at all three study sites. Validation trials with data from three sites outside the study area were successful for one site, suggesting that the model is better suited to lower elevation, less productive sites. There was no difference in the influence of Douglas-fir or Rocky Mountain juniper cover on live sagebrush cover, indicating that sagebrush responds similarly to competition from both species.

Controlling both conifers may increase sagebrush cover slightly, but responses will be small due to low levels of initial sagebrush cover. If maintenance of sagebrush cover is desired, conifer control should be initiated before conifer cover reaches 10 %, since the rate of sagebrush decline is highest at low levels of conifer cover. However, conifer control is not recommended because both conifers and sagebrush are important components of big game winter range.

INTRODUCTION

Conifer expansion is a major ecological topic in the intermountain west (Knight 1994). Sometimes referred to as conifer invasion or encroachment, conifer expansion is the increase in aerial extent or cover of conifer species within areas currently occupied by shrub steppe or grassland ecosystems (Romme et al. 2009).

The range of conifers has been expanding and contracting throughout the west over the past 12,000 years in response to climatic changes (Miller and Wigand, 1994). However, the rate of conifer expansion over the last 150 years has been unprecedented (Miller and Wigand 1994). Not only does climate have an impact, but increased grazing and decreased fire frequencies during the same period are correlated with conifer expansion and are considered likely causes (Miller and Rose 1999). On the other hand, increasing expansion in many places may reflect recovery from fire or cutting prior to, or concurrent with European settlement, or may simply be the natural expansion of conifer species at the edge of their range (Romme et al. 2009).

Regardless of the causes of expansion, conifer cover can impact species composition and therefore habitat within the forest/shrub steppe ecotone. This ecotone is particularly important winter range for elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*), providing both food and cover (Knight 1994). The common shrub within this zone, big sagebrush (*Artemisia tridentata* Nutt.), provides nutrition for many other mammal and bird species, hundreds of insects, and several species of fungi, parasitic vascular plants and lichens (Welch and Criddle 2003). Additionally, the deep roots of big sagebrush can absorb water which is unavailable to other plants and redistribute it into the upper, drier

layers of the soil through the process of hydraulic lift (Caldwell and Richards 1989).

Because of the many benefits of big sagebrush, as well as the loss and fragmentation of big sagebrush habitat across its range, managers often seek to conserve sagebrush (Knick et al. 2003).

Mountain big sagebrush (*Artemisia tridentata* Nutt. spp. *vaseyana*) and Wyoming big sagebrush (*A. t.* Nutt. spp. *wyomingensis*) can both be found at the forest/shrub steppe boundary (Kitchen and McArthur 2007); therefore, increases in conifer cover can impact both of these subspecies. Mountain and Wyoming big sagebrush occur within different ecological niches, respond differently to disturbance and are utilized differently by wildlife; therefore it is conceivable that they respond differently to increasing conifer cover.

While other studies have found a decrease in sagebrush cover with increasing conifer cover (Blackburn and Tueller 1970, Miller et al. 2000, Grove et al. 2005), I could not find any reports which tested whether there was a differential influence of conifer cover on different sagebrush species or subspecies. Also, few studies have included Wyoming big sagebrush in their analysis of conifer expansion (Rowland et al. 2008). Additionally, much of the recent research on conifer encroachment has focused on western juniper (*Juniperus occidentalis* Hook.; Burkhardt and Tisdale 1976, Miller et al. 2000, Coultrap et al. 2008, Johnson and Miller 2008, Rowland et al. 2008). Belsky (1996) describes a common attitude towards western juniper as that of an “invading weed.” The bias of these reports on western juniper may influence the management of different juniper species in other areas.

While conifer encroachment is a wide-ranging issue, solutions require a regional or local perspective. Species composition, habitat uses and management objectives differ throughout the area impacted by the expansion of conifers. In southwest Montana for example, the conifer species commonly found to be expanding into sagebrush habitat are Douglas-fir (*Pseudotsuga menziesii*(Mirb.) Franco) and Rocky Mountain juniper (*Juniperus scopulorum* Sarg.). Additional information as to the combined impacts of these two conifers on both mountain and Wyoming big sagebrush will provide information for land managers in southwest Montana as they consider controlling conifers. There has been very little research on the expansion of Rocky Mountain juniper and limited research on the impacts of Douglas-fir on sagebrush. While Grove (1998) analyzed the effects of Douglas-fir cover on mountain big sagebrush, my study builds on Grove's research by including the combined influence of Rocky Mountain juniper and Douglas-fir on the cover of both Wyoming and mountain big sagebrush.

Therefore, the primary objective of this research was to quantify the combined effects of Rocky Mountain juniper and Douglas-fir canopy cover on the live canopy cover of both Wyoming and mountain big sagebrush in order to build a best-fit model to predict the effects of increasing conifer cover on sagebrush cover. The model was then tested to see how well it predicted the observed response of sagebrush to differing levels of conifer cover. This research also tested the null hypotheses that (1) there is no difference in the relationship between total conifer cover and the cover of Wyoming or mountain live sagebrush, and (2) there is no difference in the influence of Rocky Mountain Juniper cover or Douglas-fir cover on the cover of live sagebrush.

Additionally, percent live sagebrush cover when the influence of conifer cover was minimal was compared between the Wyoming and mountain big sagebrush communities, and dominant grass associations for each plot were identified.

LITERATURE REVIEW

Sagebrush Habitat

Sagebrush habitat comprises millions of hectares throughout the west. However, authoritative estimates vary widely from 43 (Knick et al. 2003) to 60 (Beetle 1960) to 109 million hectares (Wambolt and Frisina 2002), with big sagebrush found throughout most of this area (Welch 2005). The great variability in these estimates reflects different definitions of what constitutes a sagebrush habitat or a bias against big sagebrush (Welch 2005). Sagebrush habitat in Montana is extensive and covers at least 13 million hectares (Beetle 1960; Küchler 1970; Morris et al. 1976).

Big Sagebrush

Big sagebrush cover provides many ecological and wildlife benefits (Peterson 1995, Welch 2005). Ecological benefits include erosion control, protecting understory vegetation from grazing, capturing snow, improving soil fertility and recycling deep soil moisture through the process of hydraulic lift (Peterson 1995). Big sagebrush communities provide habitat, including food and cover for 95 bird species and 90 species of mammal (Welch 2005).

Big Sagebrush as Wildlife Habitat: A large number of diverse species feed directly on big sagebrush including large and small mammals, birds, insects, fungi, parasitic vascular plants and lichens (Welch and Criddle 2003). In fact, greater sage-grouse (*Centrocercus urophasianus*), sage thrasher, (*Oreoscoptes montanus*), sage

sparrow (*Amphispiza belli*), Brewer's sparrow (*Spizella breweri*) and pygmy rabbits (*Brachylagus idahoensis*) all have an obligate association with big sagebrush, which means they require big sagebrush to complete their life cycle (Welch 2005).

Sagebrush steppes are also important winter range for big game providing both food and cover (Knight 1994). While year-round habitat is essential for elk and mule deer, the availability and condition of winter range are critical for managing sustainable herds (Knight 1994).

About half the winter and spring diet of mule deer can consist of sagebrush (Hansen and Reid 1975). On Yellowstone's Northern Range, big sagebrush made up 52 percent of the winter diet of mule deer (Wambolt 1996). Dietz and Nagy (1976) suggest that the protein level in winter maintenance diets of mule deer should not go much below 8 percent. Only a limited number of plants meet this dietary requirement during the winter and most of these are evergreen or semi-evergreen shrubs such as sagebrush (Dietz and Nagy 1976). While protein levels of grasses and forbs declines to 3 to 4 percent, and deciduous shrubs to 5 to 9 percent, evergreen shrubs can contain levels of 7 to more than 10 percent (Dietz and Nagy 1976). Studies in Colorado showed that of common shrub species, only big sagebrush contained over 10 percent crude protein during the winter (Dietz 1972).

Elk also utilize big sagebrush as a dietary component throughout the year, and based on a review of studies, Kufeld (1973) considers big sagebrush a highly valuable browse plant for elk during fall and winter. Big sagebrush can compose 5 to 20 percent of the fall and winter diet of elk (Kufeld et al. 1973). Rocky Mountain bighorn sheep (*Ovis*

canadensis) utilize big sagebrush as well. Keating et al. (1985) found 6 to 20 percent big sagebrush in winter diets of bighorn sheep populations in the upper Yellowstone Valley.

In addition to nutrition, big sagebrush provides nesting, hiding and escape cover for wildlife (Peterson 1995). For example, 42 percent of newborn elk within a forest/shrub steppe ecotone were found in big sagebrush while only 33 percent were in timber and 25 percent on the edge of sagebrush and timber (Johnson 1951). Upland birds including sage-grouse, sharp tailed grouse (*Tympanuchus phasianellus*), pheasants (*Phasianus colchicus*), and chuckar (*Alectoris chuckar*) utilize big sagebrush for nesting and escape cover (USDA, NRCS 2009).

Big Sagebrush and Hydraulic Lift: Hydraulic lift is the process in which a deep-rooted plant absorbs water from lower soil levels and releases some of it to the upper, drier layers of soil (Horton and Hart 1998). The water released into the upper soil layers is then available to shallow rooted plants. An experiment with big sagebrush illustrates this concept (Ryel et al. 2002). The deep-root tips of big sagebrush were exposed to deuterated water, and within 24 hours the deuterated water was detected in the xylem of nearby crested wheatgrass (*Agropyron cristatum* (L.) Gaertn).

It is estimated that as much as 20 percent of the water used by non-big sagebrush plants may come from the hydraulic lift of big sagebrush (Ryel et al. 2002). The role of big sagebrush in supplying water to the upper soil layers may be essential in maintaining cover of herbaceous species. Herbaceous cover can be a critical habitat component for wildlife such as sage-grouse since succulent forbs are considered a key component of brood rearing habitat (Connelly et al. 2000).

Differences between Big Sagebrush Subspecies

As recently as 1980, shrubland habitat types in western Montana did not differentiate between the subspecies of big sagebrush (Mueggler and Stewart 1980). However, literature since that time has indicated that Wyoming big sagebrush and mountain big sagebrush inhabit different ecological sites, (Frisina and Wambolt 2004), respond differently to disturbance (Baker 2006, Lesica et al. 2007), and are utilized differently by wildlife (Wambolt 1996).

Environmental Site Differences for Wyoming and Mountain Big Sagebrush

Wyoming big sagebrush occurs on the most xeric sites, compared to other big sagebrush subspecies (Frisina and Wambolt 2004). Mountain big sagebrush requires more mesic locations and is usually found at higher elevations where precipitation is greater (Frisina and Wambolt 2004). Wyoming big sagebrush communities generally receive 20-30 cm annual precipitation, whereas mountain big sagebrush sites have annual precipitation over 35 cm (USDA, NRCS 2009).

Wyoming big sagebrush is often found on shallow soils containing large amounts of clay or silt (Frisina and Wambolt 2004). The NRCS Plant Guide (USDA, NRCS 2009) states that mountain big sagebrush occurs on moderately deep, to deep, well drained soils. However, Frisina and Wambolt (2004) state that moisture required by mountain big sagebrush is usually obtained from greater precipitation rather than deeper soils. Differences have been noted in A horizon soils where mountain big sagebrush

communities had deeper A horizons than Wyoming big sagebrush communities in northern Nevada (West et al. 1978)

Differences in cover values can relate to the productivity potential of a community (Goodrich and Huber 2001). Percent cover of mountain big sagebrush ranges from 20-40 % and from 15-35 % for Wyoming big sagebrush based on literature from the Intermountain West (Kitchen and McArthur 2007). Mean cover values of 15% for Wyoming and 28% for mountain big sagebrush have been recorded in southwest Montana (Lesica et al. 2007). There are also differences in understory cover between Wyoming and mountain big sagebrush communities. Goodrich and Huber (2001) reported 55-59 % ground cover in Wyoming sagebrush, whereas groundcover in mountain big sagebrush was 90 %. While differences in cover are likely a factor of differences in precipitation, they indicate that productivity levels are generally lower in Wyoming than mountain big sagebrush communities.

Wyoming and Mountain Big Sagebrush Response to Fire

Mountain big sagebrush and Wyoming big sagebrush are both killed as a flame front passes over them, even in low severity fires (Baker 2006). Recovery of big sagebrush following fire is from seed which falls close to the parent plant (Baker 2006). Extrapolating fire rotation data from previous research across sagebrush landscapes, Baker (2006) determined that Wyoming and mountain big sagebrush have different recovery rates following fire. While studies on recovery rates of Wyoming big sagebrush are limited, Baker (2006) suggests, full recovery takes 50 to more than 120 years, whereas his estimate of 35-100 years for recovery in mountain big sagebrush is

somewhat quicker. In southwest Montana, Lesica et al. (2007) found that while sagebrush cover in mountain big sagebrush stands returned to pre-fire levels in 32 years, none of the Wyoming big sagebrush sites had recovered more than 5 percent even after 23 years (Lesica et al. 2007). Mean fire intervals, or the average number of years between fire events, are different for big sagebrush subspecies as well. Kitchen and McArthur (2007) estimate the mean fire interval of 40-80 years for mountain big sagebrush and some productive Wyoming big sagebrush communities. On the other hand, most Wyoming big sagebrush communities likely have a mean fire interval of 100-200 or more years (Kitchen and McArthur 2007).

Differential Utilization by Wildlife

Differential utilization of subspecies of big sagebrush has been noted for wildlife. Elk and mule deer preferred mountain big sagebrush as a winter forage followed by Wyoming big sagebrush over basin big sagebrush (*Artemisia tridentata* Nutt. ssp. *tridentata*) and black sagebrush (*Artemisia nova* A. Nels.) in southwest Montana (Wambolt 1996). Greater sage-grouse also prefer mountain big sagebrush over Wyoming big sagebrush (Welch et al. 1991).

Loss of Sagebrush Habitat

Sagebrush habitat is one of the most imperiled ecosystems in North America (Noss and Peters 1995). Approximately 50 percent of historical sagebrush habitat has been permanently altered by plowing, chaining, reseeding, prescribed and wild fire, agriculture, urbanization and other human developments (Harrington 2002, Welch 2005).

Roads, natural resource development, pipelines and powerlines have fragmented much of the remaining sagebrush habitat and provide corridors for the invasion of exotic species (Knick et al. 2003). Additionally, the spread of conifers into sagebrush steppe is an important management topic throughout the Intermountain West (Knight 1994, Belsky 1996, Miller et al. 2008), as well as in Montana (Patten 1969, Arno and Gruell 1986, Powell and Hansen 2007). While conifer encroachment does not account for the greatest loss to sagebrush habitat, it does occur at an important transitional zone between forest and shrublands. This area is particularly important as winter range for elk and mule deer (Constan 1972, Grover and Thompson 1986, Knight 1994).

Importance of the Forest/Sagebrush Steppe Ecotone

Ecotones, or transitions between one ecosystem and another, are often high use areas for wildlife since they provide a diversity of habitats. Bird species diversity is often associated with increased structural diversity of plant communities (Cody 1981). Elk and mule deer spend much of the period from November to April concentrated on winter ranges within or near the forest/shrub steppe ecotone (Knight 1994). Though year-long habitat is essential, wildlife biologists generally agree that availability and condition of winter range is essential for managing sustainable herds (Knight 1994).

Rocky Mountain Juniper as Wildlife Habitat: Bird species richness, diversity and evenness in a shrub/western juniper forest ecotone are highest in shrub steppe/juniper and old growth juniper compared to shrub steppe and grassland communities (Reinkensmeyer

et al. 2007). Juniper woodlands are particularly important to cavity nesting species (Reinkensmeyer et al. 2007).

Juniper is a valuable winter forage for both mule deer and elk. Juniper is one of the primary components of mule deer winter diets (MacCracken and Hansen 1981). Smith (1959) found that mule deer left livestock pellets and alfalfa hay to feed on Utah juniper and big sagebrush when these were placed in their pens in a winter feeding situation. Rocky Mountain juniper is utilized by elk, especially during winter when it is considered a valuable browse species (Kufeld 1973).

Douglas-Fir as Wildlife Habitat: Douglas-fir forests provide nesting habitat and food sources for a variety of birds (Manuwal 1983). They are also important winter habitat for ungulates because they have a relatively low snowpack, abundant shrubs and hiding cover. Mule deer in Gallatin Canyon in southwest Montana were observed more frequently in open Douglas-fir vegetation types while elk were observed feeding in sagebrush habitat, but retreated to Douglas-fir and lodgepole vegetation types after feeding (Constan 1972). In spring, an important criterion of feeding sites for elk is the distance to nearby cover (Grover and Thompson 1986).

Conifer Expansion

Conifers have been expanding into sagebrush and grassland habitats in the western U.S. for the past 150 years (Arno and Gruell 1986, Miller et al. 2008). Prior to European settlement, western juniper was mainly confined to rocky ridges (Arno and Gruell 1986, Miller and Rose 1999). Since 1860, the area occupied by juniper or pinyon

species (*Pinus* spp. L.) has increased 140-625 percent in the central and northern Great Basin (Miller et al. 2008). Throughout the west, much research on conifer expansion has focused on juniper and pinyon species, including western juniper (Burkhart and Tisdale 1976, Miller and Rose 1999, Coultrap et al. 2008, Johnson and Miller 2008, Rowland et al. 2008), Utah juniper (*Juniperus osteosporum* (Torrey) Little) and pinyon (Blackburn and Tueller 1970, Weisberg et al. 2007), and Utah and Rocky Mountain juniper (Sankey and Germino 2008).

Conifer Expansion in Montana

Rocky Mountain juniper is the dominant juniper species occurring in southwest Montana, and although it is the most widespread of 11 native species, there is not much information concerning the expansion of Rocky Mountain juniper, though it is mentioned as a component or minor component of expanding forests in Montana by Sindelar (1971), Hansen et al. (1995), and Powell and Hansen (2007). Rocky Mountain juniper is often found in association with other trees, rather than in pure stands (Sudworth 1915). In southwest Montana, Rocky Mountain juniper is found in association with Douglas-fir.

Douglas-fir is often the dominant conifer at the forest/shrubland boundary in southwest Montana. Expansion of Douglas-fir into sagebrush steppe or grasslands in southwest Montana has been documented by Sindelar (1971), Arno and Gruell (1983) Heyerdahl et al. (2006) and Powell and Hansen (2007).

Causes of Conifer Expansion

The range of conifers has been expanding and contracting in the west over the past 12,000 years in response to climatic changes (Miller and Wigand 1994). In some areas conifer density and range have decreased due to cutting, insects and drought (Powell and Hansen 2007, Romme et al. 2009). However, in many areas, the rate of expansion during the past 150 years has been unprecedented (Miller and Wigand 1994). Several factors working independently or synergistically to increase the range and density of conifers have been identified. The three most probable causes include: (1) climatic variability, (2) reduced fire frequencies, and (3) livestock grazing (Blackburn and Tueller 1970, Romme et al. 2009).

Climatic Changes: Since changes in climate affected the range of conifer forests in the past it is logical to assume that climate continues to mediate the range of juniper woodlands. The expansion of juniper in the late 19th century may be associated with warmer temperatures following the end of the Little Ice Age (Miller and Wigand 1994). Forest margins can be particularly sensitive to climate changes because they occur at the transition zone between mesic forests and more xeric plant communities (Romme et al. 2009). Sindelar (1971) and Arno and Gruell (1983) attributed pulses in the expansion of conifer to favorable moisture conditions for seed germination.

Reduced Fire Frequencies: Reduced fire frequencies are attributed to livestock grazing which reduces fine fuels, fire suppression and a cessation of ignitions by Native Americans (Arno and Gruell 1986). Fire scar dating indicates that fires on the Owyhee

Plateau in southwest Idaho were frequent prior to European settlement, but much less frequent in the century following settlement because of fire suppression, development of roads and other barriers to fire spread, and heavy livestock grazing, as well as a trend towards decreased precipitation which reduced fine fuels (Burkhardt and Tisdale 1976). However, fire scars are rare in pinyon – juniper woodlands, and there is almost no direct evidence that frequent low intensity fires maintained shrub steppes or open woodlands (Baker and Shinneman 2004). Additionally, long recovery times for Wyoming big sagebrush following fire suggest that fire return intervals in many sagebrush areas were of long duration (Baker 2006, Kitchen and McArthur 2007).

Livestock Grazing: “Coincidence in time between the onset of grazing and increasing tree density suggests a direct cause-effect relationship,” (Romme et al. 2009). Aside from the impact on fine fuels, livestock grazing can reduce herbaceous cover competition with tree seedlings (Johnsen 1962) as well as increase the density of shrubs which serve as nurse plants for tree seedlings (Sindelar 1971, Soulé et al. 2004). Livestock grazing can increase the probability of woody plant establishment in several ways, including: preferential feeding on herbaceous vegetation which decreases competition, enhancing woody plant seed dispersal and reducing soil fertility due to the loss of vegetative cover and resulting erosion (Archer 1994). However, grazing pressure may not be the main driver of tree establishment in many areas. Studying tree expansion under a range of grazing pressure, Sankey et al. (2006) could make no consistent conclusions regarding the effects of grazing.

Increases in Atmospheric Carbon Dioxide and Nitrogen: Carbon dioxide levels have been increasing over the past 200 years (Miller et al. 1994). Several authors hypothesize that increasing carbon dioxide levels have contributed to conifer expansion since levels have increased by 30% since the Industrial Revolution (Belskey 1996). Archer (1994) argues against this hypothesis since CO₂ levels had only increased 11 percent at the beginning of expansion in the late 1800s. Higher CO₂ levels increase water use efficiency in plants by reducing transpirations rates (Farquhar 1997) so junipers can spread into more xeric locations than they had in the past (Bradley and Fleishman 2008). However species other than conifers can benefit from increasing CO₂ levels. Honey mesquite (*Prosopis glandulosa* Torr. var *glandulosa*), a woody plant expanding into grasslands in the Southwest, responded to increased CO₂ with increased water use efficiency and greater root biomass when tested in isolation. However, when grown with grass, honey mesquite had no response to increased CO₂ levels (Polley et al. 1994). Atmospheric nitrogen from air pollution has also been mentioned as a possible factor in the expansion of juniper (Tausch 1999).

Regeneration Following Fire or Cutting: In many areas, conifer woodlands do not contain trees pre-dating European settlement. These forested areas therefore represent either (1) expansion into areas that were previously treeless, or (2) reforestation following cutting or burning (Baker and Shinneman 2004). Samuels and Bentacourt (1982) modeled the impacts of fuelwood cutting in pinyon-juniper woodlands and suggest these woodlands were severely reduced by Native Americans. Early mining activities

throughout the west also contributed to severely cleared forests so timber could be used for mine props and charcoal production (Tausch et al. 1981).

Natural Range Expansion: Romme et al. (2009) suggest that the spread of pinyon and juniper near the limits of their current geographical range may simply represent a long-term expansion process rather than an unnatural (or human-induced) invasion of non-wooded habitats. As an example, Utah juniper has expanded into new mountain ranges in Wyoming and Montana over the past 1000 years as well as expanded its range where it was already established (Lyford et al. 2003). Additionally, packrat middens and pollen deposits indicate that the range of pinyon and juniper has been expanding (and contracting) in the Great Basin since the Holocene (approximately 12,000 years ago; Miller and Wigand 1994).

Rates of Conifer Expansion

Rates of conifer expansion reported in the literature show significant variation. In the Greater Yellowstone Ecosystem including part of southwest Montana, average annual rates varied from 0.22 to 0.51 percent per year (Powell and Hansen 2007). Pinyon-juniper increased 11 to 33 percent in central Nevada between 1966 and 1995 (Weisberg et al. 2007). This is an annual rate of 0.37 to 1.1 percent. Rocky Mountain and Utah juniper increased 22 to 33 percent between 1985 and 2005 in southeast Idaho, which is an annual rate between 0.7 and 1.5 percent per year (Sankey and Germino 2008). The highest juniper expansion rate of 4.5 percent per year was reported for western juniper in southwest Idaho (Strand et al. 2006).

Variable expansion rates have been attributed to topographic features including slope, elevation and aspect (Bai et al. 2004, Powell and Hansen 2007). The literature agrees that expansion occurs more readily on less steep slopes (Soulé et al 2003, Bai et al. 2004). However, there is some discrepancy in the literature as to which elevation and aspect conifer expansion is most likely to occur. Some research suggests that greater expansion rates occur at lower elevations (Powell and Hansen 2007, Weisberg et al. 2007, Bradley and Fleishman 2008), while other researchers have found greater expansion rates at mid-elevations (Bai et al. 2004, Sankey and Germino 2008) or higher elevations (Johnson and Miller 2006). Reported aspects having higher expansion rates have varied as well, including southern (Bai et al. 2004, Johnson and Miller 2006, Bradley and Fleishman 2008), western (Sankey and Germino 2008) and northern (Powell and Hansen 2007, Weisberg et al. 2007).

Variation in conifer expansion rates have been attributed to other factors as well. Higher rates of conifer expansion have been located in areas with higher rather than lower disturbance from grazing (Soulé et al. 2003, Sankey and Germino 2008) and low density or younger woodlands rather than mature woodlands (Soulé et al. 2003, Powell and Hansen 2007, Weisberg et al. 2007). Sankey and Germino (2008) reported that expansion into shrub communities was faster than into grasslands. The scale of the study can be an important determinant as well. The expansion rate of pinyon-juniper measured at the single tree scale (20 m²) was three times higher than that measured on an ecotone scale (0.4 ha scale) within the same community (Weisberg et al. 2007). Therefore, it is

not surprising that the highest expansion rate identified (4.5 percent per year, Strand et al. 2006) was recorded for a relatively small area of 15 hectares.

Effects of Conifer Expansion on Sagebrush

Conifer expansion into sagebrush steppe communities has raised concerns over the effects of increasing tree canopy cover on understory vegetation. Several studies have focused on the effects of juniper cover on sagebrush communities. Tausch and West (1995) studied the effects of pinyon pine and Utah juniper canopy cover on understory vegetation in southwestern Utah. They found a linear decrease in average shrub crown area with increasing tree dominance. Coultrap et al. (2008) also defined the relationship between western juniper and shrub cover with a negative linear function. The predominant shrub in this study was big sagebrush, but no subspecies was identified. Similarly, western juniper cover in central Oregon had a negative correlation with the cover of all taxa of sagebrush (Rowland et al. 2008).

A strong curvilinear relationship ($r^2 = 0.92-0.96$) exists between the canopy cover of western juniper and the cover of mountain big sagebrush within different plant associations in northeastern California and southeastern Oregon (Miller et al. 2000). The rate of decrease in sagebrush cover was highest as juniper cover increased from 0 to 15 percent. When juniper canopies reached 50% of maximum woodland cover, the sagebrush cover had declined to 80% of maximum potential in all three mountain big sagebrush/grass associations studied.

A similar relationship between Douglas-fir canopy cover and mountain big sagebrush cover was recorded by Grove et al. (2005) in southwest Montana. On sites with no, or occasional Douglas-fir, mountain big sagebrush cover generally exceeded 20 percent. When Douglas-fir canopy cover increased to 20 percent, sagebrush cover decreased below 15 percent, and as Douglas-fir canopy cover increased above 35 percent sagebrush cover declined below 5 percent (Grove et al. 2005).

Research Justification

This study builds on other research by including two common conifer species found in the forest/shrubland ecotone in southwest Montana. Management of Rocky Mountain juniper within this ecotone based on our knowledge of western juniper may not be appropriate. Additionally, the response of both Wyoming and mountain big sagebrush to conifer cover is included in this study since both subspecies are found within in the forest/shrubland ecotone in southwest Montana as well as other areas in the Great Basin (Kitchen and McArthur 2007, Rowland et al. 2008). Knowledge of how both subspecies of big sagebrush respond to conifer cover, and whether there is a different response to different conifer species can help land managers make more informed management decisions concerning this critical habitat.

RESEARCH METHODS AND MATERIALS

Study Area

The study area was located in southwestern Montana, with two study sites in Jefferson County and one in Broadwater County (Fig. 1). The three sites were situated on the foothills and mountain slopes of the northern Rocky Mountains east of the Continental Divide. The sites were selected because they have varying densities of Rocky Mountain juniper and Douglas-fir grading into communities of Wyoming big sagebrush and mountain big sagebrush within the forest/shrub steppe ecotone.

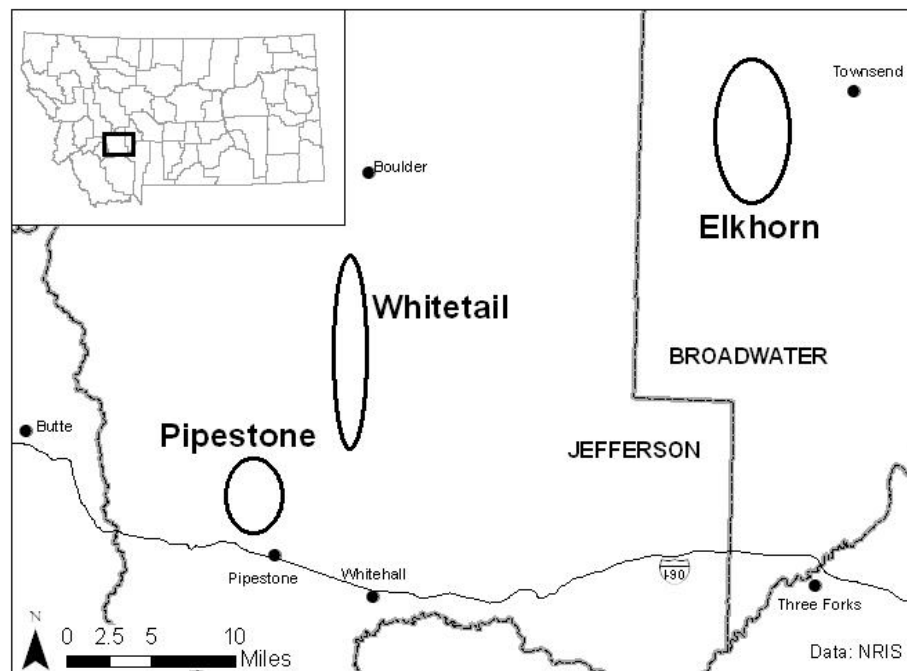


Figure 1. Location of the Elkhorn, Pipestone and Whitetail study sites in Jefferson and Broadwater counties, Montana.

Climate

The climate in southwest Montana east of the divide has a continental weather pattern with cold, dry winters, warm summers and the majority of precipitation occurring between May and September. Climate is similar at all three sites based on the three closest weather stations (WRCC 2010). Average annual precipitation at Townsend, MT (elev. 1170m), Whitehall, MT (elev. 1329m), and Boulder, MT (elev. 1497m) is 27.2, 26.0, and 28.1cm, respectively. However, elevation has a large impact on precipitation and actual precipitation at the study sites likely ranged from 30 to 50cm. Precipitation occurs mainly during the summer months, May through September with the highest amount of precipitation falling in June.

Average annual maximum temperatures range from 56.8°C at Boulder and 58.0°C at Townsend to 59.9°C at Whitehall. Average annual minimum temperatures at Boulder, Townsend and Whitehall are 28.1, 30.5 and 30.7°C, respectively. Average annual maximum and minimum temperatures at the study sites are likely slightly lower than those recorded at the lower elevation weather stations.

Elkhorn Site

The Elkhorn site is located on the east flank of the Elkhorn Mountains approximately 10-15 km west and southwest of the town of Townsend, Montana (Fig. 1). Location of plots were scattered across the landscape from the Iron Mask area west of Townsend to 1 km north of Crow Creek Campground. Latitude and longitude ranged from 46°14'N to 46°21'N and from 111°38'W to 111°43'W, respectively. The elevation

of study plots within the Elkhorn site ranges between 1456 and 1889 meters. Most plots were located on lands administered by the Helena National Forest, though some plots were on Bureau of Land Management (BLM) lands and on private parcels within the Helena National Forest.

The Elkhorn Mountains are comprised of sedimentary rocks overlain by volcanic rocks. Parent material at the Elkhorn site includes Paleozoic and Mesozoic sedimentary rocks as well as Upper Cretaceous volcanic rocks (Klepper et al. 1971). Soils include cobbly loams and extremely stony loams (USDA, NRCS 2010).

Pipestone Site

The Pipestone site is located approximately 4-12 km north of Pipestone, MT in the Pipestone Off Road Vehicle (ORV) Area (Fig. 1). Latitudes range between 45°56'N and 46°00'N and longitudes range from 112°14'W to 112°18'W. Elevation varies from 1538 to 1817 m. The lower elevations of the Pipestone ORV area are administered by the BLM and upper elevations by the Beaverhead-Deerlodge National Forest. Private lands within the area were not utilized.

The Pipestone ORV Area sits at the southern end of the Boulder Batholith. The Boulder Batholith is comprised of intrusive igneous rock formed during the Late Cretaceous time (Johnson et al. 2004). The rock is granite, mainly in the form of quartz monzonite and granodiorite (Smedes et al. 1968). Rock outcroppings are common in this area. (USDA, NRCS 2010).

Whitetail Site

The Whitetail site is located between Whitehall, MT and Boulder, MT on the west side of Whitetail Basin (Fig. 1). Plots were scattered along the narrow forest/shrub boundary with the southern plots located approximately 16 km north of Whitehall near Pony Springs, and the most northern plot about 8 km south of the town of Boulder near Bigfoot Creek. Latitudes range from 46°02'N to 46°11'N and longitudes range between 112°06'W and 112°10'W. Elevation at the Whitetail site ranges from 1582 to 1754 m. Plots were located on lands administered by the Beaverhead-Deerlodge National Forest and the BLM.

The Whitetail site is on the eastern edge of the Boulder Batholith with granitic parent material similar to that found at the Pipestone site. The southwest portion of this site also contained some Elkhorn Mountains volcanics of the Late Cretaceous age (Smedes et al. 1968). Soils are very stony with rock outcrops (USDA, NRCS 2010).

Vegetation

The study sites focused on the forest/shrubland boundary where Douglas-fir and Rocky Mountain juniper transition to sagebrush steppe. The forest/shrubland boundary is often wide with a variable density of conifers depending on topography, soils, precipitation and past disturbance. The range in elevation of the forest boundary supports both Wyoming and mountain big sagebrush as dominant understory shrubs. The elevation of the study area is near the upper end for Wyoming big sagebrush and towards the lower elevation range of mountain big sagebrush at this latitude. Habitat types (based on Mueggler and Stewart 1980) include: *Artemisia tridentata*/*Agropyron spicatum* (MONT) h.t. (big sagebrush/bluebunch wheatgrass) and *Artemisia tridentata*/*Festuca*

idahoensis (MONT) h.t. (big sagebrush/Idaho fescue) at all three sites, as well as *Artemisia tridentata/Festuca scabrella* h.t. (big sagebrush/rough fescue) at the Elkhorn site.

Field Sampling

Field measurements were recorded between August 12 and August 22, 2008 and, between May 8 and July 31, 2009. Field sampling for the Elkhorn site was completed between May 20 and June 28, 2009. Data collection at the Pipestone site was done across two field seasons: August 12 through August 22, 2008 and May 8 through July 25, 2009. Data collection at the Whitetail site occurred between June 2 and July 31, 2009.

Plot Selection

To evaluate the effects of conifer cover on sagebrush cover, eighty plots were located in each of the three study areas. Wyoming big sagebrush was the dominant understory shrub in forty of the plots, and mountain big sagebrush the dominant shrub in the other forty plots. Plots were chosen selectively to represent the full range of conifer canopy cover in each area. An attempt was made to obtain a fairly even distribution of conifer cover ranging from near 0 to the densest conifer cover possible.

Due to the multi-use nature and management activities of USFS and BLM lands, all sites had cattle grazing, some tree harvesting, old mining scars, recreational impacts such as trails and old roads, and the influence of past fires. Plots were chosen to

minimize the effects of these disturbances, although grazing did occur throughout the study area.

Plot Layout

Canopy cover and density of conifers and shrubs, understory vegetation and environmental characteristics were measured within 30 x 30 m plots (Fig. 2).

Plot Layout

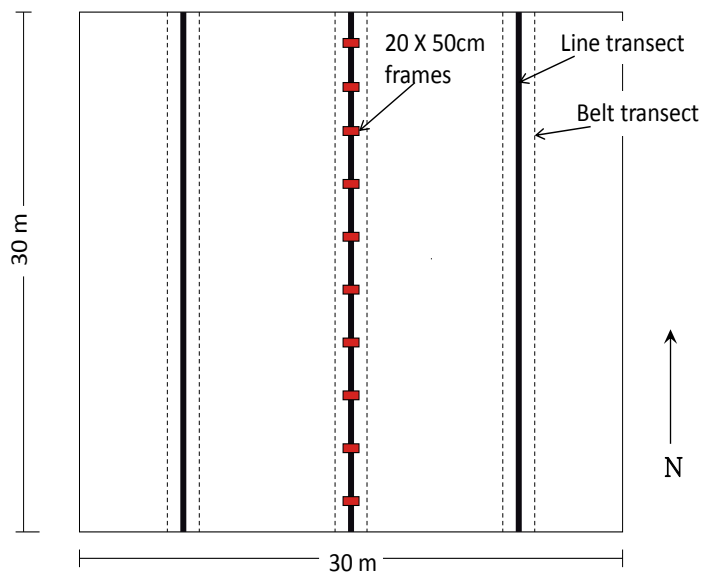


Figure 2. Plot layout for collecting vegetation and environmental data at 40 Wyoming and 40 mountain big sagebrush plots at the Elkhorn, Pipestone and Whitetail study sites in southwest Montana.

Each plot was oriented to magnetic north, with the baseline established on the southern end of the plot. Three, 30m line transects were spaced evenly across the south to north axis of the plots at 5, 15 and 25 meters along the baseline. Three, 2 x 30m belt transects were centered along the line transects for each plot. Ten, 20cm x 50cm frames were

spaced evenly along the central line transect with the base of the long end of the first frame centered at the one meter mark.

Vegetation Characteristics

Canopy Cover: Canopy cover of both conifers and shrubs was collected within the plots using the line intercept method (Canfield 1941) along the three, 30 meter transects. Gaps in canopy greater than 3cm were not included in cover measurements (Wambolt et al. 2006). Canopy cover for conifers was separated by species and whether the tree was living or dead. Total tree canopy cover included both live and dead trees since it was assumed that dead trees had impacted shrub cover. Shrub canopy was also categorized as living or dead. Shrub canopy and conifer canopy, where possible, were measured to the nearest cm using a plumb line adjacent to a tightly strung 30m tape. Tree canopies too high to measure using a plumb line were visually estimated. Canopy cover for all trees and shrubs (both living and dead) were totaled for the three transects to get the canopy cover for the plot. Canopy cover of Rocky Mountain juniper, Douglas-fir, total conifer and live sagebrush is summarized for each plot in Appendix A.

Density: Density of conifers was recorded by counting each tree within the plot. The trunk of the tree had to be within the plot to be counted. Each Douglas-fir was placed into one of four classes based on diameter at breast height (DBH) established by Arno & Gruell (1986). The four classes include seedlings (< 1m tall), saplings (< 15cm DBH), pole (15-30cm DBH) and mature (>30cm DBH). Each rocky mountain juniper was placed into classes based on basal trunk diameters (BTD) measured at ground level

near the root collar (Mueller et al. 2005). The three classes for juniper were: seedling (<3cm BTB), juvenile (3-12cm BTB) and mature (>12cm BTB). Limber pine and ponderosa pine were present in some of the plots and were classed using the same method as Douglas-fir.

The density of shrub species was recorded within the three belt transects for each plot. Shrubs were counted if their stem at ground level fell within the belt. Shrubs were categorized by species, and whether they were dead or alive. Shrubs were defined as “dead” if live cover was less than 25% of the total crown cover (Grove, 1998). Density of trees was also recorded within the belt transects. Trees and shrubs within the belt transects were not categorized by size.

Understory Composition: Understory cover including forbs, grass, and moss as well as litter, rock and bare ground were recorded within each of the ten 20 X 50cm frames for each plot. Percent of each species including rock, litter and bare ground was ocularly estimated providing a total of 100% cover in each frame. It should be noted that the herbaceous species present within the plots as well as percent cover of herbaceous species will vary throughout the season based on the ecology of the species as well as precipitation patterns. A direct comparison of species composition between sites cannot be made since data was collected on different dates and in different years. Despite this drawback, the predominant perennial grass species based on percent cover were used to designate sagebrush alliances for each plot (Davies et al. 2006). Predominant forbs based on frequency of their occurrence within plots were identified for each site/sagebrush subspecies location. A grass and forb plant list was compiled for both Wyoming and

mountain big sagebrush areas at each of the three sites (Appendix B). Nomenclature of plants follows Dorn (1984) *Vascular Plants of Montana*, where possible, or the NRCS Plants Database (USDA, NRCS 2010).

Environmental Characteristics

Latitude and longitude of each corner was recorded using a Garmin[®] GPS V. The Garmin[®] GPS V was also used to measure elevation at the southeast corner of each plot. Aspect was recorded by estimating cardinal direction and then converting to degrees. Percent slope was recorded using a Haglöf[®] electronic clinometer. Soil texture of the A horizon was evaluated within the top ten centimeters using the hand texturing method. Soil depth was measured at three locations within the plot using a 1 cm diameter soil auger pushed into the soil until it hit bedrock or unconsolidated rock fragments. The soil depth readings were averaged to get a single soil depth for each plot. Percent rock within the plot was visually estimated.

Data Analysis

Sagebrush Cover Differences between Subspecies

In order to determine whether there was a difference in live sagebrush cover between Wyoming and mountain big sagebrush communities if conifer cover was not a factor, plots with less than 2 % conifer cover were compared. Differences were determined with a t-test using PROC TTEST in SAS[®] 9.2. The significance level was set at $p \leq 0.05$. Only live sagebrush cover was used for all the analyses because live sagebrush provides the best cover and nutritional benefits to wildlife.

Relationship of Conifer Cover and Sagebrush Cover

The relationship between percent conifer cover (independent variable) and percent live sagebrush cover (dependent variable) was plotted. A best-fit line of this relationship was determined with the line fitting program XLFit[®] 5. The best-fit line was based on two factors (1) high r^2 values and (2) smoothness of the line. Charts of the relationship were generated using Microsoft Office Excel[®] 2007. The relationship was also examined at different levels of conifer cover by calculating the mean live sagebrush cover and variation around the mean using PROC MEANS in SAS[®] 9.2.

Model Development

In order to get the most accurate p-value for the model, it was important to meet the assumption of equal variance. One way to meet the assumption of equal variance is by transforming the data (Welch and Comer 1988). Since the variance of live sagebrush cover increased as mean live sagebrush cover increased, transformations within the family of Box-Cox power transformations were examined in R[®]. The square root transformation was optimal for meeting this assumption and providing a normal distribution of residuals for live sagebrush cover. Because the predictor variables, Rocky Mountain juniper, Douglas-fir and total conifer cover, were also measured on a percent cover basis, the square root transformation was done on them as well.

A full model for all sites ($n = 3$) and sagebrush subspecies ($n = 2$) was built using main effects for site, sagebrush subspecies and conifer cover. The interactions within the full model included: site by sagebrush subspecies; site by conifer cover; sagebrush

subspecies by conifer cover; and, site by sagebrush subspecies by conifer cover.

Building a full model from all site/sagebrush subspecies locations rather than individual models for each sagebrush subspecies/site combination allowed for the use of common slopes whenever the slopes were not significantly different. Therefore, the common effects, or different slopes for different sagebrush subspecies or sites could be compared. Differences were considered significant at $p \leq 0.05$.

The full model was tested with an information criterion (AIC) to see whether it could be reduced and still maintain precision (Akaike 1974). An AIC is a measure of goodness of fit of an estimated statistical model and is a tool for model selection. It provides a measure of the information lost when a particular model is used to describe a relationship. AIC is based on the concepts of parsimony (i.e. the simpler the model the better). Essentially it compares the trade-off between simplifying the model and still maintaining an adequate representation of the data (Burnham and Anderson 2002). If removing an interaction from the model reduced the AIC then that interaction was left out of the reduced model. Determination of whether to remove a term from the model was supported by analysis of F-tests to see if the inclusion of that term within the reduced model maintained precision of the model. If the F-test indicated the term was not significant ($p \leq 0.05$) that term was removed.

Two methods were used to test that the reduced model maintained similar slopes across the three sites and for both sagebrush subspecies. The reduced model was subjected to an F-test to determine whether my first null hypothesis, that the slope is the same for every site, could be rejected. Additionally, the 95% confidence intervals for

slope in the six, site by sagebrush subspecies, data sets were examined to see whether they contained common values. Slope is the important characteristic of the model because it shows the relationship between conifer cover and sagebrush cover, despite the fact that the y-intercept may be different between sites and sagebrush subspecies. The y-intercept simply describes the amount of sagebrush cover at the different sites. Therefore, the y-intercept is likely to be different due to the heterogeneous nature of sagebrush steppe landscapes and the variability of landforms, soils and precipitation patterns across the study area.

Validation

Validity of the model was examined by comparing slope estimates with internal and external data. Internal validation is a method of determining whether the model is predictive within the study area, and the external validation tests the predictive power of the model with data from outside of the study area.

Internal Validation: Internal validation was accomplished by withholding the 40 data points generated from one site/sagebrush subspecies area. The model of the remaining 200 data points from the other areas was examined to see how well it predicted the slope of the withheld points. This process was repeated six times with the 40 data points from each of the different site/sagebrush subspecies areas withheld each time.

External Validation: All 240 points from data collected in this study were used to predict the slope of the regression line of the conifer/sagebrush data collected by Grove (1998) at three other sites in southwest Montana. There were 25 data points at each of

Grove's sites which contained Douglas-fir as the conifer and mountain big sagebrush as the understory shrub. The 95% confidence interval of the slope of the reduced model was compared to the 95% confidence interval of the slope for each of Grove's three sites.

Data on mountain big sagebrush and Douglas-fir cover was collected by Grove during the summers of 1996-97. Similar techniques were used to collect mountain big sagebrush and Douglas-fir cover data from 25 plots at each of the three study areas in southwest Montana. The Sugarloaf Mountain (SLM) study area was located approximately 6 km northwest of Boulder, MT which is about 21 km north of the Whitetail site. The SLM study area is situated on the Boulder Batholith and had sandy soils. Elevation range of SLM was 1792 to 1871 meters and the aspect was predominantly east-facing. The Hells Canyon (HC) study area was located approximately 20 km northwest of Twin Bridges, MT, or about 30 km south-southwest of the Pipestone site. Parent material was intrusive igneous rock and the soils were course-loamy. Elevation ranged from 2129 to 2280 meters and the aspect was predominantly south-facing. The Medicine Lodge Peak (MLP) study area was located in Beaverhead county, approximately 24 km south of Grant, MT. The MLP is approximately 160 km south-southwest of the Pipestone site. The MLP had parent material of intrusive igneous rock and clayey soils. Elevation ranged from 2231 to 2286 meters, and the study area faced primarily to the northwest (Grove 1998).

Influence of Different Conifer Species on Live Sagebrush Cover

The reduced model was used to test my second null hypothesis that there is no difference between the influence of Rocky Mountain juniper or Douglas-fir canopy cover

on the cover of live sagebrush. This was done with two different analyses using R[®].

First, each conifer species was added back into the model to see whether the addition of either increased the AIC of the model. Second, F-tests were analyzed to determine if differences were observed in live sagebrush cover when adding each species of conifer back into the reduced model. Differences were considered significant at $p \leq 0.05$.

RESULTS

Vegetation CharacteristicsUnderstory Vegetation

Grass: Idaho fescue (*Festuca idahoensis* Elmer), bluebunch wheatgrass (*Elymus spicatus* (Pursh) Gould), prairie junegrass (*Koeleria macrantha* (Ledeb.) Schultes) and Sandberg bluegrass (*Poa secunda* Presl) were the most common grasses found throughout the study area within 91, 70, 60 and 54 % of plots respectively. Blue grama (*Bouteloua gracilis* (H.B.K.) Lag. Ex Griffiths), was common in Wyoming big sagebrush communities (59% of plots), but not in the mountain big sagebrush communities (5% of plots). Grass species identified at each Wyoming and mountain big sagebrush site are listed in Appendix B.

Grass associations, based on the grass species with the highest percent cover as recorded in the 20 X 50 cm frames, were determined for each plot. The three most common grass associations are listed in Table 1 as a percentage of plots in which they were dominant.

Table 1. Dominance of the three most commonly occurring grass species as a percentage of plots for each of the three Wyoming and mountain big sagebrush sites in southwest Montana.

Site	Sagebrush	Bluebunch Wheatgrass	Idaho Fescue	Sandberg Bluegrass
Elkhorn	Wyoming	35	18	40
Pipestone	Wyoming	60	20	20
Whitetail	Wyoming	76	13	5
Elkhorn	Mountain	10	55	10
Pipestone	Mountain	20	60	15
Whitetail	Mountain	10	83	0

Bluebunch wheatgrass was the predominant grass in 56 percent of Wyoming big sagebrush plots, while Sandberg bluegrass and Idaho fescue were predominant in 22 and 17 percent, respectively. In mountain big sagebrush communities, Idaho fescue and bluebunch wheatgrass were predominant in 66 and 13 percent of the plots, respectively.

Forbs: The most common forbs in Wyoming big sagebrush communities were fringed sagewort (*Artemisia frigida* Willd.) and pussytoes (*Antennaria* spp.) recorded in 52 and 48 % of the Wyoming plots respectively. In the mountain big sagebrush communities, pussytoes was recorded in 81 % of plots and common yarrow (*Achillea millefolium* L.) in 62 % of plots. The only non-native species occurring frequently within the study area was common dandelion (*Taraxacum officinale* Weber) which was recorded in 49 % of all plots. Forb species identified in each Wyoming and mountain big sagebrush site are listed in Appendix B.

Conifer Canopy Cover

Conifers recorded at the shrub steppe/forest interface were mostly Douglas-fir and Rocky Mountain juniper with occasional limber or ponderosa pine, especially at the Elkhorn site. The total conifer canopy cover measured along the line transects in each plot ranged from 0 to 65 percent (Table 2). Plots were selected to represent the full range of conifer cover at each site, though plots tended to have lower rather than higher conifer cover. There were 77 plots in the 0-10 % conifer cover range, 81 plots with >10-20 % cover, 41 plots with >20-30 % cover, 21 plots with >30-40 % cover and 20 plots with

>40 % cover. The conifer species with the highest cover values was Douglas-fir at all the site/sagebrush subspecies locations except for the Elkhorn Wyoming big sagebrush site.

Table 2. Highest conifer cover values recorded in the forty plots at the three Wyoming and mountain big sagebrush sites in southwest Montana.

Site	Sagebrush	Maximum Cover (%)		
		Juniper	Douglas-Fir	Total Conifer
Elkhorn	Wyoming	37	21	44
Pipestone	Wyoming	20	49	58
Whitetail	Wyoming	24	24	39
Elkhorn	Mountain	29	57	65
Pipestone	Mountain	11	49	51
Whitetail	Mountain	9	56	60

When conifer species are separated into the percentage of total conifer, the percentage of Douglas-fir is much higher in the mountain big sagebrush sites, while the percentage of Rocky Mountain juniper is much higher in the Wyoming big sagebrush sites with the exception of the Pipestone site where the percent of Douglas-fir is slightly higher (Table 3). This is likely a factor of elevation and moisture, but may also be influenced by soil and aspect as well. Note that the sum of juniper and Douglas-fir cover are slightly below or above 100 percent. Total juniper and Douglas-fir cover is less than 100 percent of the total conifer cover at the Elkhorn sites because ponderosa pine and limber pine were occasionally found within the plots at this site. Total cover of juniper and Douglas-fir at the Pipestone and Whitetail sites is slightly higher than 100 percent. This is the result of measuring overlapping juniper and Douglas-fir separately when recording individual species cover values, but removing overlapping cover values for different species when recording total conifer cover.

Table 3. Rocky Mountain juniper and Douglas-fir as a percentage of total conifer cover for all Wyoming and mountain big sagebrush sites in southwest Montana.

Site	Sagebrush	Juniper Cover as a % of Total Conifer Cover	Douglas-Fir Cover as a % of Total Conifer Cover
Elkhorn	Wyoming	70	26
Pipestone	Wyoming	48	54
Whitetail	Wyoming	70	31
Elkhorn	Mountain	48	60
Pipestone	Mountain	16	85
Whitetail	Mountain	9	93

Shrub Cover

The range of live sagebrush cover varied between the sites with maximum sagebrush cover ranging from 10 to 26 % (Table 4). Across all sites, Wyoming and mountain big sagebrush had a similar range of live sagebrush cover from 0 to 24 % and 26 %, respectively.

Table 4. Minimum and maximum percent live sagebrush cover among the forty plots at each Wyoming and mountain big sagebrush site in southwest Montana.

Site	Sagebrush	Live Sagebrush Cover Range (%)	
		Minimum	Maximum
Elkhorn	Wyoming	0	22
Pipestone	Wyoming	0	10
Whitetail	Wyoming	1	24
Elkhorn	Mountain	0	26
Pipestone	Mountain	0	15
Whitetail	Mountain	0	12

Other shrubs were recorded along the line transects but rarely added much to the total shrub cover of a plot. Two other shrubs were recorded in more than 10 percent of plots. These were rubber rabbitbrush (*Chrysothamnus nauseosus* (Pallas ex Pursh) Britt.) in 32% of plots and bitterbrush (*Purshia tridentata* (Pursh) DC.) in 12% of plots. See

Appendix B for a list of shrub species recorded for each Wyoming and mountain big sagebrush site.

Comparison of Cover Values of Sagebrush Subspecies with Minimal Conifer Influence

Live sagebrush cover was not different in mountain big sagebrush communities vs. Wyoming big sagebrush communities when the effect of conifer cover was reduced ($p = 0.6898$). Since sagebrush cover has a strong correlation with conifer cover, only plots with less than 2% conifer cover (Table 5) were compared. Mean sagebrush cover with less than 2% conifer cover was 12 and 13 percent for Wyoming and mountain big sagebrush communities, respectively.

Table 5. Comparison of sagebrush cover of Wyoming and mountain big sagebrush with less than 2% conifer cover from the study sites in southwest Montana.

Sagebrush	Live Sagebrush Cover		
	n	Mean	Standard Error
Wyoming	12	11.74 ^a	1.47
Mountain	11	12.80 ^a	2.21

^a Mean live sagebrush cover is not significantly different ($p = 0.6898$).

Variability in Sagebrush Cover at Different levels of Conifer Cover

The higher standard deviation values at 0-10 percent conifer cover indicates that there is greater variability in the amount of live sagebrush cover at lower levels of conifer cover. Conversely, there is less live sagebrush cover, but also less variability in sagebrush cover as conifer cover increases (Table 6).

Table 6. Mean and standard deviation of live sagebrush cover at varying levels of conifer cover for all 240 plots within the study area in southwest Montana.

Percent Conifer Canopy Cover	Live Sagebrush cover		
	n	Mean (% cover)	Standard Deviation
0-10	78	10.04	5.56
>10-20	81	5.94	3.48
>20-30	41	3.57	2.52
>30-40	21	2.37	2.70
>40	19	1.28	1.57

Relationship between Conifer Cover and Sagebrush Cover

There is a negative curvilinear relationship between conifer cover and live sagebrush cover. The best-fit line that represents this relationship is an exponential decay function (Fig. 3). The r^2 value of this relationship using data from all 240 plots in my study is 0.41

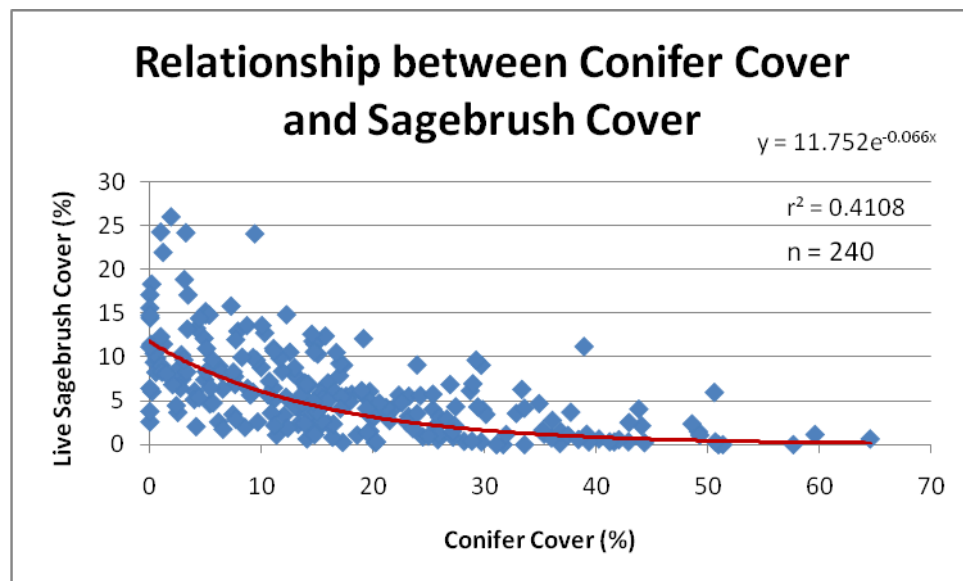


Figure 3. The best-fit line of the relationship between conifer cover and sagebrush cover using data from both Wyoming and mountain big sagebrush plots at the Elkhorn, Pipestone and Whitetail study sites in southwest Montana.

Model Development

A best fit model for the relationship between live sagebrush cover as the dependent variable and total conifer cover as the independent variable was developed by reducing the full model by as many variables as possible while still maintaining precision. The raw data for sagebrush and conifer cover was square-root transformed before developing the full model for all sites. The full model included all sites ($n = 3$) and big sagebrush subspecies ($n = 2$). Main effects for the full model were site, sagebrush subspecies and conifer. The interactions of the full model included: site by sagebrush subspecies; site by conifer cover; sagebrush subspecies by conifer cover; and, site by sagebrush subspecies by conifer cover.

An information criterion (AIC) was used to test each term to see whether it could be removed. If removing an interaction from the model reduced the AIC then that term was left out of the reduced model. The AIC of the full model was -195.45. The AIC was reduced by two units when the three-way interaction, site by sagebrush subspecies by conifer cover was removed. Removing the sagebrush subspecies by conifer interaction reduced the AIC an additional two units. While there was little change in the AIC with the removal of site by conifer, this interaction was removed, since its removal was supported by an F-test and the goal was to develop the most parsimonious model. The three terms removed (site by subspecies by conifer cover, subspecies by conifer cover and site by conifer cover) all have a p-value greater than 0.05 (Table 7). Therefore, the reduced model contains the main effects of site, sagebrush subspecies and conifer cover,

and only one interaction: site by sagebrush subspecies since these terms all had p-values less than 0.05.

Table 7. Terms removed from the full model of the relationship between total conifer cover and live sagebrush cover based on F-test results.

Term Removed	Degrees of Freedom	p-value
Site X Species X Conifer Cover	2,228	0.45
Species X Conifer Cover	1,230	0.81
Site X Conifer Cover	2,231	0.11

Slopes of the relationship between total conifer and live sagebrush cover are not different for all sites within the model. This was determined by an F-test on the reduced model to see whether the null hypothesis, that the slope is the same for every site, could be rejected ($F = 2.19$ on 2,231 df, $p = 0.12$). Therefore, I failed to reject the null hypothesis that the slope is the same for every site. Additionally, the 95% confidence intervals for slope in the six, site by subspecies, data sets were examined to see whether they contained common values (Table 8).

Table 8. Range of the 95 % confidence interval for the slope of the relationship between total conifer cover and live sagebrush cover in the Wyoming and mountain big sagebrush sites in southwest Montana.

Site	Sagebrush	95% Confidence Interval		
		Lower	Estimated	Upper
Elkhorn	Wyoming	-0.54	-0.42	-0.29
Pipestone	Wyoming	-0.54	-0.42	-0.30
Whitetail	Wyoming	-0.52	-0.38	-0.24
Elkhorn	Mountain	-0.59	-0.48	-0.36
Pipestone	Mountain	-0.51	-0.41	-0.31
Whitetail	Mountain	-0.40	-0.28	-0.16

The confidence intervals of all, site by sagebrush subspecies, locations contain common values from approximately -0.40 to -0.36. This also indicates that the slopes of the line

representing the affects of square-root conifer cover on sagebrush cover are not different across the three sites and for both subspecies.

The model is fit for both sagebrush subspecies at all sites, so the slope (-0.4006296) is the same for each line with SE 0.02461. However, the y-intercept is different for each site/sagebrush subspecies location (Table 9). The y-intercept is the modeled square-root of sagebrush cover when there is no conifer cover. For example, the y-intercept 3.86 at the Elkhorn Wyoming site indicates that the model predicts a live sagebrush cover of $(3.86)^2$ or 14.90% when conifer cover is zero. The models for the Wyoming (Fig. 4) and mountain big sagebrush communities (Fig. 5) are presented separately to reduce the confusion of having all six lines presented on one graph.

Table 9. Y-intercept and standard error of the relationship between total conifer cover and live sagebrush cover for each of the three Wyoming and mountain big sagebrush sites in southwest Montana.

Site	Sagebrush	y-intercept	Standard Error
Elkhorn	Wyoming	3.86	0.13
Pipestone	Wyoming	3.01	0.14
Whitetail	Wyoming	3.86	0.13
Elkhorn	Mountain	4.43	0.14
Pipestone	Mountain	4.02	0.15
Whitetail	Mountain	3.61	0.14

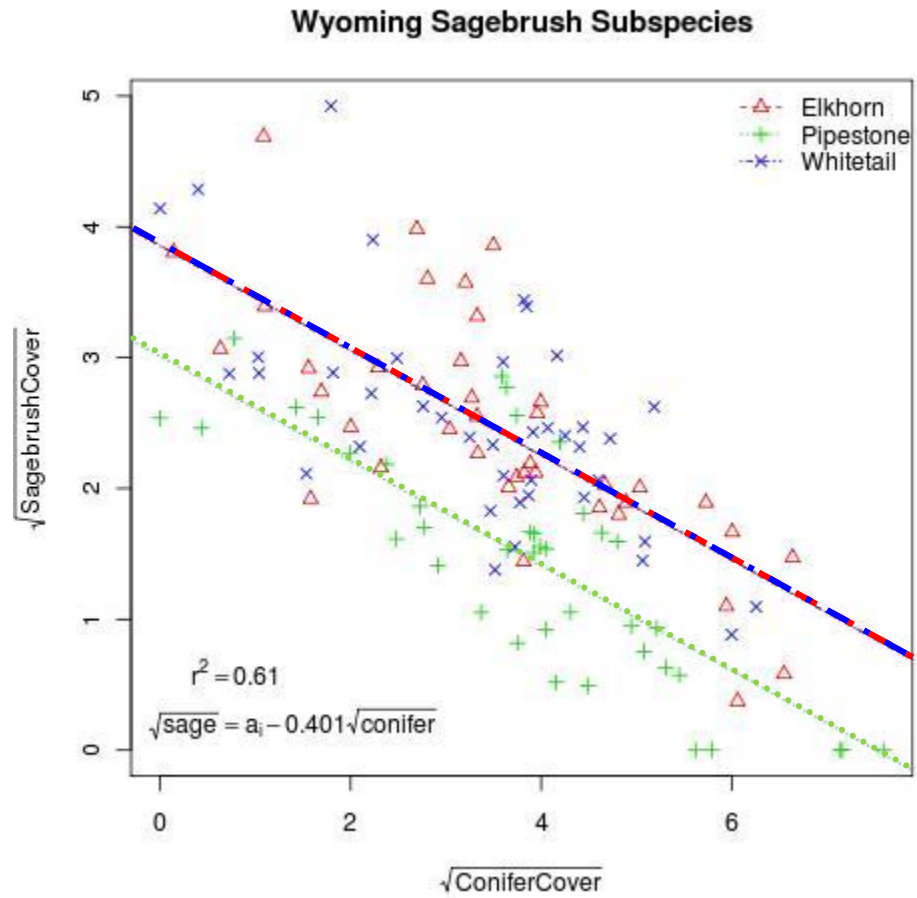


Figure 4. The best-fit model of the relationship between total conifer cover and live sagebrush cover for the Elkhorn, Pipestone and Whitetail study sites in southwest Montana.

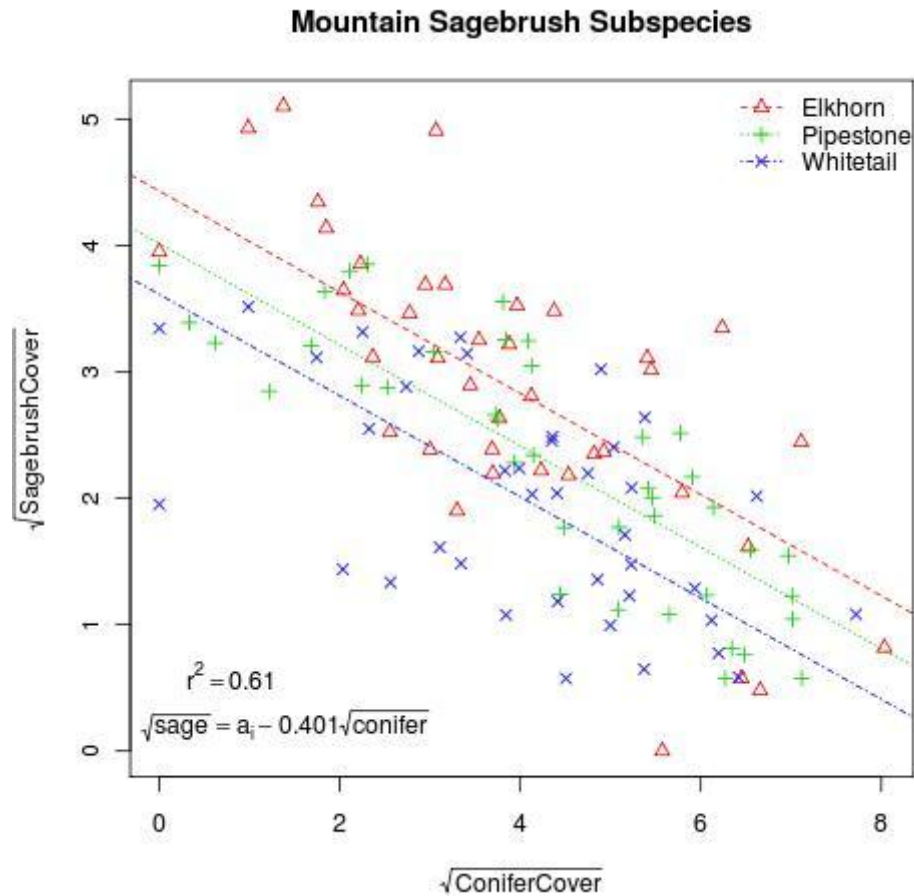


Figure 5. The best-fit model of the relationship between total conifer cover and live sagebrush cover for the Elkhorn, Pipestone and Whitetail study sites in southwest Montana.

Model Validation

The important aspect of the model is the negative slope of the linear relationship between the predictor (square-root conifer cover) and response (square-root live sagebrush cover) variables. The intercepts are not important for validation since they simply indicate the average sagebrush cover at each site and between each sagebrush subspecies, and are expected to vary. Therefore, validity of the model was examined by

comparing slope estimates using data collected during this study (internal validation), and data collected previously from three sites in southwest Montana (external validation).

Internal Validation

The model is a good predictor of the cover relationship between conifer and live sagebrush at all six site/sagebrush subspecies combinations within the study area. For all six locations, the regression line of the 200 predictor plots falls within the 95% confidence interval of the observed plots (Fig. 6). The y-intercept of the predictive data was adjusted to best-fit the observed lines.

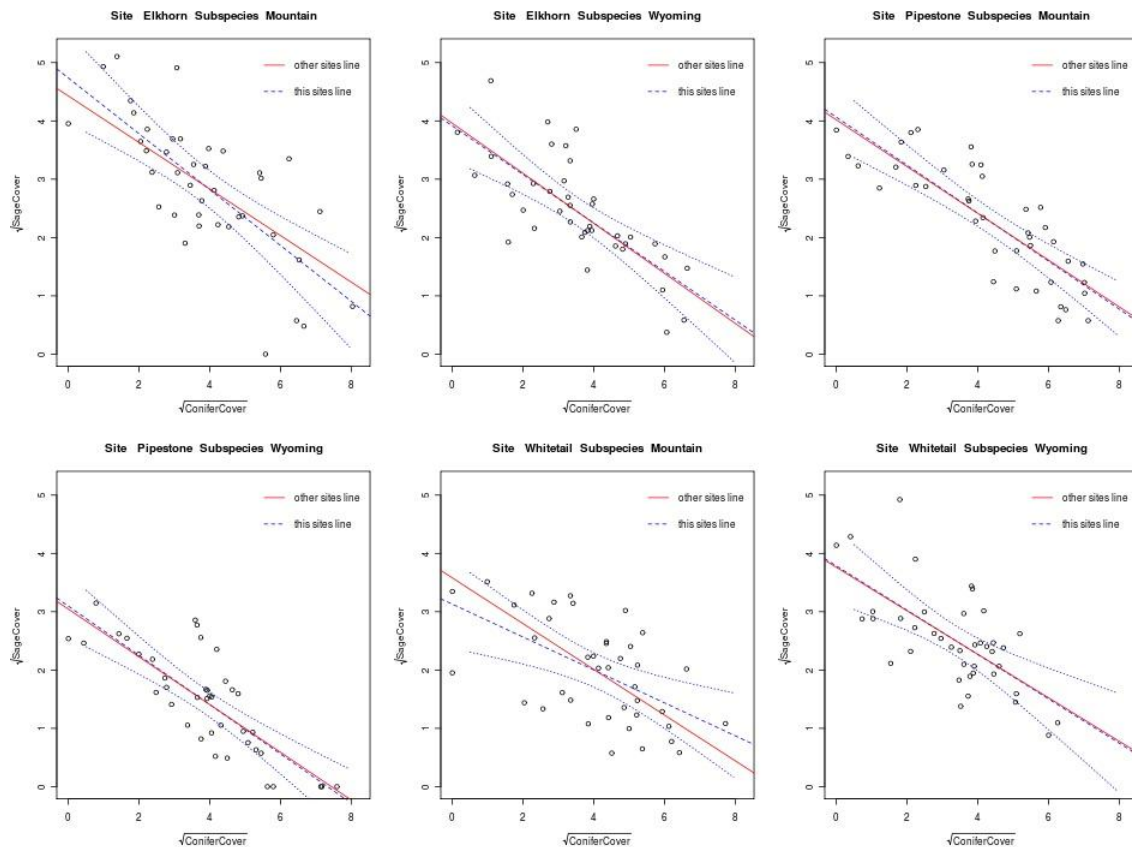


Figure 6. Regression lines of the predictive plots (red lines) and the 95 % confidence intervals of observed plots (blue lines) for all Wyoming and mountain big sagebrush sites in the study area in southwest Montana.

External Validation

Cover data from all 240 plots in this study were used to predict the relationship between Douglas-fir cover and mountain big sagebrush cover at each of Grove's (1998) study areas. The model does a good job of describing the relationship at the Sugar Loaf Mountain study area (Figure 7) since the predictive line falls within the 95% confidence interval at this site. However, my model was not as good at predicting the relationship between conifer cover and sagebrush cover at the Hells Canyon and Medicine Lodge Peak study areas since the predictive lines in these two areas are not contained within the 95% confidence interval. The y-intercept of the predictive line was adjusted to best-fit the observed lines.

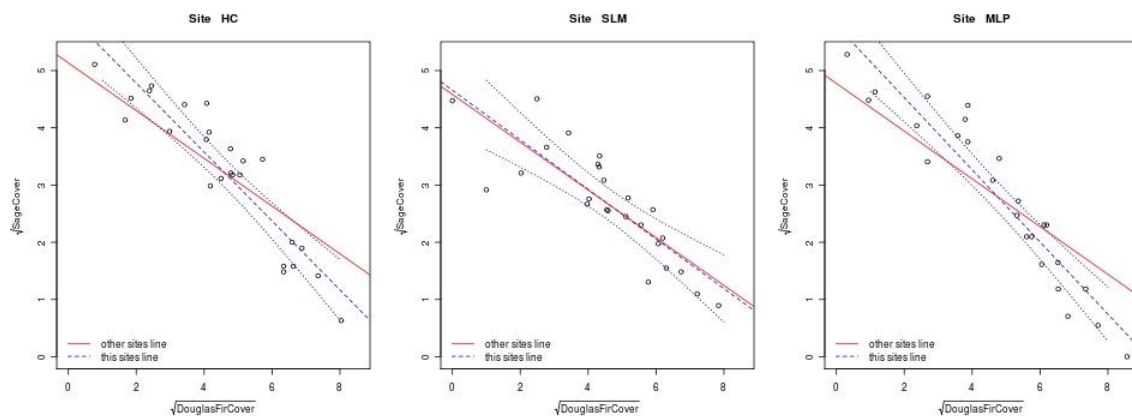


Figure 7. Regression lines of the predictive plots (red lines) are based on cover data from all 240 plots in this study and the 95 % confidence intervals and estimated slope of observed plots (blue lines) for the three study areas¹ recorded by Grove (1998) based on 25 plots at each study area.

¹ HC = Hells Canyon, SLM = Sugarloaf Mountain, and MLP = Medicine Lodge Peak.

Influence of Conifer Species on Live Sagebrush Cover

Since both Rocky Mountain juniper and Douglas-fir occur at the forest/sagebrush steppe ecotone, I wanted to determine if either species had greater influence on the

canopy cover of live sagebrush than the other. The reduced model was used to test the hypothesis that there is no difference between the influence of Rocky Mountain juniper or Douglas-fir canopy cover on the cover of live sagebrush. This was done by adding each conifer species back into the model to see whether the addition of either increased the AIC of the model. The AIC was not increased by more than 2 points by either Douglas-fir or Rocky Mountain juniper. Additionally p-values (0.07 for Douglas-fir and 0.187 for Rocky Mountain juniper) show no need to add either of these variables back into the model. Since there were no significant adverse or positive impacts when adding the conifer species back into the model, I concluded that the influence of canopy cover on sagebrush was similar for both conifer species.

DISCUSSION

This study has expanded our knowledge of the relationship between conifer cover and sagebrush cover by considering two different conifer species and both Wyoming and mountain big sagebrush. The results indicate that 61 percent of the variability in sagebrush cover in the forest/shrub steppe ecotone can be explained by the percent of conifer cover. Though little research has been done comparing Wyoming and mountain big sagebrush within the forest/shrub steppe ecotone, my findings of vegetative differences between these two communities are slightly different than other research.

Vegetative Differences between Wyoming and Mountain Big Sagebrush Communities

Collecting data from Wyoming and mountain big sagebrush communities in close proximity allowed for identification of grass associations and comparison of sagebrush canopy cover values between the two communities. Grass associations in Wyoming and mountain big sagebrush communities in my study are similar to the findings of other research. However, the low sagebrush cover values and similarity in cover between Wyoming and mountain big sagebrush in my study are atypical of other research.

Grass Associations

Community type classifications based on sagebrush taxa and dominant understory species can help characterize habitat potential and aid in management decisions (Jensen 1990). Perennial grass associations in the sagebrush alliance likely follow available soil

moisture gradients and have different potentials for supporting herbaceous production and cover (Jensen, 1990, Davies et al. 2006).

Primary grass associations in Wyoming big sagebrush communities in this study included: bluebunch wheatgrass (ARTRW/AGSP), Sandberg bluegrass (ARTRW/POSE) and Idaho fescue (ARTRW/FEID), whereas primary grass associations in mountain big sagebrush communities were Idaho fescue (ARTRV/FEID) and bluebunch wheatgrass (ARTRV/AGSP). Mueggler and Stewart (1980) classified habitat types in western Montana and recognized bluebunch wheatgrass and Idaho fescue in association with big sagebrush, but do not differentiate between subspecies of sagebrush. Reporting on the distribution of sagebrush throughout Montana, Morris et al. (1976) indicate that Wyoming big sagebrush may be associated with needle and thread (*Stipa comata* Trin. & Rupr.) on drier sites and bluebunch wheatgrass and mixed needle grass on sites with more moisture. They identified the major understory grasses in mountain big sagebrush habitats as bluebunch wheatgrass (on drier sites) as well as Idaho fescue and rough fescue (*Festuca scabrella* Torrey ex Hook.). NatureServe, a clearing house of species distributions lists five grass associations for both Wyoming and mountain big sagebrush in Montana (NatureServe Explorer 2010). Missing from this list of sagebrush/grass associations for Montana is ARTRW/FEID one of the main associations identified in this study, though it has been recognized as an association in Idaho (Davies et al. 2006) and eastern Oregon (Doescher et al. 1986).

Comparison of Cover Values of Sagebrush Subspecies

My findings that percent cover of live sagebrush is not different between Wyoming and mountain big sagebrush communities when not influenced by conifer cover does not agree with past research (Goodrich and Huber 2001, Kitchen and McArthur 2007, Lesica et al. 2007). Based on literature from the Intermountain West, Kitchen and McArthur (2007) report cover ranges for mountain big sagebrush of 20-40% and 15-35% for Wyoming big sagebrush. In southwest Montana, mean cover values of 15% for Wyoming and 28% for mountain big sagebrush were recorded (Lesica et al. 2007). Grove (1998) using similar measurement methods had mean mountain big sagebrush cover of 14.5-20.5% in plots with less than 10% Douglas-fir cover at his sites in southwest Montana.

The amount of sagebrush cover can relate to the productivity potential of the site (Goodrich and Huber 2001). Since the Wyoming and mountain big sagebrush communities at the sites in my study area were adjacent to each other, they likely have fairly similar moisture regimes and soils, so it is not surprising that sagebrush cover values would be similar between the two different subspecies.

Mean Wyoming big sagebrush cover (11.7 %) with less than 2 % conifer cover is somewhat lower than the generally reported amounts of 15-35 % (Kitchen and McArthur 2007). However, Davies et al. (2006) recorded mean a similar mean Wyoming big sagebrush cover of 12.3% in late seral stands in eastern Oregon. Mean mountain big sagebrush cover in my study area (12.8 %) was considerably lower than the often reported cover values of 20-40 % (Kitchen and McArthur 2007). Grove (1998) using

similar measurement methods recorded mean mountain big sagebrush cover of 14.5-20.5% in plots with less than 10% Douglas-fir cover at his sites in southwest Montana. A probable explanation for the low mountain big sagebrush cover values is that my study area contained relatively low elevation mountain big sagebrush communities and therefore these communities receive less precipitation and are less productive than many other mountain big sagebrush communities.

Differences in sagebrush cover are indicative of the large and heterogeneous nature of the range of big sagebrush. Even within subspecies, sagebrush cover can be influenced by soils (Davies et al. 2007), past disturbance including fire (Lesica et al. 2007), disease (Anderson and Inouye 2001) and current management practices such as livestock grazing (Goodrich and Huber 2001). Additionally, percent cover can vary greatly depending on the criteria used for measuring with the line-intercept technique (Wambolt et al. 2006). The method utilized in this study (measuring intercept with a plumb bob attached to a string rather than visual estimation, and excluding gaps in live sagebrush canopy > 3 cm) reports lower cover values than Bureau of Land Management (1996) and U. S. Forest Service (1993) methods which measure total canopy span without regard to dead foliage.

Shrub cover can be an indicator of ecological condition and resiliency (Petersen and Stringham 2008). It is also the most important variable for predicting forage production of shrubs (Wambolt et al. 1994). The amount of sagebrush cover is an important consideration for many species of wildlife. Welch (2005) reports that many animals prefer cover over 20 percent. For example, sage grouse preferentially select nest sites

under big sagebrush with canopy covers ranging from 20 to near 50 percent (Welch 2005) and pygmy rabbits (*Brachylagus idahoensis*) selectively use big sagebrush stands with higher percent cover (Katzner and Parker 1997). Sagebrush is also an important component of the winter diets of mule deer, elk and some populations of big horn sheep (Welch 2005). Therefore, maintaining adequate levels of sagebrush cover can be an important management consideration.

Relationship between Conifer Cover and Sagebrush Cover

Regression analysis detected a significant negative relationship between total conifer cover and live sagebrush cover in both Wyoming and mountain big sagebrush habitats. This is consistent with previous research in Oregon and Northern California in western juniper woodlands (Miller et al. 2000, Coultrap et al. 2008, Rowland et al. 2008), as well as in a Douglas-fir/sagebrush ecotone in southwest Montana (Grove et al. 2005). My study was different in that Wyoming and mountain big sagebrush communities were combined for analysis, while Miller et al. (2000) and Grove et al. (2005) only recorded cover values for mountain big sagebrush, Coultrap et al. (2008) do not identify the big sagebrush subspecies. However, Rowland et al. (2008) combined all sagebrush taxa in their analysis.

Coefficient of Determination Relative to Other Studies

Models of ecological relationships can help managers make predictions and informed management decisions. The larger the coefficient of determination (r^2) the greater the percentage of variation in the dependent variable is accounted for by the

independent variable (Welch and Comer 1988). Therefore, models with larger r^2 values have stronger predictive capabilities. The coefficient of determination ($r^2 = 0.61$) for my model of total conifer cover and live sagebrush cover across all site and sagebrush subspecies fell between the values of other studies. The r^2 values in my study were not as strong as those found by Miller et al. (2000; $r^2 = 0.92$ to 0.96 for western juniper and mountain big sagebrush), or Grove (1998; $r^2 = 0.67$ to 0.85 for Douglas-fir and mountain big sagebrush). Both of these studies had fewer recordings measured at low conifer cover. This would tend to increase correlation since variation in sagebrush cover tends to be higher where there is less conifer cover (Table 6).

On the other hand, the r^2 values between conifer cover and sagebrush cover in my study were higher than those reported by Coultrap et al. (2008; $r^2 = 0.12$ for western juniper and big sagebrush) and Rowland et al. (2008, $r^2 = 0.20$ for western juniper and several sagebrush species). These two studies examined conifer encroachment in a wider range of habitats and had a majority of plots with less than 10 percent conifer cover. My model also had a higher r^2 than the model developed by Petersen and Stringham (2008; $r^2 = 0.54$) who used remote sensing and geographic information systems (GIS) to estimate sagebrush cover in a juniper encroached watershed.

Model Validation

My model was a good predictor of sagebrush cover at all sites within the study area. This means that the relationship between sagebrush cover and conifer cover is similar in both Wyoming and mountain big sagebrush communities in my study area. Though the relationship between cover values of conifer and sagebrush is the same for both

Wyoming and mountain big sagebrush it is important to identify the subspecies of sagebrush within a management unit since the species can respond differently to management treatments (Bunting et al. 1987).

Model validation using data collected by Grove (1998) had mixed results. While my model was able to predict sagebrush cover within the 95% confidence interval at the Sugarloaf Mountain site, prediction values for the Hells Canyon and Medicine Lodge Peak study sites fell outside of the 95% confidence interval. Therefore, my model may have reduced accuracy outside of my study area. However, the two study areas where my model did not predict sagebrush cover as well were much higher in elevation (2129-2286 m), whereas the Sugarloaf Mountain study area fell within the elevation range of my sites. Since the Hells Canyon and Medicine Lodge Peak study areas were higher in elevation they likely received more precipitation and were therefore more productive. This suggests that my model may have greater value at low elevation, drier and less productive sites, but limited application at higher, more mesic sites with greater productivity potential.

Impacts of Different Conifer Species on Sagebrush Cover

No difference in the influence of Douglas-fir or Rocky Mountain juniper on the cover of sagebrush was detected, suggesting a similar response of sagebrush to both conifer species. However, the p-value of 0.07 for adding Douglas-fir into the model is close to the pre-determined significance level of $p \leq 0.05$, suggesting that further study

should be undertaken to determine whether Douglas-fir does have a greater influence on live sagebrush cover than Rocky Mountain juniper.

Most studies quantifying the relationship between conifer cover and sagebrush cover deal with a single species of conifer expanding into sagebrush habitat (Miller et al. 2000, Grove et al. 2005, Coultrap et al. 2008). Though Blackburn and Tueller (1970) separated cover values of pinyon and juniper, they do not indicate if there was a differential influence of either species on sagebrush cover except to state that juniper initially invades sagebrush communities and tends to be replaced by pinyon.

Summary of Findings

- (1) Sagebrush cover values of 11.7 and 12.8 % for Wyoming and mountain big sagebrush when conifer cover was less than 2 % are low compared to generally reported values, but not different between Wyoming and mountain big sagebrush communities.
- (2) My model indicates that Wyoming and mountain big sagebrush cover are negatively affected by conifer cover ($\sqrt{\text{sagebrush cover}} = a_i - 0.401\sqrt{\text{conifer cover}}$; $r^2 = 0.61$).
- (3) My model predicted the relationship between conifer cover and sagebrush cover on low elevation, low production sites. It did not predict sagebrush cover reductions due to conifer cover on high elevation, high productivity mountain big sagebrush sites.

- (4) Douglas-fir and Rocky Mountain juniper cover reduce the cover of live sagebrush to a similar extent.

MANAGEMENT IMPLICATIONS

My study concurs with other research that conifer cover reduces sagebrush cover. Conifer cover explains 61 % of the variability of big sagebrush cover within my study area and the influence of conifer on sagebrush cover begins at low levels of conifer cover. When there is no conifer cover, big sagebrush cover in my study area averages approximately 12 %. As conifer cover increases to 10 %, the mean cover of big sagebrush decreases to approximately 6 % (Fig. 3). In other words, sites with only ten % conifer cover are likely to have half the sagebrush cover of sites with no conifer cover.

Douglas-fir and Rocky Mountain juniper have a similar influence on sagebrush cover. Currently, many conifers within my study area are being treated by burning or cutting (particularly Rocky Mountain juniper and sometimes juniper in combination with small diameter Douglas-fir). Because of the long recovery rates of sagebrush following fire, burning to enhance sagebrush habitat in these areas is not recommended. If restoration of sagebrush cover is the primary management goal, cutting of both Douglas-fir and Rocky Mountain juniper can slow the rate of sagebrush loss and should increase sagebrush cover. However, large increases in sagebrush should not be expected since sagebrush productivity in this area is relatively low.

Conifer expansion into sagebrush steppe is a management issue throughout the Intermountain West, and in response, managers have been burning and cutting to reduce conifers. There are, however, three main arguments against removal of conifers within the forest/shrub steppe ecotone in southwest Montana. First, these areas are important winter range for elk and mule deer with both sagebrush and conifers provide winter

browse, escape and thermal cover. Second, the rate of conifer expansion in southwest Montana is slow (Powell and Hansen 2007) compared with expansion rates of other juniper species (Weisberg et al. 2007, Sankey and Germino 2008). Therefore, control of conifer expansion is not needed in southwest Montana. Finally, prescribed burning often increases the spread on exotic plant species which have degraded much of the remaining sagebrush steppe (Knick et al. 2003). In my opinion, Rocky mountain juniper and Douglas-fir in these areas should not be removed.

LITERATURE CITED

- Akaike, H. 1974. A new look at the statistical model identification. *IEEE Transactions on Automatic Control* 19:716-723.
- Anderson, J. E. and R. S. Inouye. 2001. Landscape-scale changes in plant species abundance and biodiversity of a sagebrush steppe over 45 years. *Ecological Monographs* 71:531-556.
- Archer, S. 1994. Woody plant encroachment into southwestern grasslands and savannas: rates, patterns and proximate causes. *In*: M. Vavra, W. A. Laycock and R. D. Pieper [EDS.]. *Ecological implications of livestock herbivory in the West*. Denver, CO: Society of Range Management. p. 13-68.
- Arno, S. F. and G. E. Gruell. 1983. Fire history at the forest-grassland ecotone in southwestern Montana. *Journal of Range Management* 36:332-336.
- Arno, S. F., and G. E. Gruell. 1986. Douglas-fir encroachment into mountain grasslands in southwestern Montana. *Journal of Range Management* 39:272-276.
- Bai, Y., K. Broersma, D. Thompson and T.J. Ross. 2004. Landscape-level dynamics of grassland-forest transitions in British Columbia. *Journal of Range Management* 57:66-75.
- Baker, W. L. 2006. Fire and restoration of sagebrush ecosystems. *Wildlife Society Bulletin* 34:177-185.
- Baker, W. L. and D. J. Shinneman. 2004. Fire and restoration of pinon-juniper woodlands in the western United States: a review. *Forest Ecology and Management* 189:1-21.
- Beetle, A. A. 1960. A study of sagebrush-section *Tridentatae* of *Artemisia*. *Bulletin* 368. Laramie, WY: University of Wyoming Agricultural Experiment Station. 83 p.
- Belsky, J. A. 1996. Viewpoint: Western juniper expansion: is it a threat to arid northwestern ecosystems? *Journal of Range Management* 49:53-59.
- Blackburn, W. H. and P. T. Tueller. 1970. Pinyon and juniper invasion in black sagebrush communities in east-central Nevada. *Ecology* 51:841-848.
- Bradley, B. A. and E. Fleishman. 2008. Relationships between expanding pinyon-juniper cover and topography in the central Great Basin, Nevada. *Journal of Biogeography* 35:951-964.

- Bunting, S. C., B. M. Kilgore and C. L. Bushey. 1987. Guidelines for prescribed burning sagebrush-grass rangelands in the northern Great Basin. Ogden, UT: US Department of Agriculture, Forest Service, Intermountain Research Station General Technical Report INT-231. 33p.
- Bureau of Land Management. 1996. Sampling vegetation attributes. Denver, CO: US Department of the Interior, Bureau of Land Management, National Applied Resource Sciences Center. Interagency technical reference BLM/RS/ST-96/002+1730.
- Burkhardt, J. W. and E.W. Tisdale. 1976. Causes of juniper invasion in southwestern Idaho. *Ecology* 57:472-484.
- Burnham, K. P. and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach, 2nd ed. New York, NY: Springer-Verlag. 488 p.
- Caldwell, M. M. and J. H. Richards. 1989. Hydraulic lift: Water efflux from upper roots improves effectiveness of water uptake by deep roots. *Oecologia* 79:1-5.
- Canfield, R.H. 1941. Application of the line interception method in sampling range vegetation. *Journal of Forestry* 39:388-394.
- Cody, M. L. 1981. Habitat selection in birds: the role of vegetation structure, competitors, and productivity. *BioScience* 31:107-113.
- Connelly, J. W., M. A. Schroeder, A. R. Sands and C. E. Braun. 2000. Guidelines to manage sage grouse populations and their habitats. *Wildlife Society Bulletin* 28:967-985.
- Constan K. J. 1972. Winter foods and range use of three species of ungulates. *Journal of Wildlife Management* 36:1068-1076.
- Coultrap, D. E., K. O. Fulgham, D. L. Lancaster, J. Gustafson, D. F. Lile, and M. R. George. 2008. Relationships between western juniper (*Juniperus occidentalis*) and understory vegetation. *Invasive Plant Science and Management* 1:3-11.
- Davies, K. W., J. D. Bates, and R. F. Miller. 2006. Vegetation characteristics across part of the Wyoming big sagebrush alliance. *Rangeland Ecology and Management* 59:567-575.
- Davies, K. W., J. D. Bates and R. F. Miller. 2007. Environmental and vegetation relationships of the *Artemisia tridentata* spp. *wyomingensis* alliance. *Journal of Arid Environments* 70:478-494.

- Dietz, D. R. 1972. Nutritive value of shrubs. *In*: Wildland shrubs – their biology and utilization. Ogden, UT: US Department of Agriculture, Intermountain Forest and Range Experiment Station. General Technical Report INT-1. 494 p.
- Dietz, D. R. and J. G. Nagy. 1976. Mule deer nutrition and plant utilization. *In*: Proceedings of the Sixth Western States Mule Deer Workshop. Boise, ID: Idaho Department of Fish and Game. p. 71-78.
- Doescher, P. S., R. F. Miller, S. R. Swanson and A. H. Winward. 1986. Identification of the *Artemisia tridentata* ssp. *wyomingensis*/*Festuca idahoensis* habitat type in eastern Oregon. Northwest Science 60:55-60.
- Dorn, R.D. 1984. Vascular plants of Montana. Cheyenne, WY: Mountain West Publishing. 276 p.
- Farquhar, G. D. 1997. Carbon dioxide and vegetation. Science News Series 287:1411.
- Frisina, M. R. and C. L. Wambolt. 2004. Keying in on big sagebrush: a guide to identifying the four subspecies of big sagebrush. Rangelands 26:12-16.
- Goodrich, S. and A. Huber. 2001. Mountain big sagebrush communities on the Bishop Conglomerate in the eastern Uinta Mountains. *In*: E. D. McArthur and D. J. Fairbanks [COMPILERS] Proceedings of the 11th Wildland Shrub Symposium: Shrubland Ecosystem Genetics and Biodiversity; 13-15 June 2000; Provo, UT. Ogden, UT: US Department of Agriculture Rocky Mountain Research Station, RMRS-P-21. p. 336-343.
- Grove, A. J. 1998. Effects of Douglas fir establishment in southwestern Montana mountain big sagebrush communities [M.S. Thesis]. Bozeman, MT: Montana State University. 150 p.
- Grove, A. J., C. L. Wambolt and M. R. Frisina. 2005. Douglas-fir's effect on mountain big sagebrush wildlife habitats. Wildlife Society Bulletin 33:74-80.
- Grover, K. E. and M. J. Thompson. 1986. Factors influencing spring feeding site selection by elk in the Elkhorn Mountains, Montana. Journal of Wildlife Management 50:466-470.
- Hansen, K., W. Wyckoff and J. Banfield. 1995. Shifting forests: historical grazing and forest invasion in southwestern Montana. Forest and Conservation History 39:66-76.
- Hansen, R. M. and L. D. Reid. 1975. Diet overlap of deer, elk, and cattle in southern Colorado. Journal of Range Management 28:43-47.

- Harrington R. D. 2002. A historical perspective of Montana's sagebrush. *Intermountain Journal of Sciences* 8:61-66.
- Heyerdahl, E. K., R. F. Miller and R. A. Parsons. 2006. History of fire and Douglas-fir establishment in a savanna and sagebrush-grassland mosaic, southwestern Montana, USA. *Forest Ecology and Management* 230:107-118.
- Horton, J. L. and S. C. Hart. 1998. Hydraulic lift: a potentially important ecosystem process. *Trends in Ecology and Evolution* 13:232-235.
- Jensen, M. E. 1990. Interpretation of environmental gradients which influence sagebrush community distribution in northeastern Nevada. *Journal of Range Management* 43:161-167.
- Johnsen, T. N. 1962. One-seed juniper invasion of northern Arizona grasslands. *Ecological Monographs* 32:187-207.
- Johnson, B.R., P.D. Illinger, J.B. Mahoney, and R.M. Friedman. 2004. Reexamining the geochemistry and geochronology of the Late Cretaceous Boulder Batholith, MT. *Geological Society of America. Abstracts with Programs*, 36:406.
- Johnson, D. D. and R. F. Miller. 2006. Structure and development of expanding western juniper woodlands as influenced by two topographic variables. *Forest Ecology and Management* 229:7-15.
- Johnson, D. D. and R. F. Miller. 2008. Intermountain presettlement juniper: distribution, abundance, and influence on postsettlement expansion. *Rangeland Ecology and Management* 61:82-92.
- Johnson, D. E. 1951. Biology of the elk calf, *Cervus Canadensis nelsoni*. *Journal of Wildlife Management* 15:396-410.
- Katzner, T. E. and K. L. Parker. 1997. Vegetative characteristics and size of home ranges used by pygmy rabbits (*Brachylagus idahoensis*) during winter. *Journal of Mammalogy* 78:1063-1072.
- Keating, K. A., L. R. Irby and W. F. Kasworm. 1985. Mountain sheep winter food habits in the upper Yellowstone Valley. *Journal of Wildlife Management* 49:156-161.
- Kitchen, S. G. and E. D. McArthur. 2007. Big and Black Sagebrush Landscapes. *In*: S. Hood and M. Miller [EDS.] *Fire ecology and management of the major ecosystems of southern Utah*. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-202. p. 73-95.

- Klepper, M.R., E.T. Ruppel, V.L. Freeman, and R.A. Weeks. 1971. Geology and mineral deposits, east flank of the Elkhorn Mountains, Broadwater County, Montana. Geological Survey Professional Paper 665. Washington, D.C.: US Government Printing Office. 66 p.
- Knick, S. T., D. S. Dobkin, J. T. Rotenberry, M. A. Schroeder, W. M. Vander Haegen and C. van Riper III. 2003. Teetering on the edge or too late? Conservation and research issues for avifauna of sagebrush habitats. *The Condor* 105:611-634.
- Knight, D. H. 1994. Escarpments and foothill transition. *In*: D. H. Knight. Mountains and plains: the ecology of Wyoming's landscapes. New Haven, CT: Yale University Press. p. 133-152.
- Küchler, A. W. 1970. Potential natural vegetation. *In*: The national atlas of the United States of America. Washington DC: US Department of the Interior, Geological Survey. p. 89-92.
- Kufeld, R. C. 1973. Foods eaten by the Rocky Mountain elk. *Journal of Range Management* 26:106-113.
- Kufeld, R. C., O. C. Wallmo and C. Feddema. 1973. Foods of the Rocky Mountain mule deer. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. Research Paper RM-111. 31 p.
- Lesica, P., S. V. Cooper and G. Kudray. 2007. Recovery of big sagebrush following fire in southwest Montana. *Rangeland Ecology and Management* 60:261-269.
- Lyford, M. E., S. T. Jackson, J. L. Betancourt, and S. T. Gray. 2003. Influence of landscape structure and climate variability on a Late Holocene plant migration. *Ecological Monographs* 73:567-583.
- MacCracken, J. G. and R. M. Hansen. 1981. Diets of domestic sheep and other large herbivores in Southcentral Colorado. *Journal of Range Management* 34:242-243.
- Manuwal, D. A. 1983. Avian abundance and guild structure in two Montana coniferous forests. *The Murrelet* 64:1-11.
- Miller, R.F. and J.A. Rose. 1999. Fire history and western juniper encroachment in sagebrush steppe. *Journal of Range Management* 52:550-559.
- Miller, R. F., T. J. Svejcar and J. A. Rose. 2000. Impacts of western juniper on plant community composition and structure. *Journal of Range Management* 53:574-585.

- Miller, R. F., T. J. Svejcar, and N. E. West. 1994. Implications of livestock grazing in the Intermountain sagebrush region: plant composition. *In*: Varva, M., W. A. Laycock, and R. D. Pieper (EDS.). Ecological implications of livestock herbivory in the west. Denver, CO: Society for Range Management. p. 101-146.
- Miller, R. F., R. J. Tausch, E. D. McArthur, D. D. Johnson, and S. C. Sanderson. 2008. Age structure and expansion of pinon-juniper woodlands: a regional perspective in the intermountain west. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. Research Paper RMRS-RP-69. 13 p.
- Miller, R.F. and P.E. Wigand. 1994. Holocene changes in semiarid pinyon-juniper woodlands: response to climate, fire, and human activities in the US Great Basin. *BioScience* 44:465-474.
- Morris, M. S., R. G. Kelsey and D. Griggs. 1976. The geographic and ecological distribution of big sagebrush and other woody *Artemisias* in Montana. *Proceedings of the Montana Academy of Sciences* 36:56-79.
- Mueggler, W.F. and W.L. Stewart. 1980. Grassland and shrubland habitat types of Western Montana. Ogden, UT: US Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. General Technical Report INT-66. 154 p.
- Mueller, R. C., C. M. Scudder, M. E. Porter, R. T. Trotter III, C. A. Gehring, and T. G. Whitham. 2005. Differential tree mortality in response to severe drought: evidence for long-term vegetation shifts. *Journal of Ecology* 95:1085-1093.
- NatureServe Explorer. 2010. Available at: <http://www.natureserve.org/explorer/> Accessed Jan. 26, 2010.
- Noss, R. F. and R. L. Peters. 1995. Endangered ecosystems. A status report on America's vanishing habitat and wildlife. Washington, DC: Defenders of Wildlife.
- Patten, D. T. 1969. Succession from sagebrush to mixed conifer forest in the northern Rocky Mountains. *American Midland Naturalist* 82:229-240.
- Petersen, S. L. and T. K. Stringham. 2008. Development of GIS-based models to predict plant community structure in relation to western juniper establishment. *Forest Ecology and Management* 256:981-989.
- Peterson, J. G. 1995. Ecological implications of sagebrush manipulation: a literature review. *Montana Fish Wildlife and Parks*. 49 p.

- Polley, H. W., H. B. Johnson and H. S. Mayeux. 1994. Increasing CO²: comparative responses of the C₄ grass *Schizachyrium* and grassland invader *Prosopis*. *Ecology* 75:976-988.
- Powell, S. L. and A. J. Hansen. 2007. Conifer cover increase in the Greater Yellowstone Ecosystem: frequency, rates, and spatial variation. *Ecosystems* 10:204-216.
- Reinkensmeyer, D. P., R. F. Miller, R. G. Anthony and V. E. Marr. 2007. Avian community structure along a mountain big sagebrush successional gradient. *Journal of Wildlife Management* 71:1057-1066.
- Romme, W. H., C.D. Allen, J. D. Bailey, W. L. Baker, B. T. Bestelmeyer, P. M. Brown, K. S. Eisenhart, M. L. Floyd, D. W. Huffman, B. F. Jacobs, R. F. Miller, E. H. Muldavin, T. W. Swetnam, R. J. Tausch and P. J. Weisberg. 2009. Historical and modern disturbance regimes, stand structures, and landscape dynamics in piñon-juniper vegetation of the western United States. *Rangeland Ecology and Management* 62:203-222.
- Rowland, M. M., L. H. Suring, R. J. Tausch, S. Geer, M. J. Wisdom. 2008. Characteristics of western juniper encroachment into sagebrush communities in central Oregon. La Grande, OR: US Department of Agriculture, Forest Service, Forestry and Range Sciences Laboratory. 23 p.
- Ryel, R. J., M. M. Caldwell, C. K. Yoder, D. Or and A. J. Leffler. 2002. Hydraulic redistribution in a stand of *Artemisia tridentata*: evaluation of benefits to transpiration assessed with a simulation model. *Oecologia* 130:173-184.
- Samuels, M. L. and J. L. Betancourt. 1982. Modeling the long-term effects of fuelwood harvests on pinyon-juniper woodlands. *Environmental Management* 6:505-515.
- Sankey, T. T., C. Montagne, L. Graumlich, R. Lawrence, J. Nielson. 2006. Twentieth century forest-grassland ecotone shift in Montana under differing livestock grazing pressure. *Forest Ecology and Management* 234:282-292.
- Sankey, T. T. and M. J. Germino. 2008. Assessment of juniper encroachment with use of satellite imagery and geospatial data. *Rangeland Ecology and Management* 61:412-418.
- Sindelar, B. W. 1971. Douglas-fir invasion of western Montana grasslands [PH.D. Thesis]. Missoula, MT: University of Montana. 130 p.
- Smedes, Harry W., Montis R. Klepper, and Robert I. Tilling. 1968. Boulder Batholith: Description of Geology and Road Log. Bozeman, MT: Geological Society of America, Rocky Mountain Section. 21p.

- Soulé, P. T., P. A. Knapp and H. D. Grissino-Mayer. 2003. Comparative rates of western juniper afforestation in south-central Oregon and the role of anthropogenic disturbance. *The Professional Geographer* 55:43-55.
- Soulé, P. T., P. A. Knapp and H. D. Grissino-Mayer. 2004. Human agency, environmental drivers, and western juniper establishment during the late Holocene. *Ecological Applications* 14:96-112.
- Strand, E. K., A. M. S. Smith, S. C. Bunting, L. A. Vierling, D. B. Hann and P. E. Gessler. 2006. Wavelet estimation of plant spatial patterns in multitemporal aerial photography. *International Journal of Remote Sensing* 27:2049-2054.
- Sudworth, G. B. 1915. Cypress and juniper trees of the Rocky Mountain region. Washington, DC: US Department of Agriculture. Bulletin 207.
- Tausch, R. J. 1999. Historic pinyon and juniper woodland development. *In*: S. B. Monsen and R. Stevens [COMPILERS] *Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 15-18 September, 1997*. Ogden, UT: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. *Proceedings RMRS-P-9*. p. 12-19.
- Tausch, R. J., and N. E. West. 1995. Plant species composition patterns with differences in dominance on a southwestern Utah pinon-juniper site. *In*: Shaw, D.W., E.F. Aldon, C. LoSapio [EDS.]. *Desired future conditions for pinon-juniper ecosystems*. Ogden, UT: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. *General Technical Report RM-GTR-258*. p. 16-23.
- Tausch, R. J., N. E. West and A. A. Nabi. 1981. Tree age and dominance patterns in Great Basin pinyon-juniper woodlands. *Journal of Range Management* 34:259-264.
- USDA, NRCS 2009. Plant Guide, Big Sagebrush. Available at: http://plants.usda.gov/plantguide/pdf/pg_artr2.pdf. Accessed March 6, 1999.
- USDA, NRCS. 2010. Plants Database. Available at: <http://plants.usda.gov/java/nameSearch>. Accessed May 5, 2010.
- USDA, NRCS. 2010. Web Soil Survey. Available at: <http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx>. Accessed Feb. 25, 2010.
- U. S. Forest Service. 1993. *Rangeland ecosystem analysis and management handbook*. FSH 2209.21. Ogden, UT: US Forest Service, Intermountain Region.

- Wambolt, C. L., W. H. Creamer and R. J. Rossi. 1994. Predicting big sagebrush winter forage by sub-species and browse form class. *Journal of Range Management* 47:231-234.
- Wambolt, C. L. 1996. Mule deer and elk foraging preference for 4 sagebrush taxa. *Journal of Range Management* 49:499-503.
- Wambolt, C. L. and M. R. Frisina. 2002. *Montana Sagebrush Guide*. Montana Department of Fish, Wildlife & Parks. 71 p.
- Wambolt, C. L., M. R. Frisina, S. J. Knapp, and R. M. Frisina. 2006. Effect of method, site, and taxon on line-intercept estimates of sagebrush cover. *Wildlife Society Bulletin* 34:440-445.
- Weisberg, P. J., E. Lingua and R. B. Pillai. 2007. Spatial patterns of pinyon-juniper woodland expansion in central Nevada. *Rangeland Ecology and Management* 60:115-124.
- Welch, S. and J. Comer. 1988. *Quantitative methods for public administration*, 2nd ed. Pacific Grove, CA: Brooks/Cole Publishing Co. 381 p.
- Welch, B. L., F. J. Wagstaff and J. A. Roberson. 1991. Preference of wintering sage grouse for big sagebrush. *Journal of Range Management* 44:462-465.
- Welch, B. L. and C. Criddle. 2003. *Countering misinformation concerning big sagebrush*. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. Research Paper RMRS-RP-40. 28 p.
- Welch, B. L. 2005. *Big sagebrush: A sea fragmented into lakes, ponds, and puddles*. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-144. 210 p.
- West, N. E., R. J. Tausch, K. H. Rea and P. T. Tueller. 1978. Taxonomic determination, distribution and ecological indicator values of sagebrush within the pinyon – juniper woodlands of the Great Basin. *Journal of Range Management* 31:87-92.
- Western Regional Climate Center. Available at: <http://www.wrcc.dri.edu/Climsum.html>. Accessed Jan. 28, 2010.

APPENDICES

APPENDIX A:

PERCENT COVER OF CONIFERS AND LIVE SAGEBRUSH AT THE
ELKHORN, PIPESTONE AND WHITETAIL STUDY SITES IN
SOUTHWEST MONTANA

Table 10. Percent cover values of Rocky Mountain juniper, Douglas-fir, total conifer and live sagebrush in the Wyoming big sagebrush plots at the Elkhorn study site in southwest Montana.

Elkhorn – Wyoming Big Sagebrush				
Plot	Juniper	Douglas-Fir	Total Conifer	Live Sagebrush
1	12.44	2.11	14.56	2.08
2	6.42	1.18	7.60	7.79
3	3.30	2.08	5.38	4.66
4	5.24	0.00	5.24	8.56
5	27.46	5.01	32.83	3.58
6	0.02	0.00	0.02	14.48
7	15.17	5.11	15.67	6.63
8	8.58	1.19	9.97	8.83
9	15.64	7.52	23.17	3.24
10	19.57	0.77	21.79	4.12
11	7.66	4.59	12.24	14.87
12	7.36	2.92	10.28	12.78
13	1.18	0.00	1.18	21.99
14	1.21	0.00	1.21	11.51
15	10.81	15.20	42.88	0.34
16	9.12	1.92	15.09	4.80
17	11.83	4.12	15.96	7.08
18	14.69	6.58	21.27	3.44
19	12.72	12.63	25.36	4.03
20	2.50	0.00	2.50	3.69
21	3.46	11.16	14.02	4.36
22	18.20	21.13	36.74	0.14
23	4.99	2.89	7.88	12.98
24	8.92	2.16	11.08	11.00
25	7.27	0.00	7.27	15.86
26	20.29	15.53	35.32	1.21
27	12.44	11.51	23.95	3.58
28	33.66	2.10	36.06	2.78
29	6.11	1.36	11.07	6.51
30	36.62	5.06	44.06	2.17
31	7.53	4.46	13.38	4.04
32	12.73	0.00	14.61	4.49
33	0.40	0.00	0.40	9.41
34	9.58	0.00	10.71	7.25
35	2.87	0.00	2.87	7.50
36	15.06	0.47	15.53	4.50
37	4.01	0.00	4.01	6.10
38	2.43	0.00	2.43	8.52
39	9.24	0.00	9.24	6.01
40	7.61	2.72	11.12	5.14

Table 11. Percent cover values of Rocky Mountain juniper, Douglas-fir, total conifer and live sagebrush in the Wyoming big sagebrush plots at the Pipestone study site in southwest Montana.

Plot	Pipestone – Wyoming Big Sagebrush			
	Juniper	Douglas-Fir	Total Conifer	Live Sagebrush
1	18.41	4.62	23.03	2.54
2	0.19	0.00	0.19	6.06
3	4.94	9.14	14.08	0.67
4	2.53	5.98	8.51	1.99
5	8.27	4.59	12.86	8.16
6	11.87	39.08	50.95	0.00
7	8.54	49.12	57.66	0.00
8	0.61	0.00	0.61	9.91
9	2.74	0.00	2.74	6.48
10	10.67	2.57	13.24	7.68
11	7.54	3.81	11.35	1.11
12	3.97	0.00	3.97	5.16
13	0.00	0.00	0.00	6.44
14	6.07	0.08	6.15	2.61
15	11.11	6.17	17.28	0.27
16	14.60	39.27	51.34	0.00
17	11.03	19.60	29.70	0.33
18	0.94	23.51	24.46	0.90
19	3.98	12.01	15.11	2.78
20	3.36	13.63	15.96	2.42
21	4.66	23.50	28.16	0.40
22	7.71	8.67	16.38	0.85
23	17.59	0.00	17.59	5.54
24	13.43	8.26	21.48	2.76
25	12.28	1.74	14.02	6.54
26	11.99	3.64	15.36	2.28
27	10.43	18.16	25.80	0.57
28	10.30	3.09	13.29	2.34
29	20.49	11.58	31.66	0.00
30	1.40	4.44	5.66	4.77
31	10.98	8.02	18.57	1.11
32	16.26	4.38	20.18	0.24
33	6.93	12.92	19.73	3.27
34	19.44	15.62	33.57	0.00
35	6.70	0.74	7.44	3.47
36	9.13	18.03	27.17	0.87
37	9.69	6.76	16.44	2.37
38	7.44	0.26	7.70	2.90
39	1.73	0.31	2.04	6.87
40	13.72	2.08	15.43	2.73

Table 12. Percent cover values of Rocky Mountain juniper, Douglas-fir, total conifer and live sagebrush in the Wyoming big sagebrush plots at the Whitetail study site in southwest Montana

Whitetail – Wyoming Big Sagebrush				
Plot	Juniper	Douglas-Fir	Total Conifer	Live Sagebrush
1	10.45	3.82	14.27	3.58
2	3.43	1.49	4.92	7.43
3	0.53	0.00	0.53	8.28
4	7.21	4.81	12.02	3.34
5	6.19	0.00	6.19	8.98
6	12.32	6.11	18.08	5.78
7	15.23	4.46	19.69	6.09
8	1.00	0.06	1.06	9.02
9	3.92	1.27	4.99	15.22
10	1.08	0.00	1.08	8.30
11	7.63	0.00	7.63	6.90
12	2.31	0.04	2.36	4.47
13	12.78	4.59	17.36	9.09
14	10.44	0.12	10.57	5.72
15	12.11	3.07	15.19	4.26
16	10.23	4.37	14.60	11.83
17	0.20	3.02	3.22	24.24
18	5.31	7.66	12.97	8.81
19	4.22	22.68	26.90	6.88
20	16.30	24.36	39.14	1.20
21	3.30	0.00	3.30	8.32
22	13.68	9.71	22.31	5.67
23	15.33	0.00	15.33	5.91
24	19.81	0.00	19.81	3.73
25	9.18	5.30	13.87	2.41
26	24.11	2.89	25.89	2.54
27	14.90	10.78	25.64	2.10
28	0.16	0.00	0.16	18.37
29	0.00	0.00	0.00	17.14
30	10.27	5.39	14.80	11.50
31	19.39	0.00	19.39	5.37
32	10.73	1.47	12.20	5.44
33	7.14	9.72	16.57	6.07
34	6.81	6.19	13.00	4.40
35	8.23	0.51	8.74	6.46
36	11.87	3.10	14.97	3.79
37	16.22	19.88	35.99	0.78
38	11.81	0.54	12.36	1.90
39	21.17	0.00	21.17	4.26
40	4.29	0.11	4.40	5.38

Table 13. Percent cover values of Rocky Mountain juniper, Douglas-fir, total conifer and live sagebrush in the mountain big sagebrush plots at the Elkhorn study site in southwest Montana.

Plot	Elkhorn – Mountain Big Sagebrush			
	Juniper	Douglas-Fir	Total Conifer	Live Sagebrush
1	13.86	29.50	44.32	0.23
2	6.89	57.42	64.54	0.67
3	1.52	1.70	3.42	17.13
4	3.99	2.54	6.53	6.38
5	8.44	4.61	13.66	4.83
6	13.60	0.00	13.60	5.70
7	10.28	20.78	31.06	0.00
8	4.86	0.00	4.86	12.16
9	29.03	1.10	29.69	9.10
10	5.20	3.82	9.00	5.69
11	18.87	20.28	38.90	11.23
12	10.90	7.38	17.89	4.93
13	7.32	26.49	33.56	4.18
14	8.04	0.46	8.69	13.62
15	0.00	0.00	0.00	15.63
16	10.69	11.01	20.56	4.77
17	5.60	0.00	5.60	9.72
18	28.82	1.28	29.23	9.67
19	1.89	0.00	1.89	26.06
20	10.61	0.00	10.89	3.62
21	5.18	2.51	7.69	12.01
22	7.29	7.74	15.03	10.37
23	0.48	4.50	4.98	14.87
24	2.13	40.43	41.61	0.33
25	3.09	0.00	3.09	18.89
26	0.82	18.32	19.14	12.13
27	17.61	5.60	23.21	5.54
28	6.71	7.50	14.21	6.93
29	0.97	0.00	0.97	24.32
30	15.59	29.57	42.57	2.61
31	10.60	6.39	16.99	7.89
32	4.17	0.00	4.17	13.30
33	6.22	6.56	12.54	10.58
34	17.61	9.24	24.24	5.62
35	0.00	10.04	10.04	13.63
36	3.28	8.59	11.87	8.38
37	9.52	0.00	9.52	9.68
38	0.90	50.32	50.58	5.98
39	10.56	5.22	15.72	12.43
40	3.62	5.78	9.40	24.12

Table 14. Percent cover values of Rocky Mountain juniper, Douglas-fir, total conifer and live sagebrush in the mountain big sagebrush plots at the Pipestone study site in southwest Montana.

Pipestone – Mountain Big Sagebrush				
Plot	Juniper	Douglas-Fir	Total Conifer	Live Sagebrush
1	0.00	0.00	0.00	14.77
2	7.62	12.47	20.09	3.13
3	6.39	0.00	6.39	8.27
4	9.24	0.00	9.24	9.97
5	5.37	20.50	25.87	1.25
6	3.92	28.00	31.92	1.17
7	0.00	0.11	0.11	11.50
8	0.00	3.36	3.36	13.23
9	1.10	33.78	34.88	4.71
10	0.00	5.31	5.31	14.84
11	1.34	15.84	17.18	5.48
12	4.93	8.94	13.88	7.08
13	8.24	25.09	33.33	6.33
14	8.42	8.60	17.02	9.30
15	8.51	33.33	40.24	0.66
16	2.53	32.18	37.71	3.72
17	4.09	38.84	42.93	2.54
18	7.54	45.37	49.15	1.51
19	2.88	13.82	16.70	10.54
20	0.00	4.44	4.44	14.44
21	2.70	27.89	29.82	4.02
22	1.88	26.83	28.71	6.17
23	0.48	41.56	42.03	0.58
24	0.84	1.99	2.83	10.29
25	1.89	37.44	39.33	0.33
26	1.38	12.67	14.04	6.90
27	8.60	44.11	50.66	0.33
28	5.52	45.02	49.27	1.09
29	0.00	0.38	0.38	10.43
30	1.37	24.59	25.95	3.14
31	1.10	18.76	19.72	1.54
32	0.02	1.46	1.48	8.11
33	2.09	13.40	15.49	5.21
34	8.84	21.27	30.11	3.47
35	0.00	48.58	48.58	2.39
36	0.00	14.73	14.73	10.60
37	3.72	27.16	29.38	4.32
38	11.08	3.43	14.51	12.64
39	5.83	31.30	36.81	1.52
40	2.29	2.76	5.04	8.37

Table 15. Percent cover values of Rocky Mountain juniper, Douglas-fir, total conifer and live sagebrush in the mountain big sagebrush plots at the Whitetail study site in southwest Montana.

Whitetail – Mountain Big Sagebrush				
Plot	Juniper	Douglas-Fir	Total Conifer	Live Sagebrush
1	1.70	5.77	7.48	8.31
2	4.19	23.42	27.40	4.34
3	2.14	2.92	5.07	11.00
4	0.03	11.64	11.64	9.89
5	0.07	23.88	23.94	9.13
6	3.73	56.40	59.60	1.17
7	1.71	27.28	28.94	6.97
8	4.71	33.78	37.46	1.07
9	3.13	38.30	41.20	0.34
10	2.48	24.17	26.61	2.93
11	3.58	42.49	43.81	4.07
12	2.50	2.96	5.41	6.51
13	0.00	0.97	0.97	12.36
14	1.99	36.68	38.40	0.60
15	5.80	15.91	15.91	5.01
16	0.00	6.56	6.56	1.78
17	0.00	14.76	14.76	1.16
18	0.00	28.86	28.86	0.42
19	2.66	8.52	11.18	2.20
20	0.00	22.56	22.56	4.83
21	3.61	4.64	8.26	10.01
22	0.26	25.10	25.36	5.78
23	0.00	0.00	0.00	11.20
24	3.01	32.19	35.20	1.66
25	0.00	18.93	18.93	6.03
26	0.00	14.66	14.66	4.93
27	0.00	3.04	3.04	9.70
28	2.68	8.46	11.13	10.72
29	1.43	26.89	27.33	2.18
30	0.00	19.49	19.49	1.40
31	0.00	24.97	24.97	0.99
32	0.80	22.78	23.58	1.84
33	0.00	0.00	0.00	3.81
34	9.14	18.91	27.14	1.51
35	2.06	19.62	20.31	0.33
36	2.00	2.14	4.14	2.07
37	2.78	6.88	9.66	2.60
38	0.00	19.42	19.42	4.16
39	0.00	17.06	17.06	4.13
40	2.89	17.60	18.97	6.19

APPENDIX B:

SPECIES LISTS FOR WYOMING AND MOUNTAIN BIG SAGEBRUSH
COMMUNITES AT THE ELKHORN, PIPESTONE AND WHITETAIL
STUDY SITES IN SOUTHWEST MONTANA

Table 16. Plant species list for the Wyoming big sagebrush plots at the Elkhorn study site in southwest Montana.

Elkhorn – Wyoming			
Scientific Name	Common Name	Scientific Name	Common Name
Trees and Shrubs		Forbs Continued	
	mountain big		
<i>Artemisia tridentata</i> spp. <i>vaseyana</i>	sagebrush	<i>Aster</i> spp.	aster
<i>Artemisia tridentata</i> spp. <i>wyomingensis</i>	Wyoming big sagebrush	<i>Astragalus mollissimus</i>	woolly locoweed
<i>Chrysothamnus nauseosus</i>	rubber rabbitbrush	<i>Besseyia</i> spp.	kittentail
	Rocky Mountain juniper		
<i>Juniperus scopulorum</i>	juniper	<i>Brassicaceae</i>	mustard
<i>Pinus flexilis</i>	limber pine	<i>Calochortus</i> spp.	mariposa lily
<i>Pinus ponderosa</i>	ponderosa pine	<i>Castilleja</i> spp.	paintbrush
<i>Pseudotsuga menziesii</i>	Douglas-fir	<i>Cerastium arvense</i>	field chickweed
<i>Rhus trilobata</i>	skunkbush sumac	<i>Crepis</i> spp.	hawksbeard
		<i>Dodecatheon conjugens</i>	shooting star
<i>Ribes</i> spp.	currant		Rocky Mountain
<i>Rosa woodsii</i>	Woods rose	<i>Douglasia montana</i>	Douglasia
Grass and Grass-Like Species		<i>Erigeron compositus</i>	cutleaf daisy
	bluebunch		
<i>Elymus spicatus</i>	wheatgrass	<i>Erigeron</i> spp.	daisy
<i>Aristida purpurea</i>	purple three awn	<i>Eriogonum</i> spp.	buckwheat
<i>Bouteloua gracilis</i>	blue grama	<i>Geum triflorum</i>	prairie smoke
		<i>Gutierrezia sarothrae</i>	broom snakeweed
<i>Bromus</i> spp.	brome	<i>Heterotheca villosa</i>	hairy goldaster
<i>Bromus tectorum</i>	cheatgrass	<i>Heuchera parvifolia</i>	little leaf alumroot
<i>Carex</i> spp.	sedge	<i>Lepidium</i> spp.	pepperweed
<i>Danthonia unispicata</i>	onespike danthonia	<i>Lewisia rediviva</i>	bitterroot
<i>Festuca idahoensis</i>	Idaho fescue	<i>Linaria dalmatica</i>	Dalmation toadflax
<i>Koeleria macrantha</i>	prarie junegrass	<i>Linum perenne</i>	wild flax
<i>Pascopyrum smithii</i>	western wheatgrass	<i>Lomatium</i> spp.	desert parsley
<i>Poa secunda</i>	Sandberg bluegrass	<i>Mertensia longiflora</i>	bluebell
<i>Poa</i> spp.	bluegrass	<i>Oxytropis</i> spp.	stem-less locoweed
<i>Stipa comata</i>	needle and thread	<i>Penstemon</i> spp.	penstemon
Cacti		<i>Phlox diffusa</i>	spreading phlox
<i>Opuntia polycantha</i>	pricklypear cactus	<i>Potentilla</i> spp.	cinquefoil
Pteridophytes		<i>Sedum</i> spp.	stonecrop
<i>Selaginella densa</i>	spike moss	<i>Senecio</i> spp.	groundsel
Forbs		<i>Sphaeralcea coccinea</i>	globemallow
<i>Achillea millefolium</i>	common yarrow	<i>Taraxacum officinale</i>	common dandelion
<i>Agoseris glauca</i>	agoseris	<i>Tragopogon dubius</i>	yellow salsify
<i>Allium</i> spp.	onion	<i>Trifolium repens</i>	white clover
<i>Androsace occidentalis</i>	western rockjasmine	<i>Vicia</i> spp.	vetch
<i>Antennaria rosea</i>	rosy pussytoes	<i>Viola</i> spp.	violet
<i>Arabis</i> spp.	rock cress	<i>Zigadenus</i> spp.	death camas
<i>Arenaria</i> spp.	sandwort		
<i>Artemisia frigida</i>	prairie sagewort		

Table 17. Plant species list for the Wyoming big sagebrush plots at the Pipestone study site in southwest Montana.

Pipestone - Wyoming			
Scientific Name	Common Name	Scientific Name	Common Name
Trees and Shrubs		Forbs	
<i>Artemisia tridentata</i> spp vaseyana	mountain big sagebrush	<i>Achillea millefolium</i>	common yarrow
<i>Artemisia tridentata</i> spp wyomingensis	Wyoming big sagebrush curl leaf mountain mahogany	<i>Agoseris glauca</i>	agoseris
<i>Cercocarpus ledifolius</i>	rubber rabbitbrush	<i>Allium</i> spp.	onion
<i>Chrysothamnus nauseosus</i>	green rabbitbrush	<i>Antennaria rosea</i>	rosy pussytoes
<i>Chrysothamnus viscidiflorus</i>	slender buckwheatbrush	<i>Arabis</i> spp.	rock cress
<i>Eriogonum microthecum</i>	Rocky Mountain juniper	<i>Arenaria</i> spp.	sandwort
<i>Juniperus scopulorum</i>	Douglas-fir	<i>Artemisia frigida</i>	prairie sagewort
<i>Pseudotsuga menziesii</i>	bitterbrush	<i>Brassicaceae</i>	mustard
<i>Purshia tridentata</i>	skunkbush sumac	<i>Centaurea maculosa</i>	spotted knapweed
<i>Rhus trilobata</i>	currant	<i>Crepis</i> spp.	hawksbeard
<i>Ribes</i> spp.	Woods rose	<i>Delphinium</i> spp.	larkspur Rocky Mountain Douglasia
<i>Rosa woodsii</i>		<i>Douglasia montana</i>	
Grass and Grass-Like Species		<i>Erigeron compositus</i>	cutleaf daisy
<i>Elymus spicatus</i>	bluebunch wheatgrass	<i>Eriogonum</i> spp.	buckwheat
<i>Bouteloua gracilis</i>	blue grama	<i>Haplopappus</i> spp.	haplopappus
<i>Carex</i> spp	sedge	<i>Heterotheca villosa</i>	hairy goldaster
<i>Festuca idahoensis</i>	Idaho fescue	<i>Leptodactylon pungens</i>	granite gilia
<i>Koeleria macrantha</i>	prairie junegrass	<i>Lesquerella</i> spp.	bladderpod
<i>Pascopyrum smithii</i>	western wheatgrass	<i>Lewisia rediviva</i>	bitterroot
<i>Poa pratensis</i>	Kentucky bluegrass	<i>Oenothera</i> spp.	primrose
<i>Poa secunda</i>	Sandberg bluegrass	<i>Orthocarpus tenuifolius</i>	owl clover
<i>Poa</i> spp.	bluegrass	<i>Penstemon aridus</i>	stiffleaf penstemon
<i>Stipa comata</i>	needle and thread	<i>Penstemon</i> spp.	penstemon
Cacti		<i>Phlox hoodii</i>	cushion phlox
<i>Opuntia polykantha</i>	pricklypear cactus	<i>Phlox hoodii</i>	cushion phlox
Pteridophytes		<i>Sedum</i> spp.	stonecrop
<i>Selaginella densa</i>	spike moss	<i>Senecio</i> spp.	groundsel
		<i>Taraxacum officinale</i>	common dandelion

Table 18. Plant species list for the Wyoming big sagebrush plots at the Whitetail study site in southwest Montana.

Whitetail – Wyoming			
Scientific Name	Common Name	Scientific Name	Common Name
Trees and Shrubs		Forbs Continued	
<i>Artemisia tridentata</i> spp. <i>vaseyana</i>	mountain big sagebrush	<i>Artemisia frigida</i>	prairie sagewort
<i>Artemisia tridentata</i> spp. <i>wyomingensis</i>	Wyoming big sagebrush	<i>Aster</i> spp.	aster
<i>Cercocarpus ledifolius</i>	curl leaf mountain mahogany	<i>Astragalus mollissimus</i>	wooly locoweed
<i>Chrysothamnus nauseosus</i>	rubber rabbitbrush	<i>Brassicaceae</i>	mustard
<i>Juniperus scopulorum</i>	Rocky Mountain juniper	<i>Cirsium undulatum</i>	wavyleaf thistle
<i>Philadelphus lewisii</i>	mock orange	<i>Crepis</i> spp.	hawksbeard
<i>Pseudotsuga menziesii</i>	Douglas-fir	<i>Erigeron compositus</i>	cutleaf daisy
<i>Purshia tridentata</i>	bitterbrush	<i>Erigeron</i> spp.	daisy
<i>Rhus trilobata</i>	skunkbush sumac	<i>Eriogonum</i> spp.	buckwheat
<i>Ribes</i> spp	currant	<i>Geum triflorum</i>	prairie smoke
<i>Rosa woodsii</i>	Woods rose	<i>Gutierrezia sarothrae</i>	broom snakeweed
Grass and Grass-Like Species		<i>Haplopappus</i> spp.	haplopappus
<i>Elymus spicatus</i>	bluebunch wheatgrass	<i>Heterotheca villosa</i>	hairy goldaster
<i>Aristida purpurea</i>	red three awn	<i>Heuchera parvifolia</i>	alumroot
<i>Bouteloua gracilis</i>	blue grama	<i>Lepidium</i> spp.	pepperweed
<i>Carex</i> spp	sedge	<i>Lewisia rediviva</i>	bitterroot
<i>Festuca idahoensis</i>	Idaho fescue	<i>Linum perenne</i>	wild flax
<i>Koeleria macrantha</i>	prairie junegrass	<i>Lomatium</i> spp.	desert parsley
<i>Pascopyrum smithii</i>	western wheatgrass	<i>Lupinus</i> spp.	lupine
<i>Poa secunda</i>	Sandberg bluegrass	<i>Oxytropis</i> spp.	locoweed
<i>Poa</i> spp.	bluegrass	<i>Penstemon</i> spp.	penstemon
<i>Stipa comata</i>	needle and thread	<i>Phacelia</i> spp.	phacelia
Cacti		<i>Phlox hoodii</i>	cushion phlox
<i>Opuntia polycantha</i>	pricklypear cactus	<i>Plantago patagonica</i>	woolly plantain
<i>Pediocactus</i>	pincushion cactus	<i>Potentilla</i> spp.	cinquefoil
Pteridophytes		<i>Senecio</i> spp.	groundsel
<i>Selaginella densa</i>	spike moss	<i>Sphaeralcea coccinea</i>	globemallow common
<i>Woodsia oregana</i>	western cliff fern	<i>Taraxacum officinale</i>	dandelion
Forbs		<i>Tragopogon dubius</i>	yellow salsify
<i>Achillea millefolium</i>	common yarrow	<i>Vicia</i> spp.	vetch
<i>Agoseris glauca</i>	agoseris	<i>Viola</i> spp.	violet
<i>Allium</i> spp.	onion	<i>Zigadenus</i> spp.	death camas
<i>Antennaria rosea</i>	rosy pussytoes		
<i>Arabis</i> spp.	rock cress		

Table 19. Plant species list for the mountain big sagebrush plots at the Elkhorn study site in southwest Montana.

Elkhorn – Mountain			
Scientific Name	Common Name	Scientific Name	Common Name
Trees and Shrubs		Forbs Continued	
<i>Artemisia cana</i>	silver sagebrush	<i>Antennaria rosea</i>	rosy pussytoes
<i>Artemisia tridentata</i> spp. <i>vaseyana</i>	mountain big sagebrush	<i>Arabis</i> spp.	rock cress
<i>Artemisia tridentata</i> spp. <i>wyomingensis</i>	Wyoming big sagebrush	<i>Arenaria</i> spp.	sandwort
<i>Chrysothamnus nauseosus</i>	rubber rabbitbrush	<i>Arnica</i> spp.	arnica
<i>Chrysothamnus viscidiflorus</i>	green rabbitbrush	<i>Artemisia frigida</i>	prairie sagewort
<i>Juniperus communis</i>	common juniper	<i>Artemisia ludoviciana</i>	cudweed sagewort
<i>Juniperus scopulorum</i>	Rocky Mountain juniper	<i>Aster</i> spp.	aster
<i>Pinus flexilis</i>	limber pine	<i>Balsamorhiza sagittata</i>	arrowleaf balsamroot
<i>Pinus ponderosa</i>	ponderosa pine	<i>Besseyia</i> spp.	kittentail
<i>Pseudotsuga menziesii</i>	Douglas-fir	<i>Brassicaceae</i>	mustard
<i>Ribes</i> spp.	currant	<i>Calochortus</i> spp.	mariposa lily
Grass and Grass-Like Species		<i>Castilleja</i> spp.	paintbrush
<i>Elymus spicatus</i>	bluebunch wheatgrass	<i>Centaurea maculosa</i>	spotted knapweed
<i>Bouteloua gracilis</i>	blue grama	<i>Collinsia parvifolia</i>	blue-eyed Mary
<i>Bromus inermis</i>	smooth brome	<i>Collomia linearis</i>	tiny trumpet
<i>Bromus</i> spp.	brome	<i>Crepis</i> spp.	hawksbeard
<i>Carex</i> spp.	sedge	<i>Delphinium</i> spp.	larkspur
<i>Danthonia unispicata</i>	onespike danthonia	<i>Dodecatheon conjugens</i>	shooting star
<i>Festuca idahoensis</i>	Idaho fescue		Rocky Mountain
<i>Festuca scabrella</i>	rough fescue	<i>Douglasia montana</i>	Douglasia
<i>Koeleria macrantha</i>	prarie junegrass	<i>Erigeron compositus</i>	cutleaf daisy
<i>Leymus cinereus</i>	basin wildrye	<i>Erigeron</i> spp.	daisy
<i>Pascopyrum smithii</i>	western wheatgrass	<i>Eriogonum</i> spp.	buckwheat
<i>Poa pratensis</i>	Kentucky bluegrass	<i>Fritillaria pudica</i>	yellow bell
<i>Poa secunda</i>	Sandberg bluegrass	<i>Geranium</i> spp.	geranium
<i>Poa</i> spp.	bluegrass	<i>Geum triflorum</i>	prarie smoke avens
<i>Stipa viridula</i>	green needlegrass	<i>Haplopappus acaulis</i>	goldenweed
Cacti		<i>Helianthella</i> spp.	false sunflower
<i>Opuntia polykantha</i>	pricklypear cactus	<i>Heterotheca villosa</i>	hairy goldaster
Pteridophytes		<i>Heuchera parvifolia</i>	little leaf alumroot
<i>Selaginella densa</i>	spike moss	<i>Lepidium</i> spp.	pepperweed
Forbs		<i>Lewisia rediviva</i>	bitterroot
<i>Achillea millefolium</i>	common yarrow	<i>Linaria dalmatica</i>	Dalmation toadflax
<i>Agoseris glauca</i>	agoseris	<i>Linum perenne</i>	wild flax
<i>Allium</i> spp.	onion	<i>Lomatium</i> spp.	desert parsley
		<i>Lupinus</i> spp.	lupine

Table 19. Continued.

Elkhorn – Mountain Continued			
Scientific Name	Common Name	Scientific Name	Common Name
Forbs			
<i>Mertensia longiflora</i>	bluebell	<i>Senecio canus</i>	wooly groundsel
<i>Nothocalais</i> spp.	false dandelion	<i>Senecio</i> spp.	groundsel
<i>Orobanche</i> spp.	broomrape	<i>Taraxacum officinale</i>	common dandelion
<i>Phacelia linearis</i>	threadleaf phacelia	<i>Vicia</i> spp.	vetch
<i>Phlox diffusa</i>	spreading phlox	<i>Viola</i> spp.	violet
<i>Potentilla</i> spp.	cinquefoil	<i>Zigadenus</i> spp.	death camas
<i>Sedum</i> spp.	stonecrop		

Table 20. Plant species list for the mountain big sagebrush plots at the Pipestone study site in southwest Montana.

Pipestone – Mountain			
Scientific Name	Common Name	Scientific Name	Common Name
trees and shrubs		Forbs Continued	
<i>Artemisia tridentata</i> spp. <i>vaseyana</i>	mountain big sagebrush	<i>Antennaria</i> spp.	pussytoes
<i>Artemisia tridentata</i> spp. <i>wyomingensis</i>	Wyoming big sagebrush	<i>Arabis</i> spp.	rock cress
<i>Cercocarpus ledifolius</i>	curl leaf mountain mahogany	<i>Arenaria</i> spp.	sandwort
<i>Chrysothamnus nauseosus</i>	rubber rabbitbrush	<i>Artemisia frigida</i>	prairie sagewort
<i>Chrysothamnus viscidiflorus</i>	green rabbitbrush	<i>Aster</i> spp.	aster
<i>Juniperus scopulorum</i>	Rocky Mountain juniper	<i>Besseyia</i> spp.	kittentail
<i>Purshia tridentata</i>	bitterbrush	<i>Brassicaceae</i>	mustard
<i>Pseudotsuga mensiesii</i>	Douglas-fir	<i>Calochortus</i> spp.	mariposa lily
<i>Ribes</i> spp.	currant	<i>Chaenactis douglasii</i>	dusty maiden
<i>Tetradymia canescens</i>	horsebrush	<i>Crepis</i> spp.	hawksbeard
grass and grass-like species		<i>Delphinium</i> spp.	larkspur
<i>Elymus spicatus</i>	bluebunch wheatgrass	<i>Dodecatheon conjugens</i>	shooting star
<i>Bouteloua gracilis</i>	blue grama	<i>Douglasia montana</i>	Rocky Mountain Douglasia
<i>Calamagrostis</i> spp.	bluejoint reedgrass	<i>Erigeron compositus</i>	cutleaf daisy
<i>Carex</i> spp.	sedge	<i>Erigeron</i> spp.	daisy
<i>Festuca idahoensis</i>	Idaho fescue	<i>Eriogonum</i> spp.	buckwheat
<i>Festuca scabrella</i>	rough fescue	<i>Heterotheca villosa</i>	hairy goldaster
<i>Koeleria macrantha</i>	prairie junegrass	<i>Lappula</i> spp.	stickseed
<i>Pascopyrum smithii</i>	western wheatgrass	<i>Leptodactylon pungens</i>	granite gilia
<i>Poa pratensis</i>	Kentucky bluegrass	<i>Lewisia rediviva</i>	bitterroot
<i>Poa secunda</i>	Sandberg bluegrass	<i>Linum perenne</i>	wild flax
<i>Poa</i> spp.	bluegrass	<i>Lomatium</i> spp.	desert parsley
<i>Stipa comata</i>	needle and thread	<i>Lupinus</i> spp.	lupine
Cacti		<i>Mertensia</i> spp.	bluebell
<i>Opuntia polycantha</i>	pricklypear cactus	<i>Orthocarpus tenuifolius</i>	owl clover
Pteridophytes		<i>Penstemon</i> spp.	penstemon
<i>Selaginella densa</i>	spike moss	<i>Phacelia</i> spp.	phacelia
Forbs		<i>Phlox hoodii</i>	cushion phlox
<i>Achillea millefolium</i>	common yarrow	<i>Sedum</i> spp.	stonecrop
<i>Agoseris glauca</i>	agoseris	<i>Taraxacum officinale</i>	common dandelion
<i>Allium</i> spp.	onion	<i>Tragopogon dubius</i>	yellow salsify
		<i>Vicia</i> spp.	vetch

Table 21. Plant species list for the mountain big sagebrush plots at the Whitetail study site in southwest Montana.

Whitetail – Mountain			
Scientific Name	Common Name	Scientific Name	Common Name
Trees and Shrubs		Forbs Continued	
<i>Artemisia tridentata</i> spp. <i>vaseyana</i>	mountain big sagebrush	<i>Artemisia ludoviciana</i>	cudweed sagewort
<i>Artemisia tridentata</i> spp. <i>wyomingensis</i>	Wyoming big sagebrush	<i>Aster</i> spp.	aster
<i>Chrysothamnus nauseosus</i>	rubber rabbitbrush	<i>Besseyia</i> spp.	kittentail
<i>Juniperus communis</i>	common juniper	<i>Brassicaceae</i>	Mustard
<i>Juniperus scopulorum</i>	Rocky Mountain juniper	<i>Calochortus</i> spp.	mariposa lily
<i>Pinus flexilis</i>	limber pine	<i>Castilleja</i> spp.	paintbrush
<i>Pseudotsuga menziesii</i>	Douglas-fir	<i>Crepis</i> spp.	hawksbeard
<i>Ribes</i> spp	currant	<i>Delphinium</i> spp.	larkspur
<i>Rosa woodsii</i>	Woods rose	<i>Erigeron compositus</i>	cutleaf daisy
<i>Tetradymia canescens</i>	horsebrush	<i>Erigeron</i> spp.	daisy
Grass and Grass-Like Species		<i>Eriogonum</i> spp.	buckwheat
<i>Elymus spicatus</i>	bluebunch wheatgrass	<i>Frageria vesca</i>	wild strawberry
<i>Agropyron</i> spp.	wheatgrass	<i>Geum triflorum</i>	prairie smoke
<i>Bouteloua gracilis</i>	blue grama	<i>Gutierrezia sarothrae</i>	broom snakeweed
<i>Bromus tectorum</i>	cheatgrass	<i>Heterotheca villosa</i>	hairy golden aster
<i>Carex</i> spp	sedge	<i>Heuchera parvifolia</i>	little leaf alumroot
<i>Danthonia unispicata</i>	onespike danthonia	<i>Lappula</i> spp.	stickseed
<i>Festuca idahoensis</i>	Idaho fescue	<i>Lepidium</i> spp.	pepperweed
<i>Festuca scabrella</i>	rough fescue	<i>Lewisia rediviva</i>	bitterroot
<i>Koeleria macrantha</i>	prairie junegrass	<i>Linaria dalmatica</i>	Dalmation toadflax
<i>Poa pratensis</i>	Kentucky bluegrass	<i>Linum perenne</i>	wild flax
<i>Poa secunda</i>	Sandberg bluegrass	<i>Lomatium</i> spp.	desert parsley
<i>Poa</i> spp.	bluegrass	<i>Lupinus</i> spp.	lupine
<i>Stipa comata</i>	needle and thread	<i>Mertensia longiflora</i>	bluebell
<i>Stipa viridula</i>	green needlegrass	<i>Oxytropis</i> spp.	locoweed
Pteridophytes		<i>Penstemon aridus</i>	stiffleaf penstemon
<i>Selaginella densa</i>	spike moss	<i>Phacelia</i> spp.	phacelia
<i>Woodsia oregana</i>	western cliff fern	<i>Phlox hoodii</i>	cushion phlox
Forbs		<i>Potentilla</i> spp.	cinquefoil
<i>Achillea millefolium</i>	common yarrow	<i>Sedum</i> spp.	stonecrop
<i>Agoseris glauca</i>	agoseris	<i>Senecio</i> spp.	groundsel
<i>Allium</i> spp.	onion	<i>Sphaeralcea coccinea</i>	globemallow
<i>Antennaria rosea</i>	rosy pussytoes	<i>Taraxacum officinale</i>	common dandelion
<i>Arabis</i> spp.	rock cress	<i>Tragopogon dubius</i>	yellow salsify
<i>Arenaria</i> spp.	sandwort	<i>Vicia</i> spp.	vetch
<i>Artemisia frigida</i>	prairie sagewort	<i>Viola</i> spp.	violet
		<i>Zigadenus</i> spp.	death camas

APPENDIX C:

BEST-FIT REGRESSION LINES FOR THE RELATIONSHIP BETWEEN
CONIFER COVER AND WYOMING AND MOUNTAIN
BIG SAGEBRUSH COVER IN SOUTHWEST MONTANA

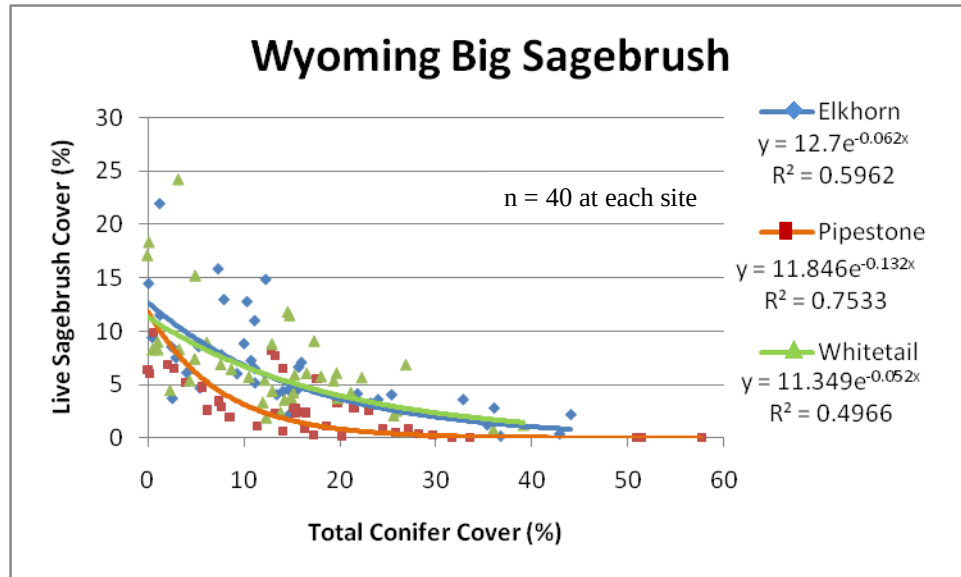


Figure 8. The relationship between total conifer cover and live sagebrush cover for the Wyoming big sagebrush plots at the Elkhorn, Pipestone and Whitetail study sites in southwest Montana.

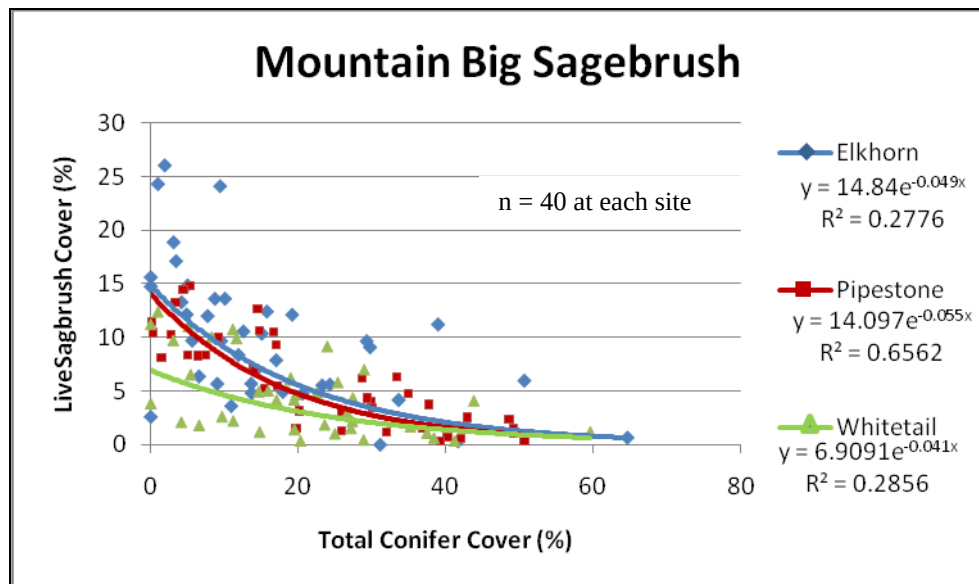


Figure 9. The relationship between total conifer cover and live sagebrush cover for the mountain big sagebrush plots at the Elkhorn, Pipestone and Whitetail study sites in southwest Montana.