

FACTORS INFLUENCING BIG SAGEBRUSH COVER IN  
SOUTHWEST MONTANA

by

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## ABSTRACT

The sagebrush steppe provides important habitat to many wildlife species. Conifer expansion of Douglas-fir and Rocky Mountain juniper into this area is a growing concern. Currently management focuses on the removal of Rocky Mountain juniper. The primary objective of this study was to determine the relationship between live sagebrush cover and aspect, slope, elevation, soil texture, soil depth and rock outcroppings. The second objective was to compare Douglas-fir and Rocky Mountain juniper's canopy areas at comparable ages.

Percent cover of shrubs and conifers as well as the abiotic factors were recorded at forty Wyoming and forty mountain big sagebrush plots at each of three study sites in southwest Montana (Pipestone, Elkhorn, and Whitetail) ( $n = 240$ ). The best-fit model utilizes the terms site, sagebrush subspecies, square root of conifer cover and site by sagebrush subspecies as the independent variables, with square roots of sagebrush cover as the dependent variable. The model found that abiotic factors had no correlation ( $p > 0.05$ ) with live sagebrush cover, but conifer cover had a negative effect on sagebrush cover.

Equations were developed to predict canopy area of Douglas-fir and Rocky Mountain juniper thru time. Our findings suggest conifers should not be removed to increase sagebrush cover due to low response of sagebrush cover. Douglas-fir is the dominant conifer on these sites and has three times more canopy than Rocky Mountain juniper at similar ages ( $p < 0.001$ ). Rocky Mountain juniper is generally thought to have higher food and cover values for deer and elk and upland game birds compared to Douglas-fir (Gunderson 1990, Kufeld 1973). Therefore, the current practice of removing Rocky Mountain juniper to increase sagebrush cover should not be continued.

## INTRODUCTION

The sagebrush steppe is among the most endangered ecosystems in the United States (Noss et al. 1995) and provides important habitat to several wildlife species. Only 50 percent of the sagebrush steppe remains today due to destructive practices such as urbanization, agriculture, oil and gas development, roads, recreation (Welch 2005) and conifer expansion (Arno and Gruell 1986). Big sagebrush (*Artemisia tridentata* Nutt.) communities have been recognized for their importance to wildlife and are no longer viewed as a pest species by many land managers (Vale 1974, Knick and Rotenberry 1997, Knick et al. 2003). However there is little research on management plans to conserve the ecotone between the big sagebrush steppe and forest habitats. A lack of previous research also exists on how abiotic environmental factors (aspect, slope, elevation, soil texture, soil depth, and rock outcroppings) affect sagebrush cover.

Natural resource agencies state that encroaching conifers are often controlled to maintain or improve forage for domestic livestock and wildlife, and to maintain diverse, healthy and dynamically stable ecosystems (USDA 1987, BLM 1997). In southwestern Montana, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) are the principle conifer species expanding into these areas. Prescribed burning and cutting are often used to control encroaching conifers (USDA 1987). However, the use of some of these practices in big sagebrush communities may eliminate big sagebrush and other non-sprouting shrubs (Wambolt and Payne 1986, Lesica et al. 2007), while possibly only having a marginal effect on Douglas-fir and Rocky Mountain juniper. Management focus is usually on the Rocky Mountain juniper

rather than Douglas-fir, even though Douglas-fir is known to grow faster (Sherich et al. 2007) and has a lesser wildlife importance (Graffney 1941, Kufeld 1973). Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis*) and mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana*) communities are essential habitats to many obligatory species, and therefore it is important to understand what is controlling sagebrush cover and when management is necessary.

The primary objective of this study was to determine the relationship between live sagebrush cover and abiotic factors such as: aspect, slope, elevation, soil texture, soil depth and percent rock outcroppings. The second objective was to compare Douglas-fir and Rocky Mountain juniper's canopy areas at comparable ages.

## LITURATURE REVIEW

The Sagebrush Steppe

The sagebrush steppe occurs in high elevation basins above 1200 meters and consists of a mosaic of shrubs, forbs and grass species dominated by sagebrush (*Artemisia spp.* Nutt.). Big sagebrush favor areas that receive the majority of their precipitation in the winter months and the least in the summer months (Smith 1940, Cook and Irwin 1992, Whitelock and Bartlein, 1993). The sagebrush steppe today covers over 30,000,000 hectares of North America (Wisdom et al. 2005), although this is only half of the amount of habitat it once provided prior to European settlement (Wallestad 1975). Due to urbanization, agriculture, oil and gas development, roads and recreation, much of the sagebrush steppe no longer exists (Welch 2005). Another cause of this area's reduction is conifer expansion. Conifer species, usually confined to moist sites, rock outcroppings and talus are establishing into the sagebrush steppe (Arno and Gruell 1986). Within southwest Montana, two conifer species, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) have become established in Wyoming big sagebrush (*Artemisia tridentata* Nutt. *ssp. wyomingensis*) and Mountain big sagebrush (*Artemisia tridentata* Nutt. *ssp. vaseyana*) plant communities.

### Forest/ Sagebrush Steppe Ecotone

The transition zone between the Douglas-fir/Rocky Mountain juniper forest and the sagebrush steppe is an important habitat to wildlife. It contains characteristics of each bordering community (Encyclopedia Britannica, 2010). An ecotone area often has higher density and diversity of species than are found in either community, this concept is called the edge effect (Harris, 1988). Elk, mule deer, and other big game species also find important winter range located in this forest/ sagebrush shrub ecotone, where a mixture of food and cover are provided (Knight 1994).

### Big Sagebrush Sub-Species

#### Wyoming Big Sagebrush

In order to evaluate the influence abiotic factors have on sagebrush cover it is important to understand the biology of the subspecies of big sagebrush. Wyoming big sagebrush is the most common shrub of the intermountain basin (Knight 1994). It is on average 0.5 meters tall, is found at elevations ranging from 1,600 to 2,800 meters and establishes on the most xeric sites of all the big sagebrush subspecies (Frisina and Wambolt 2002). These sites have shallow soils and a large amount of clay and occasionally silt in the soil profile.

### Mountain Big Sagebrush

Mountain big sagebrush is about one meter tall, with typically larger canopy cover than Wyoming big sagebrush and occurs in the foothill shrublands adjacent to mountain forests (USDA NRCS 2010b). It requires more moisture and is found in areas with greater levels of precipitation at higher, cooler elevations, typically ranging from 2,200 meters to 3000 meters (Knight 1994). The soils occupied by mountain big sagebrush are typically deeper than those occupied by Wyoming big sagebrush and range from sandy to clay textured soils (Frisina and Wambolt 2002).

### Abiotic Factors Controlling Big Sagebrush Cover

Since big sagebrush lacks the capacity to sprout from roots or root crown, longevity and seed production are essential to the persistence of this habitat. This paper will examine six abiotic factors: aspect, slope, elevation, soil texture, soil depth, and rock outcroppings, in order to examine their influence on sagebrush cover.

#### Aspect, Slope and Elevation

Aspect, slope and elevation are all important topographical variables that could be an influence on sagebrush cover. Big sagebrush cover in Wyoming (Burke et al. 1989) and topographical variables aspect, slope, elevation and fetch shared 66.6 percent of their variation thru this correlation. In Oregon and Idaho, Johnson and Miller (2006) found that when holding slope constant, a shift from north to south aspect resulted in 4.9 trees/ha/year decrease in western juniper establishment at a similar elevation. A 200 meter rise in elevation was associated with a 1.8 trees/ha/yr increase in tree establishment

with similar exposure. Waichler et al. (2001) also found strong topographic correlations with vegetative growth in old-growth western juniper woodlands. A 59 percent correlation between species composition and elevation was found and a 46 percent correlation between species composition and slope was recorded. These density and species composition studies have a high positive correlation with cover. The majority of current research focuses on western juniper and not Rocky Mountain juniper. Western Juniper occurs in a moister climate and has a higher expansion rate. However, from this information we can hypothesize that abiotic factors aspect, slope and elevation may influence sagebrush cover.

#### Soil Texture

Soil texture is another abiotic factor which may have an influence on sagebrush cover. Physical and chemical properties of the soil, particularly at the rooting zone, which for most vascular plants is to a depth of about 20 centimeters, plays a very important role in shaping vegetation (Solon 2007). Coarser textured soils permit greater infiltration and deeper percolation, which enables water to accumulate beyond depths effectively exploited by sagebrush and other herbaceous understory. This area may support more woody vegetation, which could access the water and nutrients with their deeper and more extensive root systems. Finer soils that retain moisture and nutrients in the upper soil layers generally favor vegetation with dense, shallow root systems, by limiting water percolation into lower horizons, such as grasses (Archer et al. 1994).

In Waichler et al.'s (2001) study of community characteristics on western juniper, the strongest correlation between species composition and abiotic parameters was the

percent sand in soil. Seventy percent of species composition was explained by the variation in the percent sand found in the A horizon. Big sagebrush distribution among soil texture is typically clumped around the loamy sand to sandy loam areas, however Wyoming big sagebrush is known to persist in areas with higher clay content when compared to mountain big sagebrush. On these sandier soils, mountain big sagebrush has been shown to have a higher canopy cover on average (Knight 1994). Previous research leads us to believe that soil texture may be used to predict sagebrush cover.

### Soil Depth

Soil depth to structural barriers such as ironstone and caliche, can influence the distribution and abundance of conifers versus sagebrush versus grasses and forbs. Woody plants dominate sites where geomorphic barriers are relatively deep or where their roots exploit fissures, crevasses or subterranean catchments where water and nutrients accumulate (Archer et al. 1994). Big sagebrush plants have a two-part root system with a deep tap root and a shallow, diffuse root system. Numerous studies have shown sagebrush plants create “hydraulic lift”, where deep soil moisture is brought near the soil surface by the tap root system during the day and then released into the upper soil at night. This water is then available to the diffuse root system of big sagebrush as well as to the roots of other understory plants. Big sagebrush generally occurs in deeper soils than other sagebrush and grass species, however there is a high variation found among the species ranging from 50 to 95 centimeters (Knight 1994). The USDA NRCS (2010c) estimates that on average Wyoming big sagebrush is found at soil depths of 10 to 30

centimeters where barriers such as caliche layers are possible. Mountain big sagebrush is found at depths of 18 to 36 centimeters. These results suggest that an increase in soil depth will correlate with an increase in sagebrush cover.

### Rock Outcroppings

The amount of rock found in the soil has also been correlated with vegetative distribution. The percentage of rock found on site shared 45 percent of its variation with species composition when measured in Waichler et al.'s (2001) study of old growth juniper woodlands. According to Zohary (1973) conifer canopy cover on cliffs and rock outcrops is more than other stony habitats, because in rock crevices fine soil material is accumulated and most of the rain that falls into these clefts is protected against evaporation. I hypothesized that this conifer-dominated habitat around rock outcroppings would not be favorable for sagebrush and therefore with an increase in percent rock outcroppings we will find a decrease in sagebrush cover.

### Conifer Expansion

Conifer expansion is defined as an increase in tree density or area of occupation. The rate of conifer expansion over the last one hundred and thirty years has been unprecedented. Not only is climate having an impact, but increased livestock grazing beginning in the late 1800's and decreased fire frequencies since that time have caused this trend (Sindelar 1971, Miller et al. 2000, Powell et al. 2004). Under the state and transitional model of ecosystems, these factors would cause a transition between alternative steady states (Westoby et al. 1989). Sagebrush can act as a nurse plant for tree

seedlings, providing shelter and nutrients (Arno and Gruell 1983, Miller and Rose 1999). Waugh (1986) noted that 90 percent of juniper seedlings became established under sagebrush within their study. Douglas-fir was found to be the principal invader of grassland communities in southwest Montana (Sindelar 1971). Expansion of Douglas-fir into grassland and shrubland communities has been documented by Sindelar (1971), Arno and Gruell (1983) and Heyerdahl et al. (2006). Since 1860 the area occupied by juniper species has increased 125 to 625 percent in central and northern Great Basin (Miller et al. 2000). Rates of western juniper expansion have been recorded as high as 4.5 percent per year (Strand et al. 2007). That is a 100 percent increase in juniper canopy cover in only 22 years. Research in the Greater Yellowstone Ecosystem found an average rate of conifer expansion of 0.25 percent per year (Powell et al. 2004). This rate was variable depending on elevation and aspect, with the highest rates being about 0.5 percent per year, which is an increase in canopy cover of 65 percent since grazing and fire suppression decreased fire frequencies starting about 130 years ago.

Tausch et al. (1981) states that the loss of understory vegetation from conifer expansion has reduced the amount of burnable fuel, leading to the frequency of fires diminishing and adding to the rate and area of change. Forage reduction and decreased frequency of burning will probably occur until trees dominate most of the areas suitable to their survival (Tausch et al. 1981).

### Douglas-fir and Rocky Mountain Juniper Canopy

On average Douglas-fir grows 30 centimeters per year on these forest edges (Sherich et al. 2007) while Rocky Mountain juniper grows 10.3 centimeters per year (Mueller et al. 2005). With a faster growth rate, we hypothesize that Douglas-fir will have a larger canopy cover than Rocky Mountain juniper at similar ages. Previous research on conifer canopy cover has demonstrated a negative effect on sagebrush cover (Miller 2000, Grove et al. 2005, Kitchen 2010).

Miller et al. (2000) modeled the relationship between western juniper and mountain big sagebrush cover within different plant associations in Northeast California and Southeast Oregon. The  $r^2$  values of 0.92 to 0.96 show a strong correlation between increasing western juniper cover with decreasing shrub cover in all three, mountain big sagebrush/grass associations they studied.

Grove et al. (2005) modeled a strong negative relationship between increasing Douglas-fir cover and decreasing mountain big sagebrush cover in southwest Montana ( $r$  value = -0.86). Grove found that on sites with no or occasional Douglas-fir, mountain big sagebrush cover generally exceeded 20 percent. As Douglas-fir cover increased to 20 percent, mountain big sagebrush cover decreased to below 15 percent and as Douglas-fir increased above 35 percent, sagebrush cover decreased below 5 percent.

In a companion study to this thesis, Kitchen (2010) evaluated the effects of Douglas-fir and Rocky Mountain juniper canopy cover on live big sagebrush cover among the same sites as my study. She found the combined canopy cover had a significant negative effect on sagebrush cover among all sites within the forest/shrub

steppe ecotone. Sixty-one percent of the variability in live sagebrush cover was explained by the percent of conifer cover. However, the effect of Douglas-fir and Rocky Mountain juniper canopy cover on live sagebrush cover was not different (Rocky Mountain juniper –  $p = 0.18$ , Douglas-fir -  $p = 0.07$ ). She also found that live sagebrush cover was not different in mountain big sagebrush communities vs. Wyoming big sagebrush communities ( $p = 0.69$ ). The mean sagebrush cover within Wyoming big sagebrush sites was 11.74 percent (SE = 1.47) and the average of the sagebrush cover among mountain big sagebrush sites was 12.8 percent (SE = 2.21).

Previous research is valuable to guide future management decisions for the forest/sagebrush steppe ecotone. Information concerning the abiotic factors influencing sagebrush cover as well as the effect of the individual trees' canopy areas is still needed. My research will aim to answer these questions.

### Importance of Big Sagebrush, Douglas-fir and Rocky Mountain Juniper to Wildlife

#### Big Sagebrush

Two morphological characteristics make big sagebrush an important resource to wildlife species: a deep, extensive root system and a rigid, tall stature (Welch 2005). A deep, extensive root system allows big sagebrush to draw water from a greater volume of soil than grasses and forbs. This makes big sagebrush a more dependable forage source during both seasonal and extended drought (Medin and Anderson 1979). Medin and Anderson (1979) observed declines in true mountain mahogany (*Cercocarpus ledifolius* Nutt.) and antelope bitterbrush (*Purshia tridentate* (Pursh) DC.) during marked decreases

in annual precipitation in 1962–1964. During the same time, big sagebrush produced stable yields, which suggests that it is less susceptible to drought. Hence, it is a more reliable forage source. Second, a taller and rigid stature makes big sagebrush more available for consumption during periods of deep snow (Welch 1989).

The sagebrush steppe provides habitat for 94 bird species and 87 mammals, many of which are obligatory species (The Sagebrush Steppe Campaign 2008). This habitat is also important winter range providing food to many big game species such as elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) (Personius et al. 1987). Big sagebrush foliage retains an average crude protein content of 12.4 percent during the winter months when grasses are relatively low (Wambolt 1999). Fifty-two percent of the mule deer's winter diet consists of sagebrush in the Gallatin National Forest of southwest Montana (Wambolt 1996). Research shows that of all sagebrush subspecies, mountain big sagebrush is most preferred by elk and mule deer at 56 percent winter utilization rates and Wyoming big sagebrush is the second most preferred at 39 percent winter utilization rates (Wambolt 1996). However, Striby and others (1987) found Wyoming big sagebrush as the preferred subspecies by big game during the winter based on form class assessment and found mountain big sagebrush to be second most preferred. Sagebrush also provides protective cover for mule deer fawns and elk calves, nesting habitat for songbirds, and shelter for small mammals (Kufeld 1973, Peterson 1995). A study in central Montana found that 93 percent of pronghorn sampled (*Antilocapra americana*) wintered in sagebrush areas and these shrub-grassland areas were the most preferred during summer months as well (Bayless 1969). Bighorn sheep (*Ovis Canadensis*) consume sagebrush as

the number one item in their winter diet at 25 percent (Keating et al. 1985). Sage grouse (*Centrocercus urophasianus*) are an obligate species of the sagebrush steppe (Roberson 1984). Almost 100 percent of the adult sage grouse winter diet consists of sagebrush in Montana (Wallestad 1975). Sage grouse also require 15 to 25 percent sagebrush cover for nesting and 10 to 30 percent cover during winter months (Davies et al. 2006).

The wildlife species of the sagebrush steppe require a mosaic of sagebrush cover (Baker, 2006; Lesica, 2007). For example sage grouse require barren land for leks, relatively dense stands of medium height for nesting (Klebenow 1969, Wallestad and Pyrah 1974, Aldridge and Brigham 2002, Lesica et al. 2007), open stands for brood rearing (Wallestad 1971, Klebenow 1973, Lesica 2007), and tall stands with full canopy for wintering (Wallestad 1975, Eng and Schladweiler 1992).

### Douglas-fir

Douglas-fir is a common conifer of southwest Montana, typically occurring at the shrub/forest interface. The twigs and foliage are browsed by several big game species such as pronghorn, mule deer, white-tailed deer (*Odocoileus virginianus*), elk, and mountain sheep (*Ovis spp.*). Mule deer have been documented only using trace amounts of Douglas-fir as forage in the Bridger and Little Belt Mountains of Montana (Wilkins 1957, Lovass 1958, Schwarzkoph 1973, Steerey 1979). The winged seeds are eaten by western squirrels (*Sciuridae*), mice (*Mus spp.*), and dusky-footed woodrats (*Neotoma fuscipes*). The staminate cones and needles provide a significant food source for many bird species including the dusky grouse (*Dendragapus obscurus*) (USDA, NRCS 2010e).

Douglas-fir also provides protective cover for several wildlife species by establishing moderate to dense stands (Flint 1925).

### Rocky Mountain Juniper

Rocky Mountain juniper is the dominant juniper species found in southwest Montana and is the most widespread of the eleven native species. Rocky Mountain juniper is usually found in association with other trees such as Douglas-fir and shrubs such as big sagebrush (Mueggler and Stewart 1980). Juniper provides important cover, nesting habitat and food for wildlife (USDA, NRCS 2010d). The berry-like seed cones are an important source of nutrients to several bird and mammal species. Rocky Mountain juniper provides protective and nesting cover. Chipping sparrows (*Spizella passerina*), American robins (*Turdus migratorius*), song sparrows (*Melospiza melodia*), mocking birds (*Mimus* spp.) and Sharp-tailed grouse (*Tympanuchus phasianellus*) use these trees as their primary nesting sites (Gunderson 1990, Sieg 1991, USDA, NRCS 2010d). Many other bird species including Dark-eyed Junco (*Junco hyemalis*), Myrtle Warbler (*Dendroica coronata*), and sparrows (*Emberizidae*) of various types use the dense foliage as roosting cover. This dense protective shelter is particularly important during the winter months (USDA, NRCS 2010d).

The twigs and foliage of Rocky Mountain juniper provide forage for many big game ungulate species. Deer have been adversely affected by juniper reduction because of its forage and cover values (USDA NRCS 2010d). Within the Flathead national Forest of Montana, browsing of conifers, with the exception of Rocky Mountain juniper, was almost entirely restricted to the over browsed areas (Gaffney 1941). Even though juniper

was limited in distribution and made up a relatively small volume of the total forage, which included Douglas-fir, it was the most palatable of the group. In a literature review by Kufeld (1973) of elk and mule deer food habits within the Rocky Mountain range of the Western United States and Canada, Rocky Mountain juniper was found to be a valuable food source. Elk and Mule deer utilized Rocky Mountain juniper more than Douglas-fir in winter and spring and at comparable rates in the fall. Not only is Rocky Mountain juniper an important food source, it also provides thermal cover for winter survival and shade during the summer months (USDA NRCS 2010d).

Wyoming big sagebrush, mountain big sagebrush, Douglas-fir, and Rocky Mountain juniper all provide important food, shelter and cover to wildlife species. This review has determined that within these areas, Rocky Mountain juniper has more food and cover values to wildlife than Douglas-fir.

#### Forest/ Sagebrush Steppe Ecotone Modifications

Even though conifer expansion rates in southwest Montana have not been found to be as high as in other places in the West, this is still considered an important issue by land management agencies within the state. The concerns associated with increased conifer cover are an increased fuel load, the alteration of species composition and the impact that will have on domestic livestock and wildlife (USDA 1986, USDA 1987).

Often land management agencies are dealing with these issues by treating the juniper through burning and cutting. An incomplete picture exists of the interaction between the combined conifer cover of Rocky Mountain juniper and Douglas-fir on

sagebrush cover and when and what species of conifers should be treated. Currently juniper is treated rather than the Douglas-fir even though Douglas-fir grows faster (Sherich et al. 2007, USDA NRCS 2010e).

### Prescribed Burning

One of the proposed causes of conifer expansion into the sagebrush steppe is a reduction in fire frequency (Gruell 1983, Arno and Gruell 1983, Arno and Gruell 1986). Sagebrush is highly flammable and when prescribed burning is used to manage conifer expansion it may take the sagebrush longer to recover than the conifer species being managed, as well as open the site for invasive species. Ground or low intensity fires may help in controlling Douglas-fir seedlings (trees <1.5m) and saplings (2 to 13cm DBH) and poles (18 to 30cm DBH) (Gruell et al., 1986). However mature Douglas-fir consists of a very thick bark, which provides them protection from ground fires (Flint 2005). Douglas-fir consists of branches that run the full length of the bole (Fischer and Clayton 1983) which can carry ground fires to the crown (Starker 1934), killing the tree. Rocky Mountain juniper have even lower growing branches and can therefore carry fire to the crown quicker, but typically trees over three meters have high survival (Baker and Shinneman 2004) as well as trees on rocky sites (Miller and Rose 1999).

In southwest Montana, a study on mountain and Wyoming big sagebrush found near complete mortality of sagebrush on prescribed burned sites (Lesica et al. 2007). Several studies suggest that sagebrush is easily killed by fire (Blaisdell 1953, Harniss and Murray 1973, Bushey 1986). Because mountain and Wyoming big sagebrush are non-

sprouting and must reproduce through seed, the time for recovery is highly variable (Grove 1998). Mountain big sagebrush canopy cover recovery rate following fire has been estimated at 1.6 percent per year and the average recovery time was 32 years, however the canopy cover recovery rate for Wyoming big sagebrush was more than ten times slower after fire, at less than one percent recovery a year. It was estimated that a Wyoming big sagebrush site would take anywhere from 50 to 120 years to recover after fire (Lesica et al. 2007).

Another area of concern surrounding the issue of prescribed burning is the invasion of non-native species (Lesica et al. 2007). Prescribed burning can leave bare mineral soil available for invasive species establishment. Invasive alien grasses especially benefit from fire, and promote recurrent fire, in many cases to the point where native species cannot persist and native plant assemblages are converted to alien-invaded annual grasslands. This vegetation type-conversion can affect wildlife and reduce overall biodiversity. Invasive plants and fire create substantial challenges for land managers (Brookes and Pyke 2002). The Bureau of Land Management (2004) reported that repeated wildfires, fueled by the invasive annual cheatgrass (*Bromus tectorum* L.) and other exotic species, altered vast acres of the sagebrush steppe in the Great Basin, Columbia Plateau, and other ecoregions of the West. This negative byproduct of prescribed burning should be taken into consideration when selecting a management plan for the forest/sagebrush steppe ecotone.

Cutting

Cutting is the process of selectively removing unwanted conifers, usually with chain saws. This process would require high labor however destruction of non-target species would be minimal and may occur as a single treatment or a preparatory treatment for prescribed burning. In order to develop the proper management for a sagebrush community, monitoring resources over time with the intent of providing data that reflect changes in the status or trends of the system is essential (West et al. 1984).

## METHODS

Study Area Description

Three areas within southwestern Montana were chosen to represent the region's forest/ sagebrush steppe ecotone containing Douglas-fir and Rocky Mountain juniper: Pipestone, Elkhorn, and Whitetail (Map: Fig. 1, Table 1). One mountain big sagebrush and one Wyoming big sagebrush site was chosen within each area. Study sites were geographically separated to increase the study's range of inference. The sites had the following requirements for selection: 1) presence of Rocky Mountain juniper and Douglas-fir establishment in the sagebrush steppe, 2) large enough area for 40, 30x30 meter plots with adequate access, 3) no recent impacts on the sagebrush community from burning, spraying and cutting and 4) a mixture of abiotic factors (range of aspect, elevation, slope, and rock out croppings).

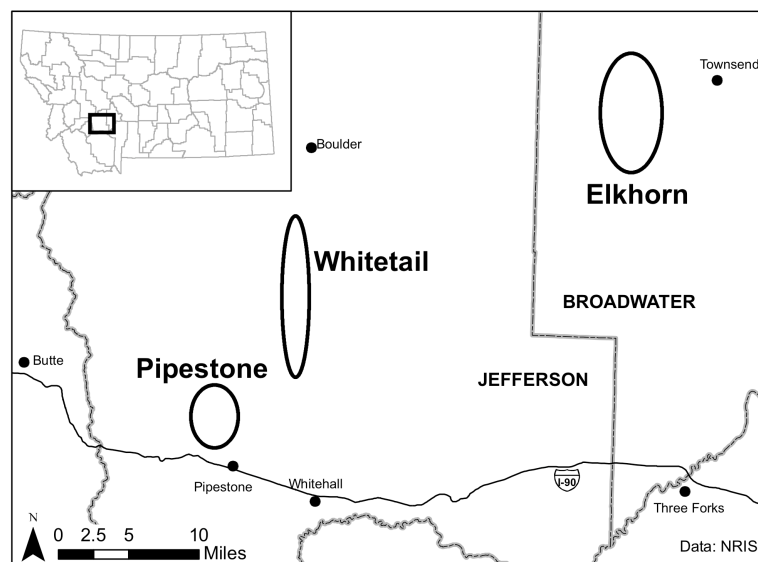


Figure 1. Map of the Elkhorn, Pipestone and Whitetail study sites in Jefferson and Broadwater counties, Montana.

Table 1. Legal descriptions and date of collection at each big sagebrush area (one mountain big sagebrush and one Wyoming big sagebrush site within each area).

<b>Site</b>	<b>Legal Description</b>	<b>Date</b>
Pipestone	45°56'N to 46°00'N 112°14'W to 112°18'W	May – August 2009
Elkhorn	46°14'N to 46°21'N 111°38'W to 111°43'W	May – August 2009
Whitetail	46°02'N to 46°11'N 112°06'W to 112°10'W	May – August 2009

### Pipestone

The Pipestone area is located in Jefferson County. This 12140 hectares travel management area is located approximately fifteen miles east of Butte and just north of I-90 (Table 1). The site consists of a mixture of Bureau of Land Management and U.S. Forest Service land. The soil's parent material is classified as intrusive igneous rock from the boulder batholith (Montagne et al. 1982) derived from volcanics of late Cretaceous age, and Butte Quartz Monzonite which includes and is coextensive with Clancy Granodiorite (Smedes et al. 1968). The Wyoming big sagebrush soils are classified as loamy, mixed, superactive, frigid Lithic Argiustolls (USDA NRCS 2010a). The mountain big sagebrush soils are classified as coarse-loamy, mixed, superactive, frigid Lamellic Haplustepts. The area's elevation ranges from 1780 to 2428 meters. Mean annual air

temperature ranges from 2.2 to 6.1 degrees Celsius and mean annual precipitation ranges from 38.1 to 48.3 centimeters, with an 80 to 95 day frost-free period (USDA NRCS 2010a). The Pipestone Wyoming site consisted of a dominant plant community of Wyoming big sagebrush with a dominant understory of bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve ssp. *Spicata*). The Pipestone mountain site consists of a dominant plant community of mountain big sagebrush with a dominant understory of Idaho fescue (*Festuca idahoensis* Elmer).

### Elkhorn

The Elkhorn site is located in Broadwater County just southwest of Townsend (Table 1). The Elkhorn BLM and US Forest Service land covers over 1416 hectares and consists of patches of private land as well. The soil's parent material is classified as colluvium and residuum from igneous rock or hard shale and sandstone (USDA NRCS 2010a) derived from Paleozoic sedimentary rocks, Mesozoic sedimentary rocks, and upper Cretaceous volcanic rocks (Klepper et al. 1971). Within the Wyoming big sagebrush site the soil is classified as loamy-skeletal, mixed, superactive Ustic Argicryolls (USDA NRCS 2010a). The mountain big sagebrush site contains soils classified as clayey-skeletal, smectitic Ustic Argicryolls. Elevation ranges from 1249 to 1554 meters. Mean annual air temperature is 5.6 to 7.2 degrees Celsius and mean annual precipitation is 25.4 to 35.6 centimeters with 95 to 120 frost-free days (USDA NRCS 2010a). The Elkhorn Wyoming site consists of a dominant plant community of Wyoming big sagebrush with a dominant understory of bluebunch wheatgrass. The Elkhorn

mountain site consisted of a dominant plant community of mountain big sagebrush with a dominant understory of Idaho fescue.

### Whitetail

The Whitetail site consists of Hay Canyon and Pony Canyon within the Beaverhead-Deerlodge National Forest of Jefferson County (Table 1). This area is a mixture of private land (Fitzgerald Ranch) leading into BLM and Forest Service land. The soil's parent material is intrusive igneous rock from the boulder batholith (Montagne et al. 1982) derived from volcanics of late Cretaceous age, and Butte Quartz Monzonite which includes and is coextensive with Clancy Granodiorite (Smedes et al. 1968). The Wyoming soils are classified as loamy-skeletal, mixed, superactive, frigid Lithic Haplustolls. The Mountain big sagebrush sites soils are classified as loamy-skeletal, mixed, superactive, frigid Lithic Argiustolls (USDA NRCS 2010a). The area's elevation ranges from 1829 to 2347 meters. Mean annual air temperature is 2.2 to 3.9 degrees Celsius and mean annual precipitation is 55.9 to 71.1 centimeters with 30 to 60 frost-free days. The Whitetail Wyoming site consists of a dominant plant community of Wyoming big sagebrush with a dominant understory of bluebunch wheatgrass. The Whitetail mountain site consists of a dominant plant community of mountain big sagebrush with a dominant understory of Idaho fescue.

### Study Design

Data was collected from the six study sites in southwest Montana (Pipestone Wyoming, Pipestone Mountain, Elkhorn Wyoming, Elkhorn Mountain, Whitetail Wyoming and Whitetail Mountain). Forty plots within each study site were subjectively selected to represent the entire range of canopy cover in comparison to sagebrush cover (Grove 1998). Latitude and longitude of each corner was recorded using a Garmin GPS V. Abiotic (slope, aspect, elevation, soil depth, soil texture, and percent rock outcroppings) and biotic (cover, density, understory vegetation, canopy area and tree age) factors were measured within each plot.

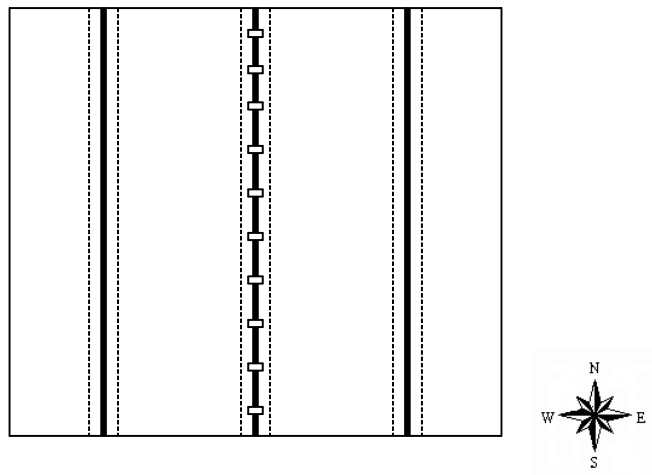


Figure 2. Plot layout for the forty Wyoming big sagebrush and forty mountain big sagebrush plots within the Pipestone, Elkhorn and Whitetail sites. 30 m x 30 m plot with three 30 m transect lines, 3, 2m x 30m belt transects and ten 20cm x 50cm Daubenmire frames.

## Field Procedure

### Abiotic Factors

In order to determine the correlations of sagebrush cover with influencing abiotic variables, slope, aspect, elevation, soil depth, soil texture, and percent rock were recorded for each plot. Slope for each plot was measured with a clinometer (Waichler et al. 2001). Aspect was measured with a compass (Johnson and Miller 2006). Elevation was determined with a Garmin GPS V at the southeast corner of each plot. Soil depth was measured with a probe from the soil surface to solum at each plot (Montagne 2009). A soil kit was used at this time to test soil texture through hand texturing (Grove, 1998, Montagne 2009, USDA NRCS 2009). Percent rock was assessed at each site through ocular estimates (Waichler et al. 2001).

### Canopy Cover

Canopy cover of both Douglas-fir and Rocky Mountain juniper was collected within plots at each study site using the line intercept method (Canfield 1940) along 3, 30 meter (m) transect lines. Transects were placed evenly across the south to north axis of the plots. Canopy cover was defined as actively growing plant material such as leaves current growth twigs and reproductive stalks (Creamer 1991, Grove 1998). Gaps in canopy cover greater than three centimeters (cm) were not counted (Wambolt et al. 2006). Measurements were recorded as percent cover (Grove 1998).

### Canopy Area

The canopy area of conifers in each sagebrush community was estimated by recording tree canopy cover and age. Conifer canopy was recorded by measuring the radius of each tree's canopy cover within the plot with a meter stick and converting it to area ( $\pi r^2$ ). The size of each tree was also recorded. Diameter at breast height (DBH) was measured 1.3 meters off of the ground for Douglas-fir (Omule 1987, Grove 2005) and the basal trunk diameter (BTD) was measured within 10 decimeters of the ground for Rocky Mountain juniper (Chojnacky 1997). These different measurements were used for each tree species because of the different growth forms. Douglas-fir typically has one main trunk, where as Rocky mountain juniper branches a great deal after the first 10 decimeters of the ground. DBH and BTD have been cited as the best, non-invasive measurement of growth and age (Omule 1987, Chojnacky 1997, Grove et al. 2005). The age of each conifer species was determined by randomly selecting and coring ten trees within each age class, at each site (Sindelar 1971). Each Douglas-fir within the plot was placed into four age classes based on DBH (Arno and Gruell 1986). The four classes include seedlings (< 1m tall), saplings (<15 cm DBH), pole (15-30cm DBH) and mature (>30 DBH). Each rocky mountain juniper was placed into classes based on BTD measured at the ground level near the root collar (Mueller et al. 2005). The three classes for juniper are seedlings (<3cm BTD), juvenile (3-12cm BTD) and mature (>12 cm BTD). Trees were cored with an increment hammer and the cores were then glued into holders, air-dried, sanded and magnified to identify growth rings (Chojnacky 1997). Three thousand seven hundred and forty Douglas-fir and 4,623 Rocky Mountain junipers

were measured for canopy area; 210 Douglas-firs and 199 Rocky Mountain junipers were measured for age.

### Statistical Analysis

Initial analysis of the data was conducted using scatter plots and box-plots through the companion study (Kitchen 2010). The plots indicated that the cover data was skewed and not normally distributed in that the variance of live sagebrush increased as the mean of live sagebrush cover increased. The family of Box-Cox power transformations was evaluated through the MASS package to meet the assumptions of normal distribution and variance (Welch and Comer 1988), and it was estimated that the best transformation would be square root. All the cover data was transformed to a square root scale.

To develop the first set of models for Objective One, a multiple linear regression analysis was conducted through R version 2.9.2 (2009) to evaluate the correlation between the abiotic factors and big sagebrush cover. The full model evaluated all sites ( $n = 3$ ) and subspecies ( $n = 2$ ). This was then repeated for individual sites ( $n = 1$ ) to assess this correlation on a small scale. All models included the interactions site, sagebrush subspecies, and the interaction between site and sub-species after tested with the information criterion (AIC) (Kitchen 2010). The models were run with a significant p-value of 0.05 with respect to coefficient of determination ( $r^2$ ). Relationships of explanatory variables were confirmed by assessing residual plots, which accounted for site, sagebrush subspecies, and conifer cover.

Analysis for Objective Two was conducted in Excel version 12.0 (2008) to evaluate the difference in canopy area of Douglas-fir and Rocky Mountain juniper. Phase

one involved constructing a simple linear regression between age against DBH for Douglas-fir or BTB for Rocky Mountain juniper. Phase two consisted of constructing a simple linear regression between canopy area and their correlating DBH for Douglas-fir and BTB for juniper. Phase three used the equations developed in phase one and two to calculate an average age for every DBH or BTB measurement and then plotted canopy area relative to age to predict canopy area at each year of age. Phase four ran a paired t-test to determine if the predicted canopy area of each tree differed at comparable ages. The paired t-test was conducted with a p-value  $\leq 0.05$ .

## RESULTS

Relationship of Live Big Sagebrush Cover and Abiotic Factors

All models from the multiple linear regression analysis for Objective One, which was to determine the relationship between live sagebrush cover for all study sites combined and abiotic factors: aspect, slope, elevation, soil texture, soil depth and percent rock outcroppings are shown below (Table 2). None of the abiotic factors significantly correlated with live sagebrush cover over all six sites combined ( $p > 0.05$ ). All residual plots of abiotic variables did not exhibit a relationship. Therefore, there was no significant relationship between live sagebrush cover and any of the abiotic variables over all sites.

Table 2. Multiple linear regression analysis summary of all abiotic factors verses live sagebrush cover.

	<b>Estimate</b>	<b>Std. Error</b>	<b>F-value</b>	<b>P-value</b>
<b>Aspect</b>	0.087	0.057	2.332	0.128
<b>Elevation</b>	0.0004	0.0002	2.238	0.136
<b>Soil Texture</b>	Varies by 9 degrees	-	1.35	0.212
<b>Slope</b>	0.005	0.004	1.094	0.297
<b>Soil Depth</b>	-0.003	0.006	0.37	0.543
<b>Rock</b>	-0.015	0.032	0.228	0.633

The result of the multiple linear regression analysis for individual sites differed (Table 3). Elevation was significant in Mountain: Elkhorn and Wyoming: Whitetail. Slope was significant for Mountain: Whitetail. Aspect was significant for Wyoming: Pipestone. Percent rock outcropping was significant for Mountain: Pipestone and Wyoming: Elkhorn ( $p < 0.05$ ).

Table 3. Significant relationship between abiotic factors and live big sagebrush cover for individual sites. P-value results from multiple linear regression analysis.

	<b>Elevation</b>	<b>Slope</b>	<b>Aspect</b>	<b>Rock</b>
<b>MTN:PIPESTONE</b>				0.04
<b>MTN:ELKHORN</b>	0.05			
<b>MTN:WHITTAIL</b>		0.05		
<b>WYO:PIPESTONE</b>			0.05	
<b>WYO:ELKHORNS</b>				<0.001
<b>WYO:WHITETAIL</b>	0.02			

I accept the null hypothesis that the abiotic factors (elevation, aspect, slope, soil texture, soil depth, and percent rock outcroppings) are not correlated with live sagebrush cover from all sites. However, relationships were found within individual sites. Elevation was significant in Mountain: Elkhorn and Wyoming: Whitetail. Slope was significant for Mountain: Whitetail. Aspect was significant for Wyoming: Pipestone. Percent rock outcropping was significant for Mountain: Pipestone and Wyoming: Elkhorn ( $p < 0.05$ ).

Canopy Area Growth of Douglas-Fir and Rocky Mountain Juniper

Analysis for Objective Two, which was to compare Douglas-fir and Rocky Mountain juniper's canopy areas at comparable ages, is displayed in two simple linear regressions in figure 5 and 6 (Means and Helm 1985, Shaw 2008). The equations to formulate these figures were calculated through simple linear regressions in figure 3 and 4. In figure 3, DBH for Douglas-fir is plotted as the dependent variable against age of the tree as the independent variable. The equation generated was  $((0.3013 * X) + 7.8902)$ , where "X" equal age of the individual Douglas-fir tree. In figure 4, BTD is plotted as the dependent variable against age for Rocky Mountain juniper as the independent variable. The equation generated was  $((0.1163 * X) + 5.6964)$ , where "X" equal the age of the individual juniper tree. In figure 5, canopy area in  $m^2$  was plotted as the dependent variable and DBH in centimeters (cm) and age in years (yrs) as the independent variables within all sagebrush sites. The equation to predict area for DBH for Douglas-fir is  $((0.6611 * X) - 0.7972)$ . The same model was graphed for Rocky Mountain juniper (Fig. 6). The equation to predict area for BTD for Rocky Mountain juniper is  $((0.6441 * X) - 2.2945)$ . Canopy area was plotted on the dependent variable and BTD (cm) and age (yrs) as the independent variables.

However the actual canopy area directly effecting live sagebrush cover by each tree differs. One-hundred DBH and BTD measurements were predicted from the above equations for ages 1 to 100 for Douglas-fir and Rocky Mountain juniper. Then canopy area for each tree was predicted from these DBH and BTD measurements for each age using the above equations. Douglas-fir canopy area is over 3 times greater than Rocky

Mountain juniper at comparable ages. A paired t-test confirms that Douglas-fir and Rocky Mountain juniper canopy areas differ significantly at comparable ages ( $p < 0.001$ ) (Table 4). I reject the null hypothesis that Douglas-fir and Rocky Mountain Juniper canopy areas are equal.

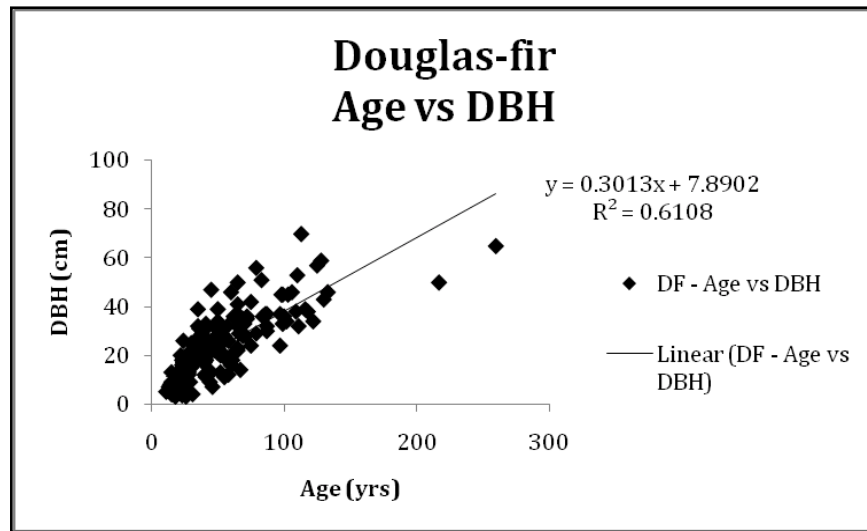


Figure 3. Simple linear regression of Douglas-fir DBH versus age in southwest Montana.

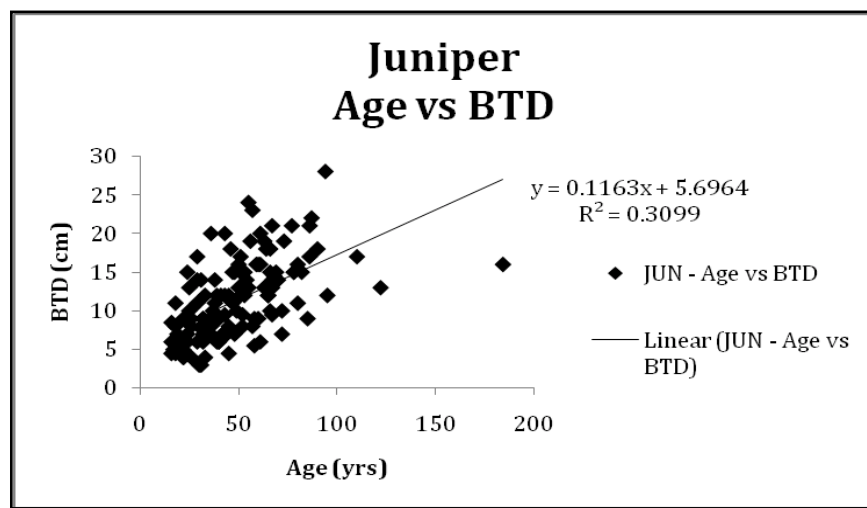


Figure 4. Simple linear regression of Rocky Mountain juniper BTD versus age in southwest Montana.

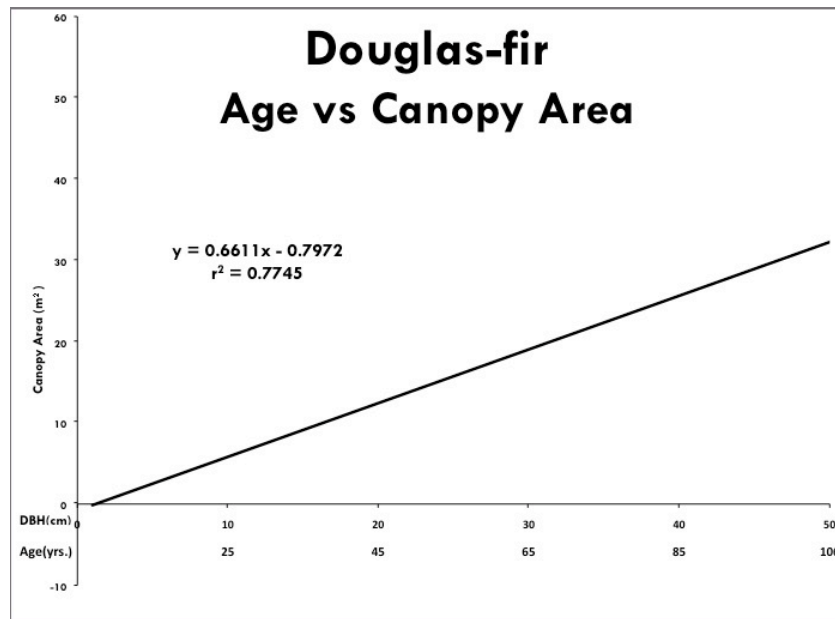


Figure 5. Simple linear regression of Douglas-fir canopy area versus DBH and age in southwest Montana.

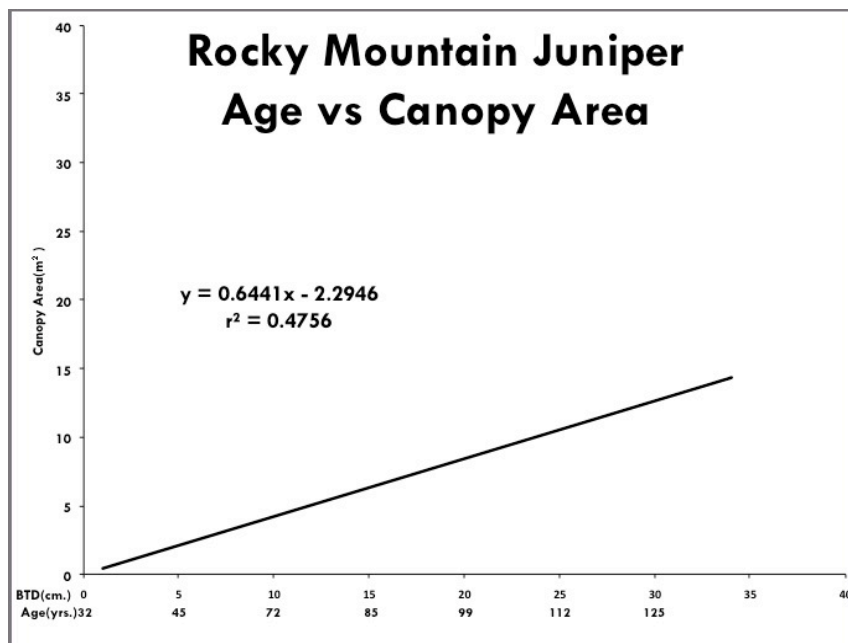


Figure 6. Simple linear regression of Rocky Mountain juniper canopy area versus BTD and age in southwest Montana.

Table 4. Paired T-test on average predicted area for Douglas-fir and Rocky Mountain juniper at similar ages over 100 years.

<b>DF – AREA</b>	<b>JUN - AREA</b>
14.47807744	5.157447155
T-Test	8.16E-46

In summary, while abiotic factors did not correlate significantly with live sagebrush cover among all sites, there was a significant correlation within individual sites. Further, canopy area of Douglas-fir is approximately 3 times greater than Rocky Mountain juniper at comparable ages.

## DISCUSSION

### Abiotic Factors

The importance of the sagebrush steppe to wildlife has been demonstrated in several studies. Sagebrush provides important nesting habitat as well as food and cover, especially during the winter months (Wallestad 1975, Roberson 1984, Striby 1985, Personius et al. 1987, Peterson 1995, Wambolt 1996, Welch 2005, Davies et al. 2006). Managing these habitats requires understanding what factors in the environment are controlling big sagebrush cover. From the six abiotic factors measured (aspect, slope, elevation, soil texture, soil depth and rock outcroppings), none had a significant correlation with live sagebrush cover among all sites; however several abiotic factors correlated with live sagebrush cover on an individual site basis. Many of the relationships between sagebrush cover and abiotic factors are consistent with previous literature.

### Aspect, Slope and Elevation

Within this study the topographical variables: aspect, slope and elevation had no correlation with live big sagebrush cover among sites, however there was a significant correlations with sagebrush cover among four of the individual sites. Aspect had a significant correlation with sagebrush cover in the Wyoming: Pipestone site. Slope had a significant correlation with sagebrush cover in the Mountain: Whitetail site. Elevation had a significant correlation with sagebrush cover in the Mountain: Elkhorn site and the

Wyoming: Whitetail site ( $p < 0.05$ ). The variance in aspect, slope, and elevation accounted for 33 to 73 percent of the variance in sagebrush cover within these individual sites.

Previous research supports a relationship between these topographical variables and plant cover (Burke et al. 1989, Knight 1994, Waichler et al. 2001, Frisina and Wambolt 2002, Johnson and Miller 2006). Sagebrush cover within Mountain, Wyoming and black sagebrush (*Artemisia nova* A. Nels.) dominated sites over a 1.7 km<sup>2</sup> area in Wyoming and the topographic variables: aspect, slope, elevation and fetch, shared 66.6 percent of their variance over all 89 plots using similar methodology (Burke et al. 1989). The closest relationship was between these topographical variables and mountain big sagebrush cover, adversely the relationship between these variables and Wyoming big sagebrush cover was insignificant. It was assumed that the Wyoming big sagebrush was too plastic, found across a range of wind exposures.

In Lesica et al.'s (2007) study, aspect, slope, and precipitation (which typically increased with elevation) were not associated with big sagebrush canopy cover recovery rates after fire. Lesica et al. (2007) states that the fact that these variables did not account for variance in sagebrush cover among sites, is most likely due to other influencing factors within the ecosystem. Other biotic impacts such as fire, mining, insects, grazing, etc., may have impacted sagebrush cover among my study sites as well.

The inconsistent relationship between live big sagebrush cover and the topographical variables within my study may also be due to the plasticity of the species and the variance in topographical variables among areas. Pipestone, Elkhorn and

Whitetail were chosen for their variety of sagebrush landscapes, though they were highly variable in slope and elevation from each other. The Pipestone site is very flat with slope ranging from 1 to 9 percent and elevation ranging from 1572 to 1817m. The Elkhorn site ranges from 0.5 to 39 percent slope, with an elevation range from 1456 to 1889m. The Whitetail site ranges from 1.5 to 58 percent slope, with an elevation range from 1591 to 1754m. Moisture gradients of the sites may have also played a role. Pipestone is a more arid site with sandier soils, allowing greater infiltration but lower water holding capacity than Whitetail and Elkhorn.

#### Soil Texture

No significant correlation was found between soil texture of the A horizon and live big sagebrush cover among sites or on an individual site basis. Historically, high valleys of southwest Montana had sagebrush as the dominant plant species on coarse (cobble or sandy) and clayey soils (Morris et al. 1976). Grasses are poorly adapted to these soils, which have droughty surface conditions, whereas deep rooted sagebrush are well adapted (Arno and Gruell, 1983). Within this soil range, mountain big sagebrush is typically found on deep well drained soil and Wyoming big sagebrush is found on more xeric sites with shallow clay, sometimes silty soils. Wyoming big sagebrush does not grow well on coarse textured soils as mountain big sagebrush can, but mountain big sagebrush does range anywhere from sandy through silty and clay soils (Wambolt and Frisina 2002). It was hypothesized that coarser well drained soils with greater infiltration and deeper percolation would achieve higher sagebrush covers.

However in a study by Lesica et al. (2007) within thirty-eight sites in southwest Montana's sagebrush steppe, no statistical difference was found between the percent sand found in the soil between Wyoming ( $40\pm 3\%$ ) and mountain big sagebrush ( $47\pm 3\%$ ) habitats. A Bouyoucos hydrometer was used on samples from a depth of 5 to 15 cm.

The lack of a significant relationship between soil texture and live big sagebrush cover among sites or within any individual site is most likely due to the plasticity of the plant's tolerance level and variance in soil texture among areas. Pipestone had a higher sand content among plots in both the Wyoming and mountain big sagebrush sites than Elkhorn and Whitetail. Also, soil texture of the A horizon was measured by hand within each plot. Lentz and Simonson's (1987) method of hand texturing the argillic horizon and Waichler et al.'s (2001) hydrometer method of particle size analysis may have given a more in depth view of soil texture's influence on sagebrush cover.

### Soil Depth

Within this study soil depth did not have a significant correlation with live big sagebrush cover among sites or within any individual site. Big sagebrush generally occurs in deeper soils than other sagebrush and grass species, however there is a high variation found among the species ranging from 50cm to 95cm (Knight 1994). Mountain big sagebrush is typically found in deeper more mesic sites where Wyoming is found on shallower more xeric sites (Wambolt and Frisina 2002). Big sagebrush root systems were studied in south central Wyoming. Mature mountain big sagebrush plants near the bottom and midway up a hillside had maximum rooting depths between 183 and 213 cm, 60 cm

deeper than roots of Wyoming big sagebrush plants just below the ridge (Sturges and Trlica 1978). Therefore we can hypothesize that sagebrush cover will increase with soil depth.

Knight (1994) stated that differences in sagebrush cover versus tree cover on site can be associated with the soil/ bedrock features. Sagebrush have a very extensive root system, but not as extensive as Douglas-fir and Rocky Mountain juniper. The Douglas-fir and Rocky Mountain juniper results from previous studies are consistent with my findings. Douglas-fir cover is typically higher on mountain big sagebrush sites with deeper soils but is very adaptable to many different soil conditions. Rocky Mountain juniper cover is typically higher in Wyoming big sagebrush sites with shallower soils.

This correlation between soil depth and live big sagebrush cover was not found among sites or within any individual sites. Again, big sagebrush cover was more likely influenced by other biotic factors within the ecosystem and the plasticity of the sagebrush sub-species itself.

#### Rock Outcroppings

Rock outcroppings were not significantly correlated with live big sagebrush cover among sites but did have a significant correlation with sagebrush cover within two of the individual sites, Mountain: Pipestone and Wyoming: Elkhorn ( $p < 0.05$ ). Variance of rock outcroppings explained between 69 to 73 percent of the big sagebrush cover within these individual sites.

Percentage of rock found in the soil has been correlated with vegetative distribution, preferring conifers over sagebrush. Arno and Gruell (1986) state that prior to 1890 fire occurring every few decades confined tree growth to rocky or topographically moist sites. It has been reported that these deep-rooted trees usually find their limits in rock outcroppings and coarse soils (Sindelar 1971). Species composition within old growth juniper woodlands in Northeast California and Southeast Oregon shared 45 percent of its variance with the percent rock on site (Waichler et al. 2001). With the preference of rocky sites by trees we hypothesized that sagebrush cover would decrease with increased percent rock cover.

It was observed that tree cover did tend to increase near rock outcroppings. However, the variability of rock outcroppings found between sites probably affected this relationship. Pipestone and Whitetail had a much higher occurrence of rock than Elkhorn. Other factors such as Pipestone's higher sand content allowing for greater infiltration may also interact with this relationship. These are very interactive and complex ecosystems, which most likely explains the inconsistency in relationships between abiotic factors and live big sagebrush cover.

#### Abiotic Summary

Overall, there was no significant relationship between abiotic factors and live big sagebrush cover among sites. On average Wyoming big sagebrush stands have lower cover than mountain big sagebrush stands. In a study by Lesica and others undisturbed Wyoming big sagebrush stands averaged  $15 \pm 2$  percent cover where mountain big

sagebrush stands averaged  $28 \pm 2$  percent cover. Lesica et al. (2007) found no reason to believe that abiotic factors will consistently be associated with sagebrush recovery time after a disturbance, but that this rate is dependent on the subspecies of sagebrush itself.

My research shows that the relationships between abiotic factors and live big sagebrush cover are variable by site and therefore require local management decisions. Knight (1994) suggests that sagebrush distribution in the landscape depends on the response of the plant species to soil moisture, salinity, depth, texture as well as climate factors. The patterns are accentuated over short distances because of wind, topography and abrupt changes in soil condition. These findings support site-by-site differences in abiotic factors' relationships with live sagebrush cover. There are several environmental factors and complex interactions, which determine plant distribution. "What may at first appear to be a simple factor – organism relationship may actually be an intricate mesh of factors which are relatively simply expressed by organisms, as in its presence or absence, its size, shape, or vigor" (Sindelar 1971).

## Conifers

### Expansion

Tausch et al. (1981) states that the loss of understory vegetation from conifer expansion has reduced the amount of burnable fuel, and the frequency of fires has diminished, adding to the speed and area of change. This reduction and decreased frequency of burning will probably occur until trees dominate most of the areas suitable to their survival (Tausch et al. 1981).

The abiotic findings give strength to the use of conifer cover to predict sagebrush cover (Kitchen 2010). In Kitchen's companion study, increasing conifer cover has a negative impact on sagebrush cover. There was no significant difference between Douglas-fir and Rocky Mountain juniper canopy cover's effect on live sagebrush cover. Conifer cover was used in the model as a combined factor.

### Canopy Area

Grove et al. (2005) modeled the relationship between Douglas-fir cover and the cover of mountain big sagebrush in southwest Montana. The  $r$  value of -0.86 indicates a strong negative correlation between increasing Douglas-fir cover and decreasing mountain big sagebrush cover. Miller et al. (2000) modeled the relationship between western juniper and mountain big sagebrush cover within different plant associations in Northeast California and Southeast Oregon. The  $r^2$  values of .92 to .96 show a strong correlation between increasing western juniper cover with decreasing shrub cover in all mountain big sagebrush/grass associations they studied.

A companion study to this one by Karen Kitchen (2010) used the reduced model including the interactions site by sagebrush subspecies by conifer cover, 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 ( $p = 0.07$  for Douglas-fir and  $p = 0.187$  for Rocky Mountain juniper). Since there were no significant adverse or positive impacts when

adding the conifer species back into the model, it was concluded that the influence of canopy cover on sagebrush was similar for both conifer species.

Kitchen's (2010) study found a large amount of the reduction in sagebrush cover occurs in the first 10 percent of conifer cover, and then the rate of sagebrush decline is reduced as conifer cover continues to increase. So management of conifers will have a minimal effect on increasing sagebrush cover after 10 percent conifer cover has expanded into the sagebrush site. Because of this, in most sites, conifer removal is not recommended. But if management is done it should be done early, before conifer cover has increased to above 10 percent.

On average, Douglas-fir grows 30 centimeters per year along these forest edges (Sherich et al. 2007) while Rocky Mountain juniper grows 10.3 centimeters per year (Mueller et al. 2005). Kitchen (2010) found that although the conifer species' effect on sagebrush cover was not significantly different, Douglas-fir had a greater correlation with the reduction of sagebrush cover than Rocky Mountain juniper (Douglas-fir - p-value = 0.07, Rocky Mountain juniper - p-value = 0.18). My model predicts canopy area increase through time of Douglas-fir and Rocky Mountain juniper within these six study sites. The canopy area Douglas-fir obtained within the sagebrush sites was 3 times larger than Rocky Mountain juniper at similar ages ( $p < 0.0001$ ). Conifer cover from each species has the same negative effect on sagebrush cover, however the larger canopy area of Douglas-fir, will have a larger negative impact on live sagebrush cover.

### Benefits to Wildlife

A literature review of studies measuring plant utilization by mule deer and elk within the Rocky Mountain range of the Western United States and Canada found Rocky Mountain juniper to be more beneficial than Douglas-fir to both of these big game species (Kufeld 1973, Kufeld et al. 1973). A ranking system was formulated by labeling each tree species as: light, moderate or heavy use, depending on percent utilization for each season and then dividing this sum by the number of citations involved in obtaining a mean rank. During the winter months both Rocky Mountain juniper and Douglas-fir were classified as “valuable” for mule deer with a ranking of 3. However Rocky Mountain juniper had a higher utilization by elk at this time of year with a ranking of 1.5, whereas Douglas-fir was classified as “least valuable” with a ranking of 1.27. During the spring, Rocky Mountain juniper was more valuable to mule deer with a ranking of 3, while Douglas-fir obtained a ranking of 2.

Mule deer have been documented only using trace amounts of Douglas-fir as forage in the Bridger and Little Belt Mountains of Montana (Wilkins 1957, Lovass 1958, Schwarzkoph 1973, Steerey 1979). Whereas a study in the Flathead National Forest found that elk subsist largely on browsing Rocky Mountain juniper (Gaffney 1941). Even though juniper was limited in distribution and made up a relatively small volume of the total forage, which included Douglas-fir, it was the most palatable of the all conifers within the study area. Not only is Rocky Mountain juniper an important food source, it also provides denser thermal cover for winter survival than Douglas-fir (USDA NRCS

2010d). Animals can stay warmer at night under the juniper canopy because the tree retains heat near the ground.

Several game bird species are also dependent on Rocky Mountain juniper. Juniper berries and buds have been documented as an important food source for Sharp-tailed grouse (Yde 1977, Nielsen 1978, Swenson 1985). In the Charles M. Russell National Wildlife Refuge in Valley County, Montana, Sharp-tailed grouse winter habits were confined to the juniper cover type (Northrup 1991). Within this study, juniper berries were the number one most common food found in grouse droppings during fall and winter. Gunderson (1990) also found that Rocky Mountain juniper was the most selected nesting cover by hens within the same area.

Overall, Rocky Mountain juniper has higher value to big game species and game birds than Douglas-fir within southwest Montana. Juniper provides vital winter forage, protective and thermal cover, as well as nesting habitat for many wildlife species.

### Conifer Management

In order to achieve mosaics of sagebrush cover, Lesica et al. (2007) recommends imposing a fire return interval of 50 to 80 years on stands in the landscape for all sagebrush subspecies. Baker (2006) recommends a mean interval of 70 to 200 years for mountain big sagebrush stands, 100 to 240 years for Wyoming big sagebrush stands and 35 to 100 years for grasslands with little sagebrush cover. Arno and Gruell (1986) recommend a combination of prescribed burning in conjunction with timber harvesting to enhance declining forage productivity for big game and livestock. However the use of prescribed fire in big sagebrush communities may eliminate big sagebrush communities

and other non-sprouting shrubs (Wambolt and Payne 1986), while possibly only having a marginal effect on Douglas-fir and Rocky Mountain juniper. Even in Lesica et al.'s (2007) study near complete sagebrush mortality was found on all burned sites. Baker (2006) suggest that fire does not need to be reintroduced until native understory plants can be restored so that the sagebrush community can fully recover from fire, especially on slower growing Wyoming big sagebrush sites and sites where invasive cheatgrass is present and will most likely increase with fire. Selective cutting of conifers may be a less destructive method to increase sagebrush cover.

#### Conifer Summary

Douglas-fir and Rocky Mountain juniper canopy cover have a negative effect on live big sagebrush cover within southwest Montana (Kitchen 2010). However, the canopy area of Douglas-fir is on average 3 times larger than Rocky Mountain juniper at comparable ages. Finally the wildlife benefits of Rocky Mountain juniper are greater to game species than Douglas-fir.

## CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Abiotic factors within southwest Montana's forest/ sagebrush steppe ecotone do not limit big sagebrush cover on a landscape level. Douglas-fir and Rocky Mountain juniper were shown to negatively affect big sagebrush cover on our study sites (Kitchen 2010). The average sagebrush cover on our sites was 12 percent. Sagebrush cover was reduced to 6 percent when conifer cover reached 10 percent (Kitchen 2010). After this threshold, sagebrush cover reduction slows while conifer cover continues to increase. Therefore, selectively cutting conifers to increase sagebrush cover is not recommended due to the small increases in sagebrush cover. Since Rocky Mountain juniper has a three-fold smaller canopy than Douglas-fir at the same age, and is generally considered to have more value to big game and game birds than Douglas-fir (Gunderson 1990, Kufeld 1973), the current practice of cutting Rocky Mountain juniper to increase sagebrush cover should not be continued.

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APPENDICES

APPENDIX A:

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

**Pipestone – Mountain Site**

<b>Plot</b>	<b>JUSC %</b>	<b>JUSC-D %</b>	<b>PSME %</b>	<b>PSME-D %</b>	<b>ARTR %</b>	<b>ARTR-D %</b>	<b>Tot ARTR %</b>
1	0	0	0	0	14.77	1.7	16.47
2	7.62	0	12.47	0	3.13	2.53	5.66
3	6.39	0	0	0	8.27	3.04	11.31
4	9.24	0	0	0	9.97	2.73	12.7
5	5.37	0	20.5	0	1.25	0.3	1.55
6	3.92	0	28	0	1.17	0.47	1.64
7	0	0	0.11	0	11.5	0.93	12.43
8	0	0	3.36	0	13.23	0.88	14.11
9	1.1	0	33.776	0	4.71	3.1	7.81
10	0	0	5.31	0	14.84	2.92	17.76
11	1.34	0	15.84	0	5.48	3.94	9.42
12	4.93	0	8.94	0	7.08	1.09	8.17
13	8.24	0	25.09	0	6.33	1.37	7.7
14	8.42	0	8.6	0	9.3	3.82	13.12
15	8.51	0	33.33	0	0.66	1.16	1.82
16	2.53	0	32.18	0	3.72	0.99	4.71
17	4.09	0	38.84	0	2.54	2.23	4.77
18	7.54	0	45.37	0	1.51	0.76	2.27
19	2.88	0	13.82	0	10.54	1.56	12.1
20	0	0	4.44	0	14.44	3.67	18.11
21	2.7	0	27.89	0	4.02	1.41	5.43
22	1.88	0	26.83	0	6.17	1.29	7.46
23	0.48	0	41.56	0	0.58	0.13	0.71
24	0.84	0	1.99	0	10.29	3.41	13.7
25	1.89	0	37.44	0	0.33	0.47	0.8
26	1.38	0	12.67	0	6.9	3.51	10.41
27	8.6	0	44.11	0	0.33	1.03	1.36
28	5.52	0	45.02	0	1.09	0.82	1.91
29	0	0	0.38	0	10.43	2.73	13.16
30	1.37	0	24.59	0	3.14	3.67	6.81
31	1.1	0	18.76	0	1.54	2.01	3.55
32	0.02	0	1.46	0	8.11	4.5	12.61
33	2.09	0	13.4	0	5.21	1.47	6.68
34	8.84	0	21.27	0	3.47	1.96	5.43
35	0	0	48.58	0	2.39	3.52	5.91
36	0	0	14.73	0	10.6	3.41	14.01
37	3.72	0	27.16	0	4.32	2.27	6.59
38	11.08	0	3.43	0	12.64	3.56	16.2
39	5.83	0	29.3	2	1.52	2	3.52
40	2.29	0	2.76	0	8.37	2.58	10.95

## Pipestone – Wyoming Site

Plot	JUSC %	JUSC-D %	PSME %	PSME-D %	ARTR %	ARTR-D %	Tot ARTR %
1	18.41	0	4.62	0	2.54	1.59	4.13
2	0.19	0	0	0	6.06	3.51	9.57
3	4.94	0	9.14	0	0.67	5.91	6.58
4	2.53	0	5.98	0	1.99	1	2.99
5	8.27	0	4.59	0	8.16	2.57	10.73
6	11.87	0	39.08	0	0	1.62	1.62
7	8.54	0	49.12	0	0	0	0
8	0.61	0	0	0	9.91	2.69	12.6
9	2.74	0	0	0	6.48	2.68	9.16
10	10.67	0	2.57	0	7.68	1.84	9.52
11	7.54	0	3.81	0	1.11	1.22	2.33
12	3.97	0	0	0	5.16	0.76	5.92
13	0	0	0	0	6.44	1.04	7.48
14	6.07	0	0.08	0	2.61	1.51	4.12
15	11.11	0	6.17	0	0.27	1.04	1.31
16	14.6	0	39.27	0	0	0.27	0.27
17	11.03	0	19.6	0	0.33	6.27	6.6
18	0.94	0	23.51	0	0.9	7.14	8.04
19	3.98	0	12.01	0	2.78	0	2.78
20	3.36	0	13.63	0	2.42	2.69	5.11
21	4.66	0	23.5	0	0.4	2.27	2.64
22	7.71	0	8.67	0	0.85	4.18	5.03
23	17.59	0	0	0	5.54	4.16	9.7
24	13.43	0	8.26	0	2.76	3.04	5.8
25	12.28	0	1.74	0	6.54	3.73	10.27
26	11.99	0	3.64	0	2.28	3.37	5.65
27	10.43	0	18.16	0	0.57	0.42	0.99
28	10.3	0	309	0	2.34	1.32	3.66
29	20.49	0	11.58	0	0	0.43	0.43
30	1.4	0	4.44	0	4.77	2	6.77
31	10.98	0	8.02	0	1.11	1.59	2.7
32	16.26	0	4.38	0	0.24	0.52	0.76
33	6.93	0	12.92	0	3.27	0.77	4.04
34	19.44	0	15.62	0	0	0.77	0.77
35	6.7	0	0.74	0	3.47	0.36	3.83
36	9.13	0	18.03	0	0.87	1.42	2.29
37	9.69	0	6.76	0	2.37	2.51	4.88
38	7.44	0	0.26	0	2.9	4.66	7.56
39	1.73	0	0.31	0	6.87	2.39	9.26
40	13.72	0	2.08	0	2.73	2.51	5.24

**Elkhorn – Mountain Site**

<b>Plot</b>	<b>JUSC %</b>	<b>JUSC-D %</b>	<b>PSME %</b>	<b>PSME-D %</b>	<b>ARTR %</b>	<b>ARTR-D %</b>	<b>Total ARTR %</b>
1	13.86	0	29.5	0	0.23	0.93	1.16
2	6.89	0	57.42	0	0.67	1.72	2.39
3	1.52	0	1.7	0	17.13	2.46	19.59
4	3.99	0	2.54	0	6.38	0.43	6.81
5	8.44	0	4.61	0	4.83	0.92	5.75
6	13.6	0	0	0	5.7	0.47	6.17
7	10.28	0	20.78	0	0	2.22	2.22
8	4.86	0	0	0	12.16	4.22	16.38
9	29.03	0	1.1	0	9.1	5.41	14.51
10	5.2	0	3.82	0	5.69	0.47	6.16
11	18.87	0	20.28	0	11.23	5.1	16.33
12	10.9	0	7.38	0	4.93	3.58	8.51
13	7.32	0	26.49	0	4.18	3.88	8.06
14	8.04	0	0.46	0	13.62	2.78	16.4
15	0	0	0	0	15.63	0.97	16.6
16	10.69	0	11.01	0	4.77	1.41	6.18
17	5.6	0	0	0	9.72	2.2	11.92
18	28.82	0	1.28	0	9.67	2.96	12.63
19	1.89	0	0	0	26.06	5.81	31.87
20	10.61	0	0	0	3.62	3.23	6.85
21	5.18	0	2.51	0	12.01	6.32	18.33
22	7.29	0	7.74	0	10.37	2.18	12.55
23	0.48	0	4.5	0	14.87	6.3	21.17
24	2.01	0.12	40.43	0	0.33	3.83	4.16
25	3.09	0	0	0	18.89	0.46	19.35
26	0.8	0.02	18.32	0	12.13	6.42	18.55
27	17.61	0	5.6	0	5.54	3.42	8.96
28	6.71	0	7.5	0	6.93	2.24	9.17
29	0.97	0	0	0	24.32	2.46	26.78
30	15.59	0	30.68	0	2.61	3.04	5.65
31	10.6	0	6.39	0	7.89	1.43	9.32
32	4.17	0	0	0	13.3	3.14	16.44
33	6.22	0	6.56	0	10.58	1.92	12.5
34	17.61	0	9.24	0	5.62	5.91	11.53
35	0	0	10.04	0	13.63	0.17	13.8
36	3.28	0	8.59	0	8.38	5.01	13.39
37	8.72	0.8	0	0	9.68	1.86	11.54
38	0.9	0	50.32	0	5.98	13.26	19.24
39	10.5	0.06	5.22	0	12.43	2.69	15.12
40	3.62	0	5.78	0	24.12	4.39	28.51

## Elkhorn – Wyoming Site

Plot	JUSC %	JUSC-D%	PSME %	PSME-D%	ARTR %	ARTR-D %	Total ARTR %
1	12.44	0	2.11	0	2.08	3.31	5.39
2	6.42	0	1.18	0	7.79	9.71	17.5
3	3.3	0	2.08	0	4.66	4.42	9.08
4	5.24	0	0	0	8.56	7.14	15.7
5	27.46	0	5.01	0	3.58	3.78	7.36
6	0.0002	0	0	0	14.48	2.11	16.59
7	15.17	0	5.11	0	6.63	2.88	9.51
8	8.58	0	1.19	0	8.83	2.11	10.94
9	15.64	0	7.52	0	3.24	4.63	7.87
10	19.57	0	0.77	0	4.12	3.69	7.81
11	7.66	0	4.59	0	14.87	1.93	16.8
12	7.36	0	2.92	0	12.78	2.92	15.7
13	1.18	0	0	0	21.99	2.03	24.02
14	1.21	0	0	0	11.51	1.56	13.07
15	10.81	0	14.73	0.47	0.34	3.47	3.81
16	9.12	0	1.92	0	4.8	1.6	6.4
17	11.83	0	4.12	0	7.08	2.5	9.58
18	14.69	0	6.58	0	3.44	2.37	5.81
19	12.72	0	12.04	0.59	4.03	0.36	4.39
20	2.5	0	0	0	3.69	0.67	4.36
21	3.46	0	11.16	0	4.36	1.23	5.59
22	18.2	0	21.13	0	0.14	5.94	6.08
23	4	0.99	2.89	0	12.98	1.56	14.54
24	8.81	0.11	2.16	0	11	0.9	11.9
25	7.27	0	0	0	15.86	1.94	17.8
26	20.29	0	15.53	0	1.21	0.54	1.75
27	12.44	0	11.51	0	3.58	1.64	5.22
28	33.66	0	2.1	0	2.78	1.2	3.98
29	6.11	0	1.36	0	6.51	2.03	8.54
30	36.62	0	5.06	0	2.17	0.79	2.96
31	7.53	0	4.46	0	4.04	2.38	6.42
32	12.73	0	0	0	4.49	3.41	7.9
33	0.4	0	0	0	9.41	1.83	11.24
34	9.58	0	0	0	7.25	2.92	10.17
35	2.87	0	0	0	7.5	2.87	10.37
36	15.06	0	0.47	0	4.5	1.08	5.58
37	4.01	0	0	0	6.1	2.52	8.62
38	2.43	0	0	0	8.52	3.07	11.59
39	9.24	0	0	0	6.01	2.6	8.61
40	7.61	0	2.72	0	5.14	1.37	6.51

**Whitetail – Mountain Site**

<b>Plot</b>	<b>JUSC %</b>	<b>JUSC-D%</b>	<b>PSME %</b>	<b>PSME-D%</b>	<b>ARTR %</b>	<b>ARTR-D %</b>	<b>Total ARTR %</b>
1	1.7	0	5.77	0	8.31	2.99	11.3
2	4.19	0	23.42	0	4.34	1.47	5.81
3	2.14	0	2.92	0	11	1.43	12.43
4	0.03	0	11.64	0	9.89	3.09	12.98
5	0.07	0	23.88	0	9.13	1.2	10.33
6	3.73	0	56.4	0	1.17	5.84	7.01
7	1.71	0	27.28	0	6.97	6.34	13.31
8	4.71	0	33.78	0	1.07	1.88	2.95
9	3.13	0	38.3	0	0.34	5.88	6.22
10	2.48	0	24.17	0	2.93	6.07	9
11	3.58	0	42.49	0	4.07	2.27	6.34
12	2.5	0	2.96	0	6.51	1.13	7.64
13	0	0	0.97	0	12.36	4.26	16.62
14	1.99	0	34.9	1.78	0.6	1.77	2.37
15	5.8	0	15.91	0	5.01	2.93	7.94
16	0	0	6.56	0	1.78	2.28	4.06
17	0	0	14.76	0	1.16	1.12	2.28
18	0	0	28.86	0	0.42	2.72	3.14
19	2.66	0	8.52	0	2.2	1.29	3.49
20	0	0	22.56	0	4.83	0.58	5.41
21	3.61	0	4.64	0	10.01	2.84	12.85
22	0.26	0	25.1	0	5.78	1.57	7.35
23	0	0	0	0	11.2	2.91	14.11
24	3.01	0	32.19	0	1.66	2.33	3.99
25	0	0	18.41	0.52	6.03	1.71	7.74
26	0	0	14.66	0	4.93	2.06	6.99
27	0	0	3.04	0	9.7	6.57	16.27
28	2.68	0	8.46	0	10.72	5.06	15.78
29	1.43	0	26.89	0	2.18	1.21	3.39
30	0	0	19.49	0	1.4	0.97	2.37
31	0	0	24.97	0	0.99	1.28	2.27
32	0.8	0	22.78	0	1.84	0.79	2.63
33	0	0	0	0	3.81	1.77	5.58
34	9.14	0	18.91	0	1.51	0.97	2.48
35	2.06	0	19.62	0	0.33	0.33	0.66
36	2	0	2.14	0	2.07	0.74	2.81
37	2.78	0	6.88	0	2.6	2.36	4.96
38	0	0	19.42	0	4.16	2.03	6.19
39	0	0	17.06	0	4.13	2.91	7.04
40	2.89	0	17.6	0	6.19	4.08	10.27

## Whitetail – Wyoming Site

Plot	JUSC %	JUSC-D%	PSME %	PSME-D%	ARTR %	ARTR-D %	Total ARTR %
1	10.45	0	3.82	0	3.58	2.92	6.5
2	3.43	0	1.49	0	7.43	3.14	10.57
3	0.53	0	0	0	8.28	1.68	9.96
4	7.21	0	4.81	0	3.34	2.7	6.04
5	6.19	0	0	0	8.98	1.9	10.88
6	12.32	0	6.11	0	5.78	2.64	8.42
7	15.23	0	4.46	0	6.09	3.08	9.17
8	1	0	0.06	0	9.02	1.64	10.66
9	3.92	0	1.27	0	15.22	1.82	17.04
10	1.08	0	0	0	8.3	1.73	10.03
11	7.63	0	0	0	6.9	3.98	10.88
12	2.31	0	0.04	0	4.47	3.51	7.98
13	12.78	0	4.59	0	9.09	4.68	13.77
14	10.44	0	0.12	0	5.72	2.8	8.52
15	12.11	0	0.44	2.63	4.26	5.98	10.24
16	10.23	0	4.37	0	11.83	2.42	14.25
17	0.2	0	3.02	0	24.24	3.82	28.06
18	5.31	0	7.66	0	8.81	5.64	14.45
19	4.22	0	22.68	0	6.88	0.77	7.65
20	16.3	0	24.36	0	1.2	2.62	3.82
21	3.3	0	0	0	8.32	4.59	12.91
22	13.68	0	9.71	0	5.67	3.19	8.86
23	15.33	0	0	0	5.91	4.2	10.11
24	19.81	0	0	0	3.73	2.09	5.82
25	9.18	0	5.3	0	2.41	4.2	6.61
26	21.18	2.93	2.89	0	2.54	2.08	4.62
27	14.7	0.2	10.78	0	2.1	1.92	4.02
28	0.16	0	0	0	18.37	3.22	21.59
29	0	0	0	0	17.14	5.32	22.46
30	10.27	0	5.39	0	11.5	4.63	16.13
31	19.39	0	0	0	5.37	1.19	6.56
32	10.73	0	1.47	0	5.44	3.37	8.81
33	7.14	0	9.72	0	6.07	7.77	13.84
34	6.81	0	6.19	0	4.4	3.3	7.7
35	8.23	0	0.51	0	6.46	3.8	10.26
36	11.87	0	3.1	0	3.79	6.6	10.39
37	16.22	0	19.88	0	0.78	1.93	2.71
38	11.81	0	0.54	0	1.9	2.48	4.38
39	21.17	0	0	0	4.26	2.49	6.75
40	4.29	0	0.11	0	5.38	6	11.38

APPENDIX B:

ABIOTIC FACTORS AT THE ELKHORN, PIPESTONE AND WHITETAIL STUDY  
SITES IN SOUTHWEST MONTANA

## Pipestone – Mountain Site

Plot	elevation	aspect	slope	soil depth	rock	soil text	Date
1	5766	135	4	33.3	0	loamy sand	8/12/2008
2	5794	135	4	13.25	0	sandy loam	8/12/2008
3	5738	157.5	6	26	0	loamy sand	8/13/2008
4	5754	157.5	4	12	3.5	loamy sand	8/13/2008
5	5688	157.5	6	61	0	sandy loam	8/13/2008
6	5725	157.5	5	41.5	4	sandy loam	8/13/2008
7	5811	180	4.5	22	0	sandy loam	8/21/2008
8	5784	180	3	45	0	sandy loam	8/21/2008
9	5785			40.6	4	loamy sand	8/21/2008
10	5783	225	4.5	38.1	0	sandy loam	8/21/2008
11	5557	292.5	4.5	14	0	sandy loam	8/22/2008
12	5690	135	5	31	5	sandy loam	5/11/2009
13	5666	135	7	37	11	sandy loam	5/11/2009
14	5701	135	5	30	N/A	loamy sand	5/11/2009
15	5753	135	3	17	N/A	loamy sand	5/13/2009
16	5735	135	4	27	N/A	loamy sand	5/13/2009
17	5803	180	4	48	1	loamy sand	5/13/2009
18	5823	180	2	12	1	loamy sand	5/13/2009
19	5843	157.5	4.3	45	1	loamy sand	5/19/2009
20	N/A	135	2.1	30	0	loamy sand	5/19/2009
21	N/A	135	1.7	34	8	loamy sand	5/19/2009
22	5768	90	3.8	30		sandy loam	5/30/2009
23	5827	112.5	3	30.5	4	sandy loam	5/30/2009
24	5758	90	3.3	27	4	sandy loam	5/30/2009
25	5740	180	3.2	22.3	6	sandy loam	5/30/2009
26	5721	225	3	36.3	2	sandy loam	6/30/2009
27	5743	67.5	2	36.3	0	sandy loam	6/30/2009
28	5734	112.5	2	39	0.5	sandy loam	6/30/2009
29	5740	135	4	31.3	N/A	loamy sand	6/30/2009
30	5730	90	4.5	41.7	0.25	sandy loam	6/30/2009
31	5835	112.5	5	18	2	sandy loam	7/4/2009
32	5815	112.5	3	19	0	loamy sand	7/4/2009
33	5941	90	7	28	0	loamy sand	7/4/2009
34	5961	45	10	22	17	loamy sand	7/4/2009
35	5955	112.5	8	17	1	loamy sand	7/4/2009
36	N/A	157.5	5	12	0.5	loamy sand	7/4/2009
37	5794	90	4	25.3	5	sandy loam	7/5/2009
38	5539	202.5	3.5	13	60	loamy sand	7/25/2009
39	5542	202.5	10	14	1	loamy sand	7/25/2009
40	5530	202.5	10	11	1	loamy sand	7/25/2009

## Pipestone - Wyoming Site

Plot	elevation	aspect	slope	soil depth	rock	soil text	Date
1	5510	135	5	45	3	sandy loam	8/13/2008
2	5499	135	4	27	0	sandy loam	8/13/2008
3	5454	112.5	7	15.5	7	loamy sand	8/15/2008
4	5531	90	4	16.5	0	loamy sand	8/15/2008
5	5518	225	2	25	0	loamy sand	8/18/2008
6	5483	202.5	5	38	0	loamy sand	8/18/2008
7	5468	202.5	4	22	0	loamy sand	8/18/2008
8	5612	202.5	3	23	3	loamy sand	8/20/2008
9	5591	202.5	2	31	0	loamy sand	8/20/2008
10	5577	112.5	2	31	0	loamy sand	8/20/2008
11	5550	112.5	2	13	0	loamy sand	8/20/2008
12	5575	180	6.5	20.3	0	loamy sand	8/22/2008
13	5575	202.5	4.5	19.5	0	sandy loam	8/22/2008
14	5575	202.5	4	17.8	0	sandy loam	8/22/2008
15	5157	90	7	21	N/A	N/A	5/14/2009
16	5457	135	3	N/A	15	N/A	5/16/2009
17	5448	157.5	2	31.5	0	N/A	5/16/2009
18	5463	157.5	6	16	N/A	loamy sand	5/16/2009
19	5523	157.5	6	11	8	loamy sand	5/18/2009
20	5560	157.5	4	17	N/A	loamy sand	5/18/2009
21	5552	180	8	12	20	loamy sand	5/18/2009
22	N/A	135	3	6	1.5	loamy sand	5/18/2009
23	5153	90	2.5	9	0	sandy loam	5/29/2009
24	5046	360	4.1	6	20	sandy loam	5/29/2009
25	5177	22.5	5.9	21	15	sandy loam	5/29/2009
26	5126	22.5	9	6	15	sandy loam	5/29/2009
27	N/A	180	4	14	0.5	sandy loam	6/8/2009
28	5507	202.5	3	25	0	sandy loam	6/8/2009
29	5501	315	5	51.5	0	loamy sand	7/1/2009
30	5536	202.5	3	18	0	sandy loam	7/2/2009
31	5514	247.5	2	20.5	8	sandy loam	7/2/2009
32	5516	202.5	6	11	12	loamy sand	7/2/2009
33	5568	135	7	17		loamy sand	7/3/2009
34	5532	90	5	25	3	sandy loam	7/3/2009
35	5512	135	1	17	0	sandy	7/3/2009
36	5509	135	8	N/A	8	loamy sand	7/3/2009
37	5480	135	7	17.3	0	loamy sand	7/3/2009
38	5480	157.5	7	21	0	loamy sand	7/3/2009
39	5548	90	4	15	0	loamy sand	7/4/2009
40	5554	90	8	16.5	7	sandy loam	7/4/2009

**Elkhorn - Mountain Site**

<b>Plot</b>	<b>elevation</b>	<b>aspect</b>	<b>slope</b>	<b>soil depth</b>	<b>rock</b>	<b>soil text</b>	<b>Date</b>
1	6105	22.5	12	14.5		loam	5/20/2009
2	6090	67.5	10	22		loam	5/20/2009
3	6132	67.5	11	17.6	0	loam	5/21/2009
4	5645	67.5	15.2	15.5	1	loam	5/21/2009
5	5587	67.5	15	16	1	loam	5/21/2009
6	5554	67.5	8.6	19	0	loam	5/21/2009
7	5622	22.5	8.6	13	0	loam	5/22/2009
8	5622	45	14.7	16	0.5	loam	5/22/2009
9	5737	90	7.4	12	0	loam	5/22/2009
10	5683	90	12.6	12	0	loam	5/22/2009
11	5589	360	14.9	11	0	loam	5/23/2009
12	5837	360	16.9	8	0	loam	5/23/2009
13	5960	360	17	8	0.5	loam	5/23/2009
14	5676	45	4	10	0	loam	5/23/2009
15	6172	22.5	5	10	1	sandy loam	5/24/2009
16	5983	157.5	8	8	1	loam	5/24/2009
17	5703	247.5	5	7	1	loam	5/24/2009
18	5914	90	4.4	8	0.5	sandy loam	26-May
19	5720	112.5	6.9	19	0	sandy loam	5/26/2009
20	5773	90	7.5	17	1	sandy loam	5/26/2009
21	5705	112.5	7.2	24.5	1	sandy loam	5/26/2009
22	6092	292.5	5.8	22.6	0	sandy loam	6/18/2009
23	6077	22.5	17	18	0	sandy loam	6/19/2009
24	6158	315	39	18.6	0	silty loam	6/19/2009
25	6066	270	20	17	1	silty loam	6/19/2009
26	6113	360	20.2	28	0	silty loam	6/19/2009
27	6088	180	13	27	0	silty loam	6/19/2009
28	6025	180	17.5	17	0.5	silty loam	6/19/2009
29	6168	225	4	19.3	0	silty loam	6/26/2009
30	6127	180	36	17	17	silty loam	6/26/2009
31	6106	180	28	30	12	sandy loam	6/26/2009
32	6079	180	19	19	3	sandy loam	6/26/2009
33	6079	157.5	16	11	5	sandy loam	6/26/2009
34	6140	157.5	14	14	5	sandy loam	6/26/2009
35	6157	180	8	14	0	sandy loam	6/27/2009
36	6068	225	8	19	1	silty loam	6/27/2009
37	6086	225	16.8	N/A	3	silty loam	6/27/2009
38	6197	337.5	5.7	31	0	sandy loam	6/27/2009
39	6192	337.5	16	17.3	0	silty loam	6/27/2009
40	6190	247.5	4	19	0	silty loam	6/27/2009

## Elkhorn – Wyoming Site

Plot	elevation	aspect	slope	soil depth	rock	soil text	Date
1	4926	202.5	2	31	0	sandy loam	5/24/2009
2	4918	225	2	19	0	sandy loam	5/24/2009
3	4912	225	2.6	11	0	sandy loam	5/24/2009
4	4894	270	1.8	10.5	0.5	sandy loam	5/24/2009
5	4883	135	1	15.5	0	sandy loam	5/25/2009
6	4849	202.5	0.5	12	0	sandy loam	5/25/2009
7	5181	67.5	13	18.3	0.5	sandy clay loam	6/11/2009
8	5228	135	11.7	13.6	1		6/11/2009
9	5235	135	11.5	8.5	1	loam	6/12/2009
10	5206	112.5	12	17	N/A	loam	6/12/2009
11	5226	90	10.5	18.3	1	sandy clay loam	6/12/2009
12	5271	90	28	14.3	N/A	N/A	6/12/2009
13	5312	45	29	10	1.5	loam	6/12/2009
14	5212	22.5	35	19	N/A	N/A	6/12/2009
15	5270	202.5	7.5	14	N/A	loam	6/13/2009
16	5184	135	5	10	0	loam	6/13/2009
17	5191	360	5	11.6	N/A	sandy clay loam	6/13/2009
18	5204	45	7	11	<.5	loam	6/13/2009
19	5225	90	14	15.6	1	sandy clay loam	6/13/2009
20	5291	22.5	16	8	0	sandy clay loam	6/13/2009
21	5210	247.5	11.9	10.6	2	loam	6/14/2009
22	5143	90	27	8	0	sandy clay loam	6/14/2009
23	5204	67.5	13.6	11	1	loam	6/14/2009
24	5202	45	15.2	13	1.5	loam	6/14/2009
25	5187	45	10.1	9.6	1.5	loam	6/14/2009
26	5241	45	4	17.6	0	silty loam	6/22/2009
27	5237	67.5	9	19	0	silty loam	6/22/2009
28	5239	90	10	18	0	silty loam	6/22/2009
29	5253	90	7	25	0	silty clay loam	6/22/2009
30	5225	67.5	10	16	0	silty clay loam	6/22/2009
31	5233	225	6	20	0	silty loam	6/23/2009
32	5289	270	4	26	0.25	silty loam	6/23/2009
33	5245	292.5	2.5	32	0	silty loam	6/23/2009
34	5257	225	8	32	0.25	silty loam	6/23/2009
35	5267	225	6	16	0	silty loam	6/23/2009
36	5230	247.5	7	27	0.25	silty loam	6/23/2009
37	4780	337.5	2.3	31	0	sandy loam	6/28/2009
38	4778	90	1	14	0.25	sandy loam	6/28/2009
39	4819	315	2.5	15	0	sandy loam	6/28/2009
40	4847	157.5	28	18	0	sandy loam	6/28/2009

## Whitetail – Mountain Site

Plot	elevation	aspect	slope	soil depth	rock	soil text	Date
1	5460	360	24	12	0	silty loam	7/16/2009
2	5460	360	33	13	0.5	silty loam	7/16/2009
3	5458	315	23	9.3	0	silty loam	7/17/2009
4	5505	315	25	8.6	0	silty loam	7/17/2009
5	5500	315	28	10	0	silty loam	7/17/2009
6	5515	360	48	14	2	silty loam	7/17/2009
7	5575	360	49	13	2	silty loam	7/17/2009
8	5575	180	43	13	2	silty loam	7/17/2009
9	5525	180	43	13	3	silty loam	7/17/2009
10	5650	360	43	14	1	silty loam	7/21/2009
11	5755	360	58	16	13	silty loam	7/21/2009
12	5736	360	36	10.3	3	silty loam	7/21/2009
13	5729	180	11	9	4	silty loam	7/21/2009
14	5755	360	46	12	3	silty loam	7/21/2009
15	5630	180	18	21	3	silty loam	7/27/2009
16	5678	135	8	19.3	0	silty loam	7/27/2009
17	5705	135	5.5	23	1	silty loam	7/27/2009
18	5740	112.5	4	21.6	0	silty loam	7/27/2009
19	5695	225	14	21.5	0	silty loam	7/27/2009
20	5726	67.5	8	19	0	silty loam	7/27/2009
21	5633	90	23	18	0	loam	7/28/2009
22	5648	45	5	20	2	loam	7/28/2009
23	5638	67.5	2	18	0	loam	7/28/2009
24	5660	360	34	19	0.25	loam	7/28/2009
25	5684	135	15	16	16	loam	7/28/2009
26	N/A	360	2	20	9	loam	7/28/2009
27	5689	225	1	19	2	loam	7/30/2009
28	5728	225		17	0	loam	7/30/2009
29	5725	202.5	4	23	10	loam	7/30/2009
30	5430	45	11	11	7	loam	7/30/2009
31	5420	45	2	14	9	loam	7/30/2009
32	5400	67.5	22	13.6	1	loam	7/30/2009
33	5420	45	6	14	0	loam	7/30/2009
34	5415	157.5	11	17	N/A	loamy sand	7/31/2009
35	5400	180	17	22	18	loamy sand	7/31/2009
36	5425	315	2	15	4	loamy sand	7/31/2009
37	5435	180	7	38	3	sandy loam	7/31/2009
38	5430	360	6	14.6	2	sandy loam	7/31/2009
39	5560	360	6	17	0	loam	7/31/2009
40	5551	180	1	13	0	loam	7/31/2009

## Whitetail – Wyoming Site

Plot	elevation	aspect	slope	soil depth	rock	soil text	Date
1	5307	90	49	10.5	40	sandy clay loam	6/2/2009
2	5319	90	49	10.2	35	sandy clay loam	6/2/2009
3	5322	90	48	10	30	sandy clay loam	6/2/2009
4	5442	90	55	14	35	sandy clay loam	6/3/2009
5	5350	180	30	8	30	sandy loam	6/3/2009
6	5386	202.5	28	9	30	sandy loam	6/3/2009
7	5445	202.5	27	9	35	sandy loam	6/3/2009
8	5285	247.5	5	14	0.5	silty loam	7/6/2009
9	5288	292.5	11	8	1	silty clay loam	7/6/2009
10	5287	112.5	1.5	15	1	silty loam	7/6/2009
11	5270	157.5	25	10	25	sandy loam	7/6/2009
12	5263	225	20	11.6	30	sandy loam	7/6/2009
13	5265	1880	39	16	40	silty loam	7/7/2009
14	5235	157.5	43	19.6	42	silty loam	7/7/2009
15	5260	135	35	15	47	silty loam	7/7/2009
16	5278	67.5	5	14	2	silty loam	7/7/2009
17	5245	45	30	13.6	20	silty loam	7/7/2009
18	5329	22.5	38	8	16	silty loam	7/14/2009
19	5350	360	39	13	20	silty loam	7/14/2009
20	5399	22.5	45	13.6	25	silty loam	7/14/2009
21	5379	180	34	22.6	15	silty loam	7/14/2009
22	5448	225	40	11.3	30	silty loam	7/14/2009
23	5328	180	35	13	35	loamy sand	7/18/2009
24	5389	180	39	12.5	40	sandy loam	7/18/2009
25	5389	180	38	14.3	40	sandy loam	7/18/2009
26	5426	180	45	8	50	sandy loam	7/18/2009
27	5385	180	40	16	50	sandy loam	7/18/2009
28	5220	337.5	11	12	1	silty loam	7/19/2009
29	N/A	360	16	6.5	1	silty loam	7/19/2009
30	5235	360	23	15.6	1	silty loam	7/19/2009
31	5195	135	22	7	2	silty loam	7/19/2009
32	5190	112.5	16	18.6	1	silty loam	7/19/2009
33	5229	112.5	18	9	19	silty loam	7/19/2009
34	5230	45	9	12.6	10	silty loam	7/19/2009
35	5300	180	27	14.3	25	silty loam	7/20/2009
36	5370	180	30	13.5	15	silty loam	7/20/2009
37	5429	225	43	7.5	15	silty loam	7/20/2009
38	5493	202.5	28	21	7	silty loam	7/20/2009
39	5480	157.5	36	20	30	silty loam	7/20/2009
40	5350	180	30	7.5	20	silty loam	7/20/2009

APPENDIX C:

PREDICTED DBH/BTD AND AREA FOR DOUGLAS-FIR AND ROCKY  
MOUNTAIN JUNIPER AT SIMILAR AGES. T-TEST VERIFIES A SIGNIFICANT  
DIFFERENCE

<b>AGE</b>	<b>DF - DBH</b>	<b>JUN - BTD</b>	<b>DF - AREA</b>	<b>JUN - AREA</b>
1	8.1915	5.8127	4.61820065	1.44946007
2	8.4928	5.929	4.81739008	1.5243689
3	8.7941	6.0453	5.01657951	1.59927773
4	9.0954	6.1616	5.21576894	1.67418656
5	9.3967	6.2779	5.41495837	1.74909539
6	9.698	6.3942	5.6141478	1.82400422
7	9.9993	6.5105	5.81333723	1.89891305
8	10.3006	6.6268	6.01252666	1.97382188
9	10.6019	6.7431	6.21171609	2.04873071
10	10.9032	6.8594	6.41090552	2.12363954
11	11.2045	6.9757	6.61009495	2.19854837
12	11.5058	7.092	6.80928438	2.2734572
13	11.8071	7.2083	7.00847381	2.34836603
14	12.1084	7.3246	7.20766324	2.42327486
15	12.4097	7.4409	7.40685267	2.49818369
16	12.711	7.5572	7.6060421	2.57309252
17	13.0123	7.6735	7.80523153	2.64800135
18	13.3136	7.7898	8.00442096	2.72291018
19	13.6149	7.9061	8.20361039	2.79781901
20	13.9162	8.0224	8.40279982	2.87272784
21	14.2175	8.1387	8.60198925	2.94763667
22	14.5188	8.255	8.80117868	3.0225455
23	14.8201	8.3713	9.00036811	3.09745433
24	15.1214	8.4876	9.19955754	3.17236316
25	15.4227	8.6039	9.39874697	3.24727199
26	15.724	8.7202	9.5979364	3.32218082
27	16.0253	8.8365	9.79712583	3.39708965
28	16.3266	8.9528	9.99631526	3.47199848
29	16.6279	9.0691	10.19550469	3.54690731
30	16.9292	9.1854	10.39469412	3.62181614
31	17.2305	9.3017	10.59388355	3.69672497
32	17.5318	9.418	10.79307298	3.7716338
33	17.8331	9.5343	10.99226241	3.84654263
34	18.1344	9.6506	11.19145184	3.92145146
35	18.4357	9.7669	11.39064127	3.99636029
36	18.737	9.8832	11.5898307	4.07126912
37	19.0383	9.9995	11.78902013	4.14617795
38	19.3396	10.1158	11.98820956	4.22108678
39	19.6409	10.2321	12.18739899	4.29599561
40	19.9422	10.3484	12.38658842	4.37090444

41	20.2435	10.4647	12.58577785	4.44581327
42	20.5448	10.581	12.78496728	4.5207221
43	20.8461	10.6973	12.98415671	4.59563093
44	21.1474	10.8136	13.18334614	4.67053976
45	21.4487	10.9299	13.38253557	4.74544859
46	21.75	11.0462	13.581725	4.82035742
47	22.0513	11.1625	13.78091443	4.89526625
48	22.3526	11.2788	13.98010386	4.97017508
49	22.6539	11.3951	14.17929329	5.04508391
50	22.9552	11.5114	14.37848272	5.11999274
51	23.2565	11.6277	14.57767215	5.19490157
52	23.5578	11.744	14.77686158	5.2698104
53	23.8591	11.8603	14.97605101	5.34471923
54	24.1604	11.9766	15.17524044	5.41962806
55	24.4617	12.0929	15.37442987	5.49453689
56	24.763	12.2092	15.5736193	5.56944572
57	25.0643	12.3255	15.77280873	5.64435455
58	25.3656	12.4418	15.97199816	5.71926338
59	25.6669	12.5581	16.17118759	5.79417221
60	25.9682	12.6744	16.37037702	5.86908104
61	26.2695	12.7907	16.56956645	5.94398987
62	26.5708	12.907	16.76875588	6.0188987
63	26.8721	13.0233	16.96794531	6.09380753
64	27.1734	13.1396	17.16713474	6.16871636
65	27.4747	13.2559	17.36632417	6.24362519
66	27.776	13.3722	17.5655136	6.31853402
67	28.0773	13.4885	17.76470303	6.39344285
68	28.3786	13.6048	17.96389246	6.46835168
69	28.6799	13.7211	18.16308189	6.54326051
70	28.9812	13.8374	18.36227132	6.61816934
71	29.2825	13.9537	18.56146075	6.69307817
72	29.5838	14.07	18.76065018	6.767987
73	29.8851	14.1863	18.95983961	6.84289583
74	30.1864	14.3026	19.15902904	6.91780466
75	30.4877	14.4189	19.35821847	6.99271349
76	30.789	14.5352	19.5574079	7.06762232
77	31.0903	14.6515	19.75659733	7.14253115
78	31.3916	14.7678	19.95578676	7.21743998
79	31.6929	14.8841	20.15497619	7.29234881
80	31.9942	15.0004	20.35416562	7.36725764
81	32.2955	15.1167	20.55335505	7.44216647

82	32.5968	15.233	20.75254448	7.5170753
83	32.8981	15.3493	20.95173391	7.59198413
84	33.1994	15.4656	21.15092334	7.66689296
85	33.5007	15.5819	21.35011277	7.74180179
86	33.802	15.6982	21.5493022	7.81671062
87	34.1033	15.8145	21.74849163	7.89161945
88	34.4046	15.9308	21.94768106	7.96652828
89	34.7059	16.0471	22.14687049	8.04143711
90	35.0072	16.1634	22.34605992	8.11634594
91	35.3085	16.2797	22.54524935	8.19125477
92	35.6098	16.396	22.74443878	8.2661636
93	35.9111	16.5123	22.94362821	8.34107243
94	36.2124	16.6286	23.14281764	8.41598126
95	36.5137	16.7449	23.34200707	8.49089009
96	36.815	16.8612	23.5411965	8.56579892
97	37.1163	16.9775	23.74038593	8.64070775
98	37.4176	17.0938	23.93957536	8.71561658
99	37.7189	17.2101	24.13876479	8.79052541
100	38.0202	17.3264	24.33795422	8.86543424
			14.47807744	5.157447155
			T-Test	8.16E-46