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Sagebrush Ecology of Parker Mountain, Utah

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SAGEBRUSH ECOLOGY OF PARKER MOUNTAIN, UTAH

by

Nathan E. Dulfon

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Range Science

Approved:

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UTAH STATE UNIVERSITY
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ABSTRACT

Sagebrush Ecology of Parker Mountain, Utah

by

Nathan E. Dulfon, Master of Science

Utah State University, 2016

Major Professor: Dr. Eric T. Thacker
Department: Wildland Resources

Parker Mountain, is located in south central Utah, it consists of 153 780 ha of high elevation rangelands dominated by black sagebrush (*Artemisia nova* A. Nelson), and mountain big sagebrush (*Artemisia tridentata* Nutt. subsp. *vaseyana* [Rybd.] Beetle) communities. Sagebrush obligate species including greater sage-grouse (*Centrocercus urophasianus*) depend on these vegetation communities throughout the year. Parker Mountain is owned and managed by Utah School and Institutional Trust Lands Administration, Bureau of Land Management, and the United States Forest Service. Land management on Parker Mountain include wildlife conservation and providing sustainable ecosystem services such as livestock grazing.

My research described the species composition of the black sagebrush communities, evaluated the long-term vegetation responses to two mechanical (Dixie harrow/Lawson aerator) and one chemical treatment (tebuthiuron), and herbaceous biomass responses to tebuthiuron treatments in mountain big sagebrush communities on Parker Mountain.

My results indicated when black sagebrush canopy cover was <20%, average grass canopy cover was highest (13%). When black sagebrush canopy cover exceeded 40%, grass canopy cover was lowest (8%). Forb canopy cover was relatively consistent (5%) across black sagebrush communities with >20% canopy cover. Communities with <20% black sagebrush canopy cover had the lowest forb canopy cover.

Tebuthiuron reduced mountain big sagebrush percent canopy cover (>9 years), increased grass canopy cover, and increased forb canopy cover more than the two mechanical brush control methods. Tebuthiuron treatments shifted sites from xeric to more mesic plant communities, which resulted in increased percent forb cover required by greater sage-grouse during late-brooding.

Herbaceous biomass increased under tebuthiuron treatments in mountain big sagebrush pastures. Tebuthiuron treatments also reduced live sagebrush canopy cover for at least 9 years.

(137 pages)

PUBLIC ABSTRACT

Sagebrush Ecology of the Parker Mountain

Nathan E. Dulfon

On Parker Mountain located in south central Utah, management actions such as controlling mountain big sagebrush (*Artemisia tridentata* Nutt. subsp. *vaseyana*), with mechanical and chemical treatments can increase forage for livestock and benefit wildlife such as greater sage-grouse (*Centrocercus urophasianus*). Tebuthiuron treatments were applied on Parker Mountain from 2000-2012 with assistance from the Utah School and Institutional Trust Lands Administration, the Utah Department of Food and Agriculture, and the Natural Resources Conservation Service. Treatments applied to mountain big sagebrush on Parker Mountain provide an important opportunity to evaluate the value of mountain big sagebrush treatments in an adaptive management approach.

Previous research demonstrated that chemical and mechanical treatments implemented to reduce mountain sagebrush canopy cover resulted in increased forb canopy cover. Subsequent tebuthiuron treatments were then applied (0.37 kg ha^{-1}-0.74 kg ha^{-1} active ingredient) to approximately 202 ha per year over 6 years. The Parker Mountain Adaptive Resources Management local working group in conjunction with Utah State University Extension proposed a two-year research project to evaluate the long-term vegetation responses to sagebrush canopy cover reduction treatments on herbaceous biomass. The project proponents were also interested in documenting the vegetation composition of the black sagebrush (*Artemisia nova* A. Nelson) community on Parker Mountain because approximately 70% of the mountain is the black sagebrush ecotype. The research project provided important information and quantified the

herbaceous vegetation responses in terms of vegetation canopy cover relative to

sagebrush management techniques used on Parker Mountain.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Sagebrush Biome

Since the last glacial maximum, sagebrush (*Artemisia* ssp. L.) taxa, have

dominated plant communities across large portions of western North America (Schlaepfer

et al., 2014). Palynological records indicate sagebrush pollen found in the Snake River

Plain of Idaho and from the Great Salt Lake in Utah dates back to approximately 12

million years (Bartlein et al., 1998; Davis and Ellis, 2010). Today, the sagebrush biome is

composed of several dominant sagebrush species, such as Wyoming big sagebrush (*A.*

tridentata subsp. *wyomingensis* [Nutt.] Beetle & Young), basin big sagebrush (*A. t.*

subsp. *t.* Nutt.), and mountain big sagebrush (*A. t.* subsp. *vaseyana* Nutt. [Rydb.] Beetle).

Silver sagebrush (*A. cana* Pursh), little sagebrush (*A. arbuscula* Nutt.), and black

sagebrush (*A. nova* A. Nelson) are also widespread across western North American

sagebrush dominated rangelands.

Sagebrush taxa occur in different ecological sites across the landscape, which are

influenced by soils, climate, topographic position, and disturbance history (West, 1983;

Miller et al., 2011). Collectively, sagebrush species have historically occurred on 1 090

000 km^2 in the western United States (Fig. 1.1; Beetle, 1960; McArthur and Plummer,

1978; Beck et al., 2012).

Sagebrush-A Keystone Species

Big sagebrush (*A. t.* Nutt.) ecosystems are one of the largest potential natural

vegetation (PNV) type found in western North America (Miller et al., 2011; Beck et al.,

2012). The distribution of sagebrush ecosystems ranges from Baja California (Mexico)

north to British Columbia (Canada), east to North Dakota, and south to New Mexico and

Arizona (Shultz, 2012). Generally, big sagebrush is the dominant species over areas it

occupies, influences all organisms in the ecosystem (Braun et al., 1976; Knick et al.,

2003; Connelly et al., 2011), and is considered a keystone species (Khanina, 1998;

Smirnova, 1998; Beck et al., 2012). Consequently, many bird, mammal, reptile, and other

invertebrate species rely on big sagebrush ecosystems (West and Young, 2000; Rowland

et al., 2006). Sagebrush ecosystems provide habitat for sagebrush obligate and sagebrush

associated species, many of which are currently of conservation concern (Connelly et al.,

2004; Rowland et al., 2011). Sagebrush obligate species include the greater sage-grouse

(*Centrocerus urophasianus*), sage thrasher (*Oreoscoptes montanus*), sagebrush sparrow

(*Artemisiospiza nevadensis*), and pronghorn antelope (*Antilocapra americana*) (Rowland

et al., 2006; Schlaepfer et al., 2014). Sagebrush provides forage and thermal/security

cover for sagebrush obligates and wild ungulate species (Best, 1972; Kufeld et al., 1973;

Reynolds, 1981; McAdoo et al., 1989; Ngugi et al., 1992; Wambolt, 1996; Beck et al.,

2012). Sagebrush dominated rangelands also provide nutrient and water cycling, carbon

storage in soils, and microhabitats for an array of herbaceous plant species (West and

Young, 2000).

Mountain Big Sagebrush

Mountain big sagebrush (also known as "mountain sagebrush") is the most

common sagebrush species in montane (of mountainous country) habitats in western

North America. Mountain big sagebrush is second only to Wyoming big sagebrush in

extent of area covered (Goodrich, 2005; Shultz, 2009). The estimated area covered by

mountain sagebrush is approximately 260 000 km^2 within the sagebrush biome (Beetle,

1960; Shultz, 2009, 2012). Mountain sagebrush communities have been found in British

Columbia (Canada), Alberta (Canada), Arizona, California, Colorado, Idaho, Montana, New Mexico, North Dakota, Nevada, Oregon, Utah, Washington, and Wyoming (Fig. 1.2). Within its distribution, mountain sagebrush is usually found growing in rocky soils, montane meadows, and in forested areas dominated by mixed conifers and quaking aspen (*Populus tremuloides* Michx.) at elevations ranging from 780-3 100 m. Mountain sagebrush communities are found in soils that are typically 45-90 cm deep, and are often loamy to gravelly, but can contain greater amounts of clay (Goodrich, 2005; Shultz, 2009, 2012; Tilley et al., 2011)

Mountain sagebrush is a medium-sized shrub ranging from 40-120 cm tall, rarely exceeding 150 cm. This non-sprouting sagebrush species, has a flat-topped crown (i.e., black sagebrush is the only other sagebrush species that exhibits flat-topped crowns), and the vegetative branches are of nearly equal length. Evergreen leaves (12-15 mm long; 3-7 mm wide) are broadly cuneate (wedge shaped), and shallowly three lobed to irregularly toothed (rarely). The leaves are pungently aromatic due to the high phenolic and coumarin content within the foliage. A solution composed of alcohol/water and crushed leaves of mountain sagebrush fluoresces bright blue under a black light (Wyoming sagebrush leaves do not fluoresce at all). The narrowly paniculate inflorescences (10-15 cm long; 2-6 cm wide) rise above the crown from inflorescence branches giving each individual plant what has been described as a "cake and candle" appearance. Leaves of the flowering stem are mostly shorter than vegetative leaves and can be entire or three lobed. Flowering heads are bell shaped (1.5-3 mm wide: 2-3 mm long) and contain 3-9 florets per head. The involucre bracts of the flowering heads are hairy. Mountain sagebrush flowers in mid-summer to late fall (Shultz, 2009, 2012).

Mountain sagebrush can be found in association with other shrubs such as black sagebrush, Wyoming sagebrush, mountain snowberry (*Symphoricarpos oreophilus* A. Gray), green rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.), and antelope bitterbrush (*Purshia tridentata* [Pursh] DC.). Grass species such as Kentucky bluegrass (*Poa pratensis* L.), bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] Á. Löve), Idaho fescue (*Festuca idahoensis* Elmer), prairie junegrass (*Koeleria macrantha* [Ledeb.] Schult.), needle-and-thread grass (*Hesperostipa comata* [Trin. & Rupr.] Barkworth), and bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey) also inhabit mountain sagebrush communities. Typically, mountain sagebrush grows in areas that receive ≥350 mm annual precipitation, but can grow at lower elevations in snow drift accumulation areas and shaded north facing slopes (Winward, 1970; Marlow et al., 1987; Kaltenecker and Wicklow-Howard, 1994; Monson and Anderson, 1995; Shultz, 2009, 2012; Tilley et al., 2011).

In general, mountain sagebrush communities are more productive compared to Wyoming sagebrush communities (Goodrich, 2005; Davies and Bates, 2010b). Mountain sagebrush has higher herbaceous diversity of understory species, and has higher potential for greater canopy cover when compared to Wyoming sagebrush communities. Average crown cover of Wyoming big sagebrush communities is rarely >25% in patches larger than 0.5 ha. However, canopy cover >25% are common in mountain sagebrush communities. Without fire or other disturbances for >30 years, mountain sagebrush canopy cover can range from 25-40%. Though mountain sagebrush canopy cover of nearly 50% has been recorded (Tart, 1996; Goodrich and Huber, 2004). Mountain sagebrush annual production ranges from 418-2 354 kg ha^{-1}. Mountain sagebrush sites associated with bluebunch wheatgrass and blue grama (*Bouteloua gracilis* [Willd. Ex

Kunth] Lag. Ex Griffiths) had lower annual production juxtaposed to sites associated with snowberry and slender wheatgrass (*E. trachycaulus* [Link] Gould ex Shinners), which may be attributed to higher annual precipitation (Goodrich, 2005).

Greater sagebrush canopy cover and higher herbaceous productivity in the understory of mountain sagebrush communities promotes higher fire frequency than Wyoming sagebrush communities. Previous research indicated historical mean fire rotation in mountain sagebrush communities ranged from 12-200 years compared to 100-240 years in Wyoming sagebrush communities (Houston, 1973; Winward, 1991; Miller and Rose, 1999; Goodrich, 2005). Recovery time for mountain sagebrush communities that have been burned with fire range from 20-100 years or more. In comparison, Wyoming sagebrush communities required 50-120 years or more to return to pre-burn canopy cover (Baker, 2006; Lesica et al., 2007). Although plant species are reduced in density and production for a few years, essentially all species in mountain sagebrush ecosystems recover following a fire event (Goodrich, 2005).

Black Sagebrush

Black sagebrush has the broadest geographical range of all the native dwarf sagebrush. Geographical distribution of black sagebrush across the landscape is second only to basin big sagebrush (Rosentreter, 2005). Black sagebrush communities can be found across western North America in Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Utah, and Wyoming (Kearney et al., 1960; Shultz, 1986; Mozingo, 1987; Cronquist et al., 1994; Kartesz, 1999; Flora of North America Association, 2009; Fryer, 2009). Black sagebrush communities occupy approximately 112 100 km² of rangeland in the western United States. The majority of this area is located in Nevada and Utah (Fig. 1.3; Fryer, 2009).

Black sagebrush is an aromatic, non-sprouting, low growing evergreen shrub ranging from 10-30 cm in height, but is usually <50 cm. Black sagebrush exhibits widely distributed branches and vegetative stems of approximately equal height, which give each plant a hedged or flat-topped appearance. Leaves are usually dark green, but can be gray-green. Leaf blades (4-7 mm long; 2-4 mm wide) on vegetative branches are cuneate, and shallowly three lobed (rarely four or five lobed). Surfaces of the leaves are sparsely hairy, with glandular hairs exposed, which give leaves their gland-dotted dark green appearance. Leaves on inflorescence branches are usually entire and evergreen. The slender paniculate inflorescences (4-10 cm long; 0.5-3 cm wide) are mostly upright. Each flower head contains 2-4 florets. Black sagebrush flowers mid-summer to late fall (Shultz, 2009, 2012)

Black sagebrush vegetation types typically form wide, often continuous tracts along elevational zones that separate black sagebrush from other plant communities, and can occur from 1 400-3 400 m (Harrington, 1964; Munz and Keck, 1973; Beatley, 1976; Beetle, 1977; McArthur et al., 1979; Martin and Hutchins, 1981; Youngblood and Mauk, 1985; DeVelice et al., 1986; Mozingo, 1987; Cronquist et al., 1994; Kartesz, 1999; Flora of North America Association, 2009). Within its elevational range in Utah, black sagebrush can coexist with horsebrush (*Tetradymia canescens* DC.), greasewood (*Sarcobatus vermiculatus* [Hook.] Torr.), shadscale (*Atriplex confertifolia* [Torr. & Frém.] S. Watson), basin big sagebrush, Wyoming big sagebrush, pinyon- juniper (*Pinus* and *Juniperus* sp. L.), and mountain brush communities (Welsh et al., 1987). Low-elevation black sagebrush communities commonly form stands with a sparse herbaceous understory component (Kitchen and McArthur, 2007). On the contrary, high elevation black sagebrush communities can have higher forb abundance (Goodrich, 2005).

Black sagebrush communities are commonly found on soils that are shallow and rocky (Beetle, 1979; Hickman, 1993; Cronquist et al., 1994). Soils where black sagebrush is found are usually overlying bedrock, clay pan, or a cemented layer of iron oxide that is 5-76 cm deep (Cornelius and Talbot, 1955). However, where black sagebrush coexists with big sagebrush subspecies, soils are typically deeper (Beatley, 1976). Burke et al. (1989) suggested there may be a soil-nutrient gradient among black sagebrush and big sagebrush vegetation types, with black sagebrush communities representing the low-fertility end of the gradient. Soils where black sagebrush dominates tend to have less organic matter, nitrogen, and phosphorus than soils favoring big sagebrush subspecies (Matson et al., 1985; Schultz and McAdoo, 2002). Black sagebrush has been commonly observed in calcareous soils derived from limestone or other calcareous parent materials. However, in southern Utah, black sagebrush communities have been observed growing on soils derived from dolomite and volcanic material, which can be found on Parker Mountain located in south central Utah (Thatcher, 1959; Beatley, 1976; Fryer, 2009).

Black sagebrush can grow on all topographic positions (Thatcher, 1959; West, 1969; Zamora and Tueller, 1973; Hupp and Braun, 1989; Grayson et al., 1996; Schultz and McAdoo, 2002), and is commonly found on windy ridges that are free of snow in the winter (Gullion, 1964; Nelson and Sturges, 1986; Burke et al., 1989). Though black sagebrush communities are found growing on all topographic positions, at higher elevations they are commonly bound to southern facing slopes (Davis and Stevens, 1986; Fryer, 2009).

Black sagebrush is common on xeric soils, but can grow in moist sites (Hironaka, 1963; West, 1979; Shultz, 1986). Soils supporting black sagebrush communities are relatively drier for most of the growing season because the shallow soils have reduced

water holding capacity when compared to soils that support big sagebrush subspecies (Schultz and McAdoo, 2002; Goodrich, 2005; Kitchen and McArthur, 2007; Fryer, 2009).

Montane black sagebrush communities (above pinyon-juniper woodland ecosystems in mountainous country) are stable and generally more resistant to invasion by cheatgrass (*Bromus tectorum* L.) when compared to lower elevation black sagebrush ecosystems (Robertson and Kennedy, 1954; Fryer, 2009). At two sites on the Tavaputs Plateau in Utah (Ashley National Forest [ASNF] 67-26, 68-1), stands of black sagebrush were plowed and seeded with crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.), and other introduced species. When livestock and lagomorphs were excluded, black sagebrush returned to pretreatment conditions within 20 years, and displaced the introduced grasses (Goodrich, 2005).

At another site on the Ashley National Forest, in Utah, black sagebrush was sprayed with 2,4-D. At 14, 19, and 23-year post treatment, canopy cover of black sagebrush was measured at 5, 12, and 17%, respectively. At 23 years post treatment, there was no difference in black sagebrush canopy cover when compared to control (Goodrich, 2005).

Fires in black sagebrush communities are relatively infrequent compared to big sagebrush communities due the lack of fuel and non-continuous fuels, which has made black sagebrush intolerant of fire. Black sagebrush does not re-sprout after a fire has occurred. However, black sagebrush is capable of seedling establishment post fire. Montane stands of black sagebrush on the Tavaputs Plateau have returned to pre-fire canopy cover within 20 years after burning (Wasser, 1982; Goodrich, 2005).

Disturbance in Sagebrush

Much of the sagebrush biome has been degraded or lost because of brush control (Alley, 1956; Davies et al., 2012; Sturges, 1993), energy extraction (Walston et al., 2009), historical over grazing by livestock, and agricultural and urban development (West, 1983; West and Young, 2000; Schroeder et al., 2004; Miller et al., 2011; Beck et al., 2012). The anthropogenic effects of these activities have accelerated and aided in the removal, modification, and fragmentation of historical sagebrush habitat (Meinke et al., 2009; Knick and Connelly, 2011; Manier et al., 2013; Schlaepfer et al., 2014). Other biological and climatic stresses that include conifer expansion, invasive annual grass replacement, and irregular annual precipitation (unusually wet and dry years) have further reduced the historical distribution of sagebrush communities since the early 1980's (Welch, 2005; Shultz, 2009).

Historically, sagebrush communities within the sagebrush biome were influenced by periodic wildfires. Wildfires reduced sagebrush canopy cover, which resulted in increased herbaceous vegetation and heterogeneity within and between sagebrush communities (Wright and Bailey, 1982). However, with Euro-American settlement of western North America, fire-return intervals have been lengthened in some sagebrush plant communities, which may be attributed in part to improper grazing (Miller and Rose, 1999; Miller and Heyerdahl, 2008; Davies et al., 2012). Improper grazing practices that reduce the herbaceous understory thus fine fuels, also may be attributed to lengthened fire return intervals, especially in mountain sagebrush communities (West, 1983; Miller et al., 1994; Miller and Rose, 1999; Wrobleske and Kauffman, 2003). Herbaceous vegetation generally decreases as sagebrush abundance increases, which is a result of interspecific competition for limited resources such as light, water, nutrients, and space (Rittenhouse

and Sneva, 1976). When sagebrush stands become too dense and the herbaceous understory is limited, sagebrush canopy reduction treatments may be necessary to increase herbaceous vegetation abundance and cover (Connelly et al., 2000; Olson and Whitson, 2002; Crawford et al., 2004; Beck et al., 2009; Davies et al., 2012).

History of Sagebrush Control

Cultural, mechanical, and chemical treatments to reduce sagebrush canopy cover have been applied to sagebrush biomes for decades in an attempt to improve rangeland forage production (Hedrick et al., 1966). Before the end of World War II (WWII), fire and mechanical methods were the most common methods available to reduce sagebrush stands. Following WWII, mechanical and chemical methods were developed. Major reasons for treatments on sagebrush dominated rangeland prior to 1940s were related to agriculture (Baker et al., 1976). Various types of machinery are currently used to reduce sagebrush canopy cover on rangelands. Commonly used mechanical treatments include Dixie harrow, Lawson aerator, and anchor chains (Ely chain/Dixie Sager) (Davis, 1981). After WWII, chemical herbicides were increasingly used to reduce shrub cover to meet increasing forage demands (Peters et al., 2007).

The area of treated rangelands peaked between the 1950s and 1960s reaching 1 124 421 ha treated annually. The use of tebuthiuron ((N-[5-(dimetylethyl)-1,3,4-thiadiazol-2yl]-N,N'-dimethylurea) as sagebrush control has increased since the late 1970s, and has rapidly become one of the preferred herbicide by both private individuals and public agencies (Fig. 1.4; Baker et al., 1976; Peters et al., 2007).

Sagebrush Reduction Treatments

The Dixie harrow was invented and first used in the 1930s on the Dixie National

Forest located in southern Utah. The first uses where part of a rangeland experiment

where the Dixie harrow was used to clear brush and loosen soil for reseeding projects in

mountain sagebrush communities. The Dixie harrow was first used to rehabilitate

mountain meadows, which had become degraded by improper livestock grazing practices

(Davis, 1981).

The Dixie harrow used in today's rangeland applications consists of several pipes

~10-15 cm in diameter that are attached to a metal 25 cm I-beam. Each pipe has metal

fins welded to it in an opposite systematic arrangement. The I-beam is then attached to a

tractor that pulls the Dixie harrow across the landscape. The pipes are attached so that

they have movement and rotate as they are pulled across the terrain. The rotation of the

pipes clears plant debris off the fins as plant debris builds up. Effectiveness of the Dixie

harrow decreases in rocky terrain because the harrow brings many rocks to the surface,

which raises the harrow off the ground resulting in decreased damage to sprouting shrubs

(Valentine, 1989). The Dixie harrow is a good option for mechanically thinning mountain

sagebrush because it kills 30-70% of the brush it comes in contact with. The Dixie

harrow can also be used to eliminate most of the dead and live shrubs with multiple

passes (Elder, 2013), and also aids in covering broadcasted seed with soil in rangeland

restoration projects (Davis, 1981). The Dixie harrow treatments cost approximately

$74.00 ha^{-1} (U.S.) including seed (Dahlgren et al., 2006).

The use of spiral-blade choppers (often called "aerators" or "renovators"), such as

those used on the Lawson aerator, has gained popularity since the 1990s, especially in

brush-dominated landscapes. The Lawson aerator is commonly used as an alternative to

chaining, harrowing, or herbicide treatment for shrub cover reduction and increasing

herbaceous components of sagebrush communities. They are also used in pasture settings

to increase water infiltration and reduce soil compaction. The Lawson aerator features

one or two drums mounted on a frame, which have small blades welded to the heavy

drums in a staggered, spiral pattern around the drum, rather than the elongated

longitudinally mounted blades (Cox, 2008). The Lawson aerator can also be equipped

with a seed box to promote additional herbaceous establishment. Passes of an aerator

crush sagebrush and other shrubs, leaving some plants or partial plants alive. Dixie

harrow in comparison to Lawson aerator, rip brush out of the ground leaving exposed

soil. Lawson aerators can provide brush control, while conserving soil and leaving the

vegetation biomass behind. Treatments costs using a Lawson aerator is approximately

$74.00 ha^{-1} (Dahlgren et al., 2006).

A chemical tool that can have utility in sagebrush dominated restoration projects

is tebuthiuron (N-(5-(1, 1-dimethylethyl)-1,3,4-thiadiazol-2-yl)-N,N'-dimethylurea).

Tebuthiuron is a pelleted, soil active herbicide with capabilities to selectively thin

sagebrush by using low application rates (Whitson and Alley, 1984; Whitson et al., 1988;

Whitson, 1991; Halstvedt, 1994; Johnson et al., 1996; Olson and Whitson, 1996, 2002;

Dahlgren et al., 2006). Tebuthiuron inhibits photosynthetic activity of sagebrush, which

depletes carbohydrate reserves, and induces mortality. When tebuthiuron is applied at a

rate of 0.1-0.5 kg active ingredient (AI) ha^{-1}, sagebrush plants rooted within a 0.5 m

radius of an herbicide pellet are affected. Selective elimination of individual sagebrush

plants results in the increase of grasses and forbs in microhabitats formerly occupied by

sagebrush (Whitson and Alley, 1984; Olson and Whitson, 2002). Tebuthiuron indirectly

enhances herbaceous plant production by reducing interspecific competition following

sagebrush thinning. However, the response of herbaceous plants to sagebrush removal with tebuthiuron is also influenced by current vegetation present, soil conditions (texture and depth), application rate, amount/pattern of post-treatment precipitation, and the length of grazing rest after treatment (Clary et al., 1985; Emmerich, 1985; DowElanco, 1994; Braun, 1998; Olson and Whitson, 2002).

The efficiency of tebuthiuron in causing sagebrush mortality is highly influenced by specific soil properties. Tebuthiuron does not dissociate in high pH soils and becomes less effective when the chemical binds to organic matter and clay particles (Chang and Stritzke, 1977; Weber, 1980). Soil organic matter is more important in regulating tebuthiuron availability compared to soil clay content. However, most soils dominated by big sagebrush are so low in organic matter that soil clay content becomes the primary factor in tebuthiuron's effectiveness to kill sagebrush. Tebuthiuron has a soil half-life of 12-15 months in areas receiving 102-152 cm of annual precipitation, but the half-life may be extended in areas with lower annual precipitation (Elanco Products, 1975). Soil microbes and plants metabolize tebuthiuron once in the system (DowElanco, 1994). The slow decomposition rate of tebuthiuron is beneficial for thinning sagebrush species and suppressing any new sagebrush seedling recruits (Emmerich, 1985). Research on the effects of alteration of sagebrush dominated rangelands indicates sagebrush removal significantly reduces soil moisture loss (Sturges, 1973), increases dry matter production by forbs and grass that remain, and makes grass more readily available to livestock (Daubenmire, 1970; Baker et al. 1976). The effects of tebuthiuron on plant community structure and function within the sagebrush biome are poorly understood, and relatively little information exists on using tebuthiuron for conservation or restoration purposes (Marrs, 1984, 1985; Olson and Whitson, 2002).

Expected treatment longevity for sagebrush stands treated with tebuthiuron has been widely debated, but is no less than 15 years, and is not longer than 25-30 years (Braun, 1998). Evidence from other research indicates that any control of sagebrush outside of continuous agricultural practices is short lived (Harniss and Murray, 1973; Thilenius and Brown, 1974). To increase forage production for livestock, sagebrush control must be conducted on a continual basis to maintain forage increases (Baker et al., 1976).

Impacts of Mountain Sagebrush Control Treatments

Reported herbaceous vegetation responses to mountain sagebrush canopy reducing treatments may differ in duration across the western United States (Table 1.1). Dahlgren et al., (2006) assessed the vegetation canopy cover responses to Dixie harrow, Lawson aerator, and tebuthiuron treatments that reduced mountain sagebrush canopy cover. Forb canopy cover in the tebuthiuron plots was 8% higher than control at the end of the study (Dahlgren et al., 2006). Murray (1988) applied tebuthiuron 20P and 40P at a rate of 0.6 and 1.1 kg AI ha^{-1}, which was effective at reducing canopy cover of mountain sagebrush and increasing grass biomass by ~50% in all treatments when compared to control (Table 1.1). Other research (Clary et al., 1985; Wachocki et al., 2001; Payton et al., 2011) indicated that Dixie harrow and tebuthiuron treatments of mountain sagebrush did not increase herbaceous cover or biomass at the end of each study (Table 1.1).

Site specific scientific evaluations of vegetation responses to Dixie harrow, Lawson aerator, and tebuthiuron treatments are lacking in scientific literature, especially long-term vegetation cover and biomass responses to tebuthiuron treatments in mountain sagebrush communities (Dahlgren et al., 2006). Most scientific literature only reported results that represent short-term (less than four year post treatment) results of vegetation

cover and biomass responses to treatments in mountain sagebrush. Vegetation cover and biomass responses to sagebrush canopy reducing treatments also vary between sites studied (Table 1.1).

Research Questions

As part of the adaptive management approach on Parker Mountain, local managers sought to evaluate long-term vegetation responses to chemical and mechanical treatments in mountain sagebrush communities. This information will be important to determine if treatments are increasing the herbaceous cover/biomass benefiting livestock and wildlife. The research I conducted quantifies vegetation cover and herbaceous biomass response to Dixie harrow, Lawson aerator, and tebuthiuron treatments in mountain sagebrush communities, which will help better manage rangelands for wildlife habitat and forage production for livestock. Managers also sought to describe plant community diversity of black sagebrush across Parker Mountain to describe habitat used by sagebrush obligate species.

The proceeding chapters follow "Range Ecology and Management" guidelines. My research addresses the following questions:

1. What are the long-term vegetation responses to treatments (i.e., Lawson aerator, Dixie harrow, and tebuthiuron) in mountain sagebrush communities? (Chapter 2)

2. When does mountain sagebrush canopy cover begin to limit the herbaceous components of the sagebrush understory? (Chapter 2)

3. Does tebuthiuron treatments in mountain big sagebrush communities increase herbaceous biomass? (Chapter 3)

4. What is the shrub, forb, and grass composition of high elevation black sagebrush communities on Parker Mountain? (Chapter 4)

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Tables and Figures

Table 1.1
Research assessing the vegetation responses to Dixie harrow, Lawson aerator, and tebuthiuron treatments in *Artemisia tridentata* subsp. *vaseyana* communities in the American west (1985-2011). Studies followed by an asterisk measured herbaceous biomass. Studies without asterisk measured herbaceous canopy cover. Minus symbols represent significant decreases, plus symbols represent significant increases, and equal symbols represent no significant difference between treatment and control at the end of each study.

Study	Duration (year)	Treatment Type	State	Shrub	Grass	Forb
Dahlgren et al., 2006	4		UT			
		Dixie Harrow		- (41%)	=	+ (27%)
		Lawson Aerator		- (54%)	=	=
		Tebuthiuron 0.30 kg AI ha-1 (20P)		- (36%)	=	+ (35%)
Payton et al., 2011	3		CO			
		Dixie Harrow		=	=	- (51%)
Murray, 1988 *	3		ID			
		Tebuthiuron 0.60 kg AI ha-1 (20P)		- (95%)	+ (54%)	=
		Tebuthiuron 0.60 kg AI ha-1 (40P)		- (83%)	+ (48%)	=
		Tebuthiuron 1.10 kg AI ha-1 (20P)		- (87%)	+ (50%)	=
		Tebuthiuron 1.10 kg AI ha-1 (40P)		- (93%)	+ (52%)	=
Wachocki et al., 2001	4		UT			
		Tebuthiuron 0.34 kg AI ha-1 (?P)		- (58%)	=	=
		Tebuthiuron 0.56 kg AI ha-1 (?P)		- (76%)	=	=
		Tebuthiuron 0.78 kg AI ha-1 (?P)		- (83%)	=	=
Clary et al., 1985 *	3		UT			
		Tebuthiuron 0.60 (?P)		- (99%)	=	=
		Tebuthiuron 1.00 (?P)		- (73%)	=	=
		Tebuthiuron 1.30 (?P)		- (83%)	=	=
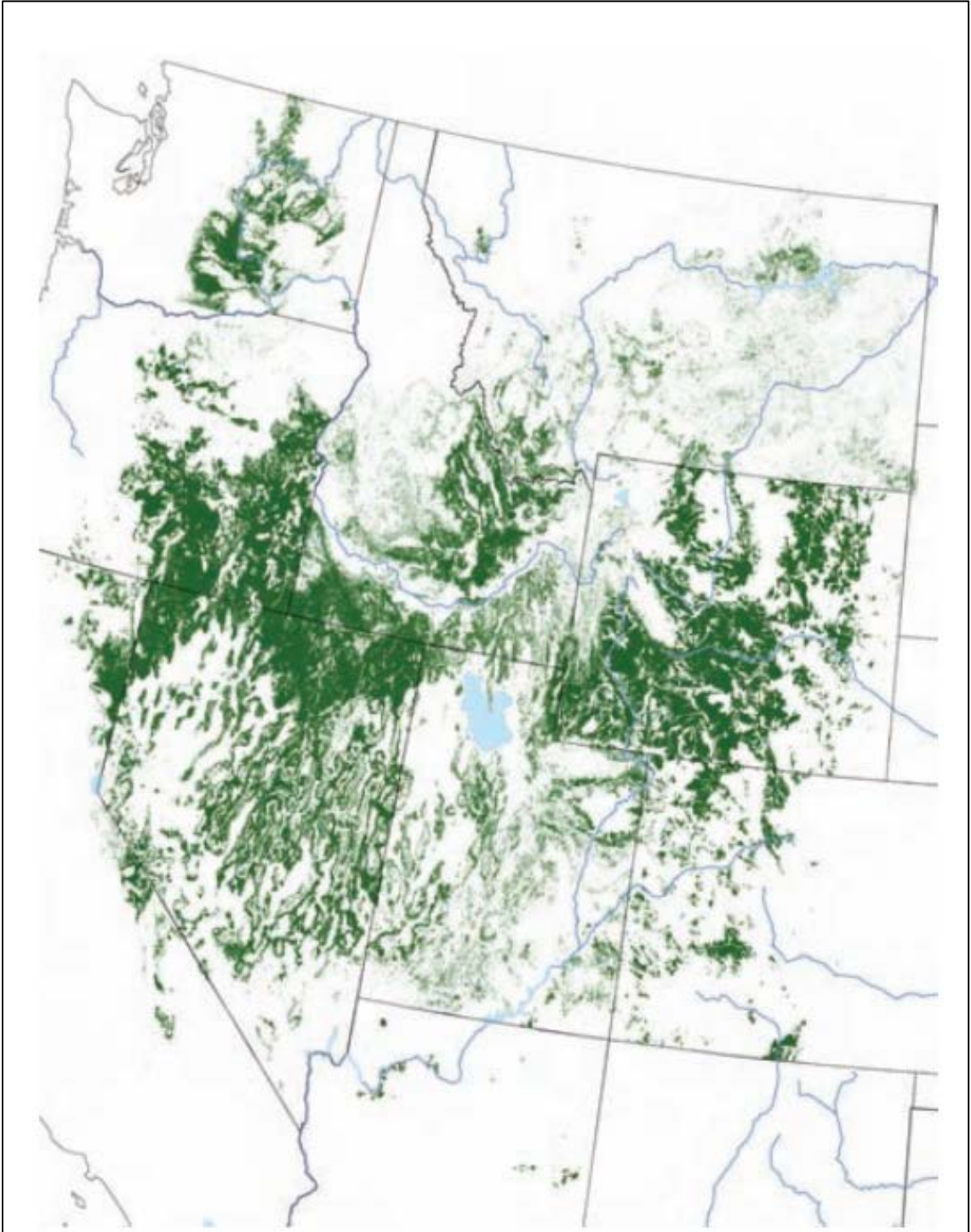
Fig. 1.1. Generalized map of *Artemisia* ssp. distribution in the American West (Shultz, 2012).
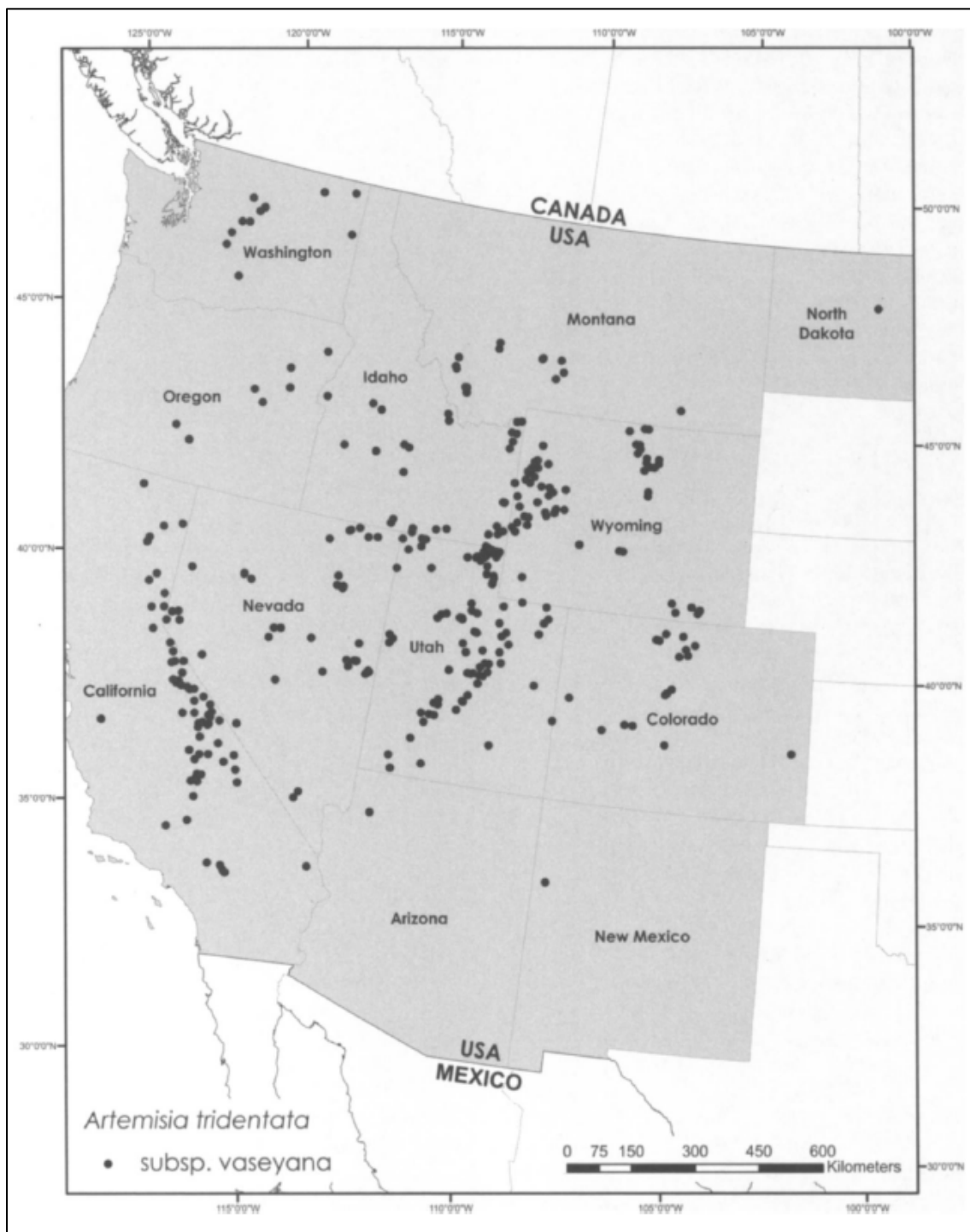
Fig. 1.2. Distribution of *Artemisia tridentata* subsp. *vaseyana* in the American West (Shultz, 2009).
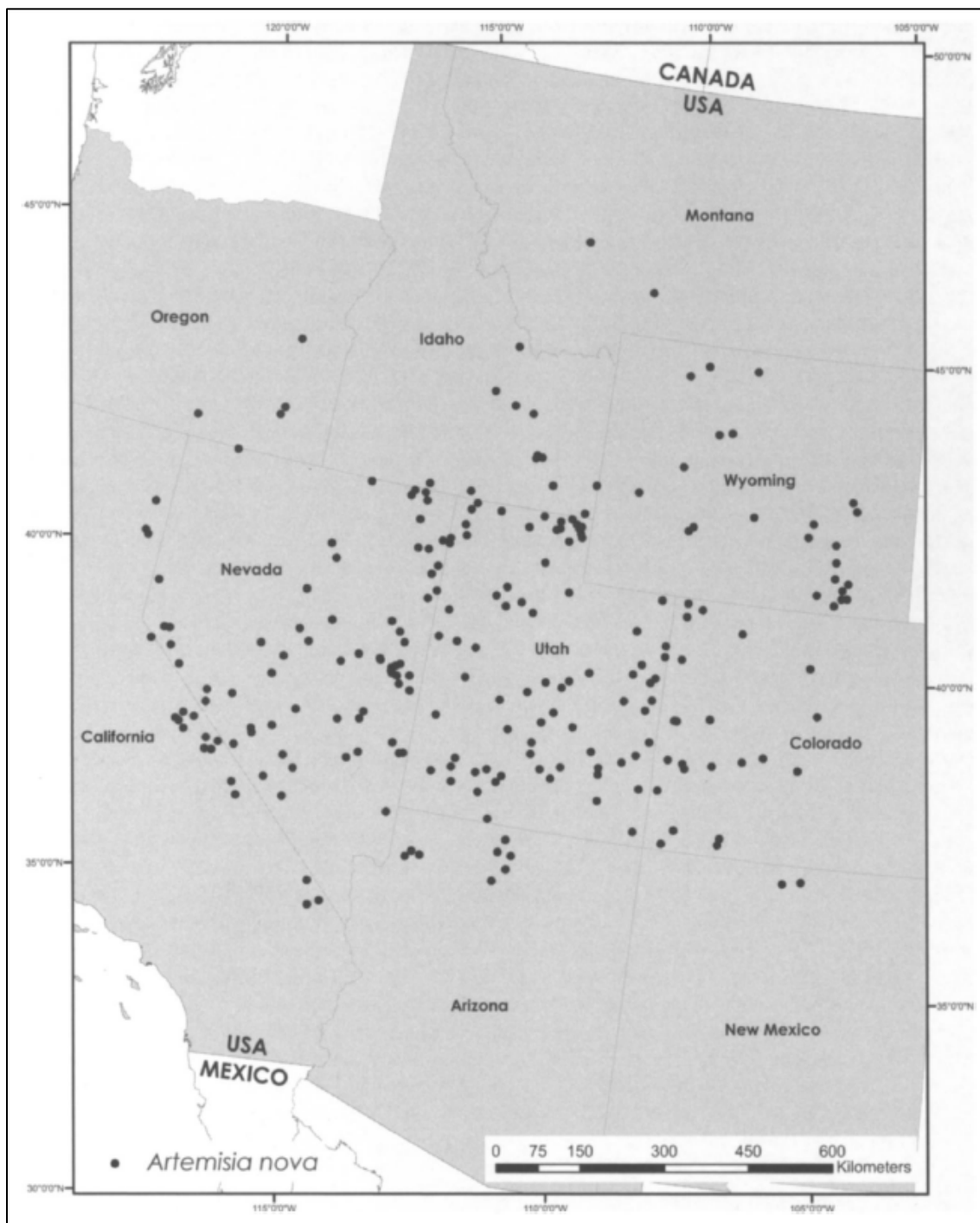
Fig. 1.3. Distribution of *Artemisia nova* in the American West (Shultz, 2009).
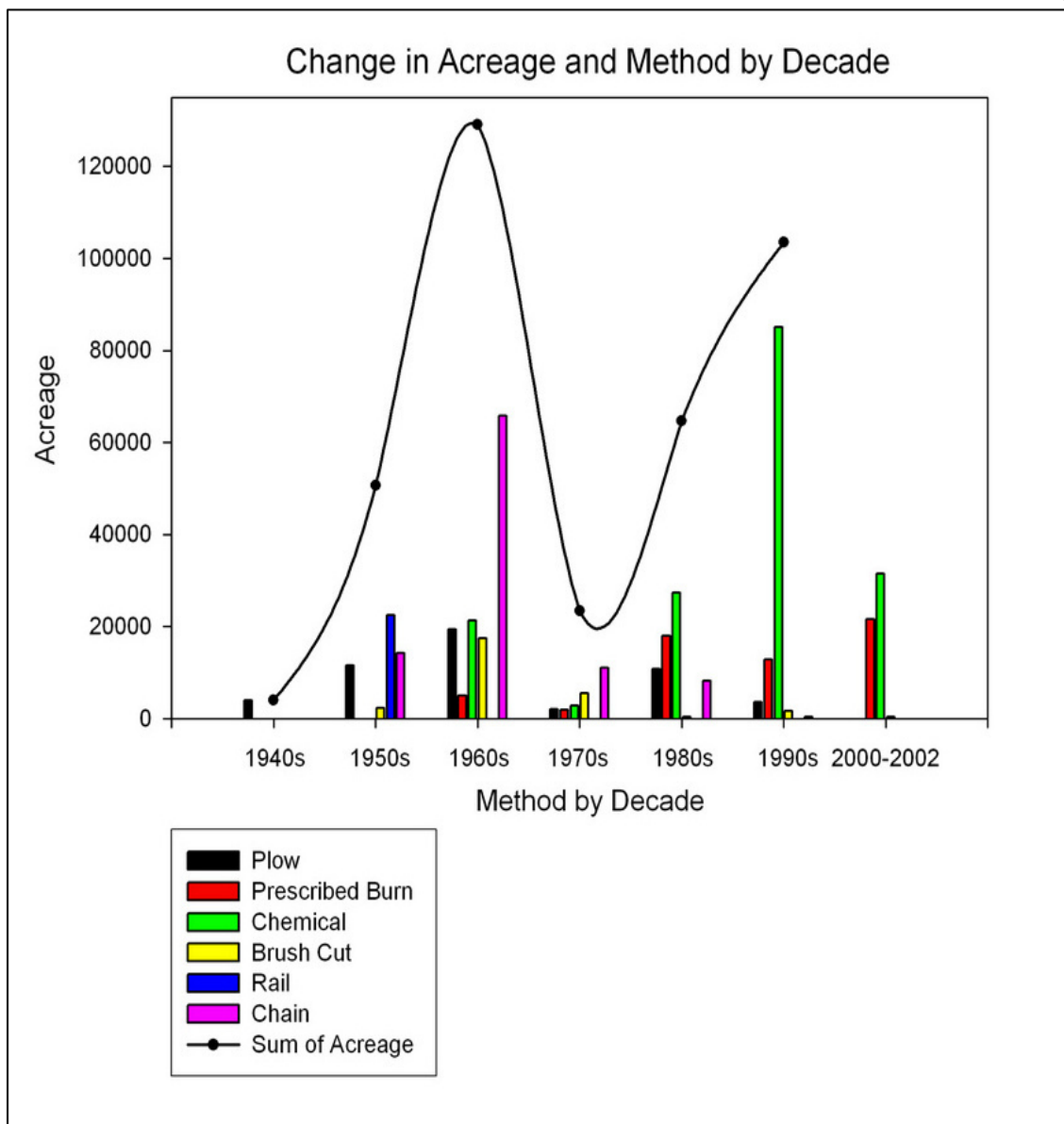
Fig. 1.4. Estimates of *Artemisia* ssp. treated with various treatments from 1940-2002. (Peters et al., 2007).

CHAPTER 2

LONG-TERM VEGETATION RESPONSE TO CHEMICAL AND MECHANICAL

MOUNTAIN BIG SAGEBRUSH CONTROL ON PARKER MOUNTAIN IN SOUTH

CENTRAL UTAH

Abstract

In some mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana* Nutt.
[Rybd.] Beetle) communities, dense shrub canopy cover has limited herbaceous
understory due to multiple factors. Historically, treatments objectives were to reduce
sagebrush canopy cover and increase forage production for livestock. Recently these
treatments have been increasingly applied to improve habitat for wildlife species such as
greater sage-grouse (*Centrocercus urophasianus*). However, long-term scientific
evaluations to shrub reduction treatments are generally lacking. I used line intercept and
line-point intercept methods to evaluate vegetation canopy cover responses in mountain
big sagebrush communities to mechanical (Dixie harrow/Lawson aerator) and chemical
(Spike 20P or tebuthiuron) treatments in 16 randomly selected 40.5 ha plots with four
replicates, which included controls on Parker Mountain in south central Utah. Shrub
canopy cover in mechanical treatments was similar to untreated plots, but lower in
tebuthiuron treatments. Forb canopy cover was highest in tebuthiuron treatments. My
study provides further evidence that indicates tebuthiuron treatments is beneficial in
enhanced herbaceous species cover in high elevation mountain big sagebrush
communities compared to Dixie harrow and Lawson aerator treatments.

Introduction

Mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana* Nutt. [Rydb.]

Beetle), also known as "mountain sagebrush" is the most common sagebrush of montane

habitats. Mountain sagebrush occupies an area that is approximately 260,000 km^2

(Beetle, 1960; Shultz, 2009, 2012). Often mountain sagebrush can be the dominant

species over areas it occupies (Braun et al., 1976; Connelly et al., 2011; Knick et al.,

2003) and is considered a keystone (Beck et al., 2012; Khanina, 1998; Smirnova, 1998).

Consequently, many bird, mammal, reptile, and other invertebrate species rely on

mountain sagebrush communities (West and Young, 2000). Mountain sagebrush provides

habitat for sagebrush obligate and sagebrush associated species, such as greater sage-

grouse (*Centrocerus urophasianus*) which is currently a species of conservation concern

(Rowland et al., 2006). Historically, the vegetation composition of mountain sagebrush

communities within the sagebrush biome was influenced by periodic wildfires. Wildfires

reduced the sagebrush canopy cover, which increased herbaceous vegetation and

heterogeneity in mountain sagebrush plant communities (Wright and Bailey, 1982).

Research indicates historical mean fire return intervals in mountain sagebrush

communities ranged from 12-200 years (Houston, 1973; Winward, 1991; Miller and

Rose, 1999). Recovery time for mountain sagebrush communities that have been burned

ranges from 20-100 years or more (Baker, 2006; Lesica et al., 2007). Although some

species are reduced in density and production for a few years, most plant species recover

following fire (Goodrich, 2005).

However, with Euro-American settlement of the western United States, fire-return

intervals have been lengthened in some mountain sagebrush communities, which may be

attributed in part to improper grazing (Miller and Heyerdahl, 2008). Past improper

grazing practices reduced herbaceous understory thus reducing fine fuels, which lengthened fire return intervals in mountain sagebrush communities (West, 1983; Miller et al., 1994; Miller and Rose, 1999; Wrobleske and Kauffman, 2003).

Herbaceous vegetation generally decreases as sagebrush abundance and canopy cover increases as a result of competition for limited resources such as light, water, nutrients, and space (Rittenhouse and Sneva, 1976). When sagebrush stands become too dense and herbaceous understory is limited, sagebrush reduction treatments may be necessary to increase herbaceous vegetation (Connelly et al., 2000; Olson and Whitson, 2002; Crawford et al., 2004; Beck et al., 2009; Davies et al., 2012).

Various types of mechanical and chemical treatments have been used to reduce mountain sagebrush on rangelands. Mechanical treatments typically have included the Dixie harrow and Lawson aerator (Davis, 1981). Herbicides are also a common tool for mountain sagebrush reduction projects. Tebuthiuron (N-(5-(1,1-dimethylethyl)- 1,3,4-thiadiazol-2-yl)- N,N'-dimethylurea), a pelleted, soil active herbicide has been used to selectively thin mountain sagebrush (Whitson and Alley, 1984; Whitson et al., 1988; Halstvedt, 1994; Johnson et al., 1996; Olson and Whitson, 1996, 2002; Dahlgren et al. 2006).

Patterson (1952) questioned sagebrush control projects in the past as a serious threat to populations of greater sage-grouse, pronghorn antelope (*Antilocapra americana*), and mule deer (*Odocoileus hemionus*) (Baker et al., 1976). However, mountain sagebrush treatments have been increasingly applied in an effort to enhance habitat conditions for wildlife species (Heady and Child, 1999; Chi, 2004; Dahlgren et al., 2006; Davies et al., 2009; Payton et al., 2011; Taylor and Messmer, 2011; Beck et al., 2012).

Dahlgren et al., (2006) assessed the vegetation responses to Dixie harrow, Lawson aerator, and tebuthiuron treatments to reduce mountain sagebrush canopy cover. Forb canopy cover in the tebuthiuron plots was 8% higher than control at the end of the study (Dahlgren et al., 2006). In another study, Murray (1988) applied tebuthiuron 20P and 40P at a rate of 0.6 and 1.1 kg AI ha^{-1}, which reduced mountain sagebrush canopy cover and increased grass biomass by ~50% in all treatments when compared to control. However, Clary et al., (1985), Wachocki et al., (2001), and Payton et al., (2011) reported that Dixie harrow and tebuthiuron treatments of mountain sagebrush did not increase herbaceous cover or biomass at the end of the study (Table 1.1).

Long-term evaluations of Dixie harrow, Lawson aerator, and tebuthiuron treatments used to reduce mountain sagebrush canopy cover are lacking in scientific literature (Dahlgren et al., 2006). Most results of mountain sagebrush treatments are short term (less than four year post treatment) (Table 1.1). The objective of my research was to determine the long-term vegetation cover response of mountain sagebrush, grasses, and forbs to Lawson aerator, Dixie harrow, and tebuthiuron treatments.

Study Area

I conducted research in the Parker Lake Pastures on Parker Mountain located in Garfield, Piute, Sevier, and Wayne counties in south central Utah. Parker Mountain is part of the Colorado Plateau (Colorado Plateau, 2016). Parker Mountain is bounded to the north by the Fish Lake Plateau, to the west by Grass Valley, to the east by Boulder Mountain, and to the south by the Aquarius Plateau. The mountain is an eastward-sloping plateau that consists of approximately 153 780 ha (Elmore and Messmer, 2006) and has an elevation gradient of 2 134-3 018 m (Chi, 2004). The study area is located in the Parker Lake pasture on Parker Mountain which is approximately 1 100 ha.

Climate data for Parker Mountain provided by parameter-elevation regressions on independent slopes model (PRISM) indicates over the past 50 years (January 1, 1964-December, 31, 2014), Parker Lake on Parker Mountain received 567 mm of average annual precipitation. Parker Mountain is influenced by the Arizona monsoonal system, which feeds moisture and summer precipitation from July to September into western North America (Lin et al. 1996; Chi, 2004). Although Parker Mountain receives some summer precipitation, most of the moisture throughout the year comes from snow pack in the late fall, winter, and early spring months (Fig. 2.1). The 52 year (Jan. 1, 1964-Jan. 1, 2016) average minimum temperature was -11.5 C (January) and the average maximum temperature was 22.4 C (August) (PRISM, 2004).

Detailed soil information on Parker Mountain are limited. The main soil types in the Parker Lake area consists of 70% Pachic Argicryolls, and 30% Xeric Argicryolls (Fig. 2.2; Soil Survey Staff, 2015).

Utah School and Institutional Trust and Lands Administration (SITLA) manages 43 863 ha on the western portion of Parker Mountain, which includes the Parker Lake study area. The Parker Lake area has maintained cattle (*Bos taurus*) herbivory for at least 100 years. Cattle still graze the area at 1.46 ha per animal unit month (AUM) (Chi, 2004). Springs and shallow lakes occur above 2 621 m elevation on the plateau. In addition, over 80 livestock water developments provide season water sources for livestock and wildlife on Parker Mountain (Chi, 2004).

In the Parker Lake area, mountain sagebrush, black sagebrush (*A. nova* A. Nelson), and silver sagebrush (*A. cana* Pursh) coexist between stands of quaking aspens (*Populus tremuloides* Michx.) (Chi, 2004). Other shrubs and sub-shrubs in the Parker Lake Pasture include yellow rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.),

Wood's rose (*Rosa woodsii* Lindl.), and mountain snowberry (*Symphoricarpos oreophilus* A. Gray). Dominant grasses include squirreltail (*Elymus elymoides* [Raf.] Swezey), sheep fescue (*Festuca ovina* L.), prairie Junegrass (*Koeleria macrantha* [Ledeb.] Schult.), muttongrass (*Poa fendleriana* [Steud.] Vasey), needle and thread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth), and Letterman's needlegrass (*Achnatherum lettermanii* [Vasey] Barkworth). The most abundant forbs include small-leaf pussytoes (*Antennaria parvifolia* Nutt.), purple milkvetch (*Astragalus agrestis* Douglas ex G. Don), lesser rushy milkvetch (*A. convallarius* Greene), Eaton's fleabane (*Erigeron eatonii* A. Gray), spiny phlox (*Phlox hoodii* Richardson), longleaf phlox (*P. longifolia* Nutt.), and elegant cinquefoil (*Potentilla concinna* Richardson) (Chi, 2004; United States Department of Agriculture, Natural Resources Conservation Services., 2015).

Methods

I analyzed vegetation cover response data to three brush control treatments: Dixie harrow, Lawson aerator, and tebuthiuron from 2000-2009. Within the Parker Lake pasture there were 16 plots (40.5 ha each) that were randomly selected. There were four replicates of the Lawson aerator, Dixie harrow, tebuthiuron, and control. Plots were established using 1 m aerial photographs to identify mountain sagebrush stands with canopy cover >35%. Within each plot five transects were randomly placed (80 total transects). Each transect is 20 m long. A random direction was used to determine the direction of each transect (Fig. 2.3; Dahlgren, 2006).

In fall 2000, tebuthiuron plots were treated with 0.3 kg AI ha^{-1} and Lawson aerator and Dixie harrow treatments were applied to randomly selected plots in fall 2001. All vegetation surveys (repeated measures) were conducted during July from 2000-2007

and in 2009. Line intercept was used to estimate live shrub canopy cover (5 cm gap) in all

plots (Canfield, 1941). A variation of the line-point intercept method was used to

measure ground cover and herbaceous canopy cover (Levy and Madden, 1933). Twenty

points of ground cover and herbaceous canopy cover were collected from each transect

by using a pole with a nail point, which was lowered to the soil surface at each meter

along each transect (Dahlgren, 2006).

Data Analyses

To analyze treatment data, I created four vegetation cover categories: shrub, grass,

sage-grouse forb, and mesic forb by combining species within each category. Sage-

grouse forbs consisted of all the forbs in the study areas that sage-grouse use during the

brooding season (Dahlgren et al., 2015). Mesic forbs consisted of all the forbs in the

study area that where considered facultative upland, facultative, and facultative wetland

forbs from the National Wetland Plant List (Table 2.1; Lichvar et al., 2012; Lichvar,

2014).

I inspected the vegetation cover data from all plots to look for outliers (Appendix

A2-A17). All variables for each treatment were analyzed with generalized additive

mixed models using 84% confidence intervals (Payton et al., 2003). Each vegetation

response model takes into account the fixed effect of treatment type and the random

effects of each plot from repeated measures (Appendix A1).

I validated each vegetation response model by testing model fitness (Appendix

A2-A17). I also confirmed that the best models were selected for treatment comparisons

via increasing degrees of freedom by using "day of research" instead of "year of

research". I tested model fitness by evaluating the significance of model prediction by

inspecting model parametric coefficients and test statistics of the smoother terms

(Appendix A18).

The temporal vegetation response analysis for the Parker Lake Pasture

Experiment was performed in R 3.2.3 (R Core Team, 2016) using a generalized additive

models with mixed effects. The models were analyzed individually using the "mgcv"

(version 1.8.0) (Wood, 2011) and "nmle" (Pinheiro et al., 2014) packages.

Results

Live sagebrush canopy cover was reduced after treatments were applied.

However, the treatments differed in their ability to suppress shrub canopy cover over the

9 year study period (Fig. 2.4). Percent sagebrush canopy cover in Dixie harrow plots was

similar to control plots after 5 years. But two years later sagebrush canopy cover

increased in control plots. Shrub canopy cover response was similar in the Lawson

aerator treatments, but treatments remained effective at controlling sagebrush for six

years after treatment. Shrub canopy cover in tebuthiuron plots had lower shrub canopy

cover when compared to control plots for the entire study period (9 years). Tebuthiuron

plots had 14% less shrub cover when compared control plots in 2009 (Fig. 2.4).

Mechanical treatments did not increase grass canopy cover over the course of the

study. The Dixie harrow treatments increased grass cover in a single year, two years post

treatment. Grass cover in plots treated with tebuthiuron were similar to control plots for

seven years. However, grass cover in tebuthiuron plots showed an increasing trend

beginning in 2007. Tebuthiuron increased grass cover ~9% in 2009 and exhibited an

upward trend (Fig. 2.5).

Lawson aerator treatments also did not increase sage-grouse forb cover (Dahlgren

et al. 2015) cover. Sage-grouse forb cover in Dixie harrow and tebuthiuron treatments

were similar to control plots during the first two years. However, sage-grouse forb cover increased in Dixie harrow and tebuthiuron treated plots two years post treatment for seven years. Dixie harrow plots had a 5% increase of grouse forb cover when compared control plots in 2009, though it is likely this is not biologically meaningful. However, tebuthiuron increased sage-grouse forb cover 11% in 2009 and exhibited an upward trend (Fig. 2.6).

Both mechanical treatments were ineffective at increasing mesic forb cover juxtaposed to control plots. However, tebuthiuron increased mesic forb cover 8% and exhibited an increasing trend when compared to control plots in 2009 (Fig. 2.7).

Discussion

Tebuthiuron was superior to the mechanical treatments in its ability reduce mountain sagebrush canopy cover and increase grass and forb cover for at least 9 years (Fig. 2.4, 2.5, 2.6, and 2.7). The ineffectiveness of mechanical treatments to increase herbaceous components in mountain sagebrush communities may be attributed to soil types found within mechanical treatment plots, removal of plant residues, soil moisture loss, drought, and longevity of livestock grazing rest.

Rocky and shallow soil types found within Lawson aerator and plots inhibited the Lawson aerator from decreasing shrub canopy cover. Complete treatment within Lawson aerator plots was inhibited by because the drum aerator bounced across the shallow/rocky soils, thus leaving immature sagebrush plants to compete with herbaceous plants (Dahlgren et al. 2006). Similarly, Dixie harrow treatments will only kill 40-50% of the sagebrush plants it comes into contact with rocky, uneven terrain (Stewart, 1950). Though the mechanical treatments were effective at reducing sagebrush canopy cover for

several years, herbaceous responses were reduced because of the lack of sagebrush kill and drought in 2002 (Dahlgren, 2006).

In my study the use of tebuthiuron increased mesic forb species (Fig. 2.7). This could be explained by the fact that tebuthiuron treatments leave sagebrush "skeletons" which collects snow, moderates wind speed and provides some shade, which increases soil moisture (Olson et al., 1994). Increases in soil moisture may also affect how long vegetation remains green thus increasing the forage quality and thus benefiting all herbivores, especially in drought years. On the contrary, mechanical treatments reduced plant community structure by removing plant residues, exposed soil, and reduced microsites for mesic forbs to coexist.

My results are similar to Murray (1988) and suggest that tebuthiuron has the ability to increase grass cover and decrease sagebrush canopy cover (Table 1.1). A general trend from my results indicates as sagebrush canopy decreases, interspecific competition between shrubs and herbaceous plants is reduced. Tebuthiuron treatments reduced mountain sagebrush canopy cover longer than both mechanical treatments, which promoted more herbaceous cover. More importantly my results show that tebuthiuron increases forb cover for at least 9 years following treatments suggesting that the gains in herbaceous species persists longer than mechanical treatments.

Results from Clary et al., (1985) and Wachoki et al., (2001) showed no increases in herbaceous vegetation at the end of the studies (Table 1.1). This may be due in part to drought or other factors such as high application rates of tebuthiuron. Johnsen and Morton (1989) showed that tebuthiuron persists in the soil for more than two years (particularly in a semiarid environment) and suppresses non-targeted vegetation for several years. This highlights the need to carefully consider application rates, if

application rates are too high, tebuthiuron can damage non-target species (perennial grasses and forbs), and the ability of tebuthiuron to damage herbaceous species may persist for more than four years (Murray 1988). It is therefore necessary to determine minimum dosages required to achieve the desired thinning effects while avoiding over application of tebuthiuron to prevent undesirable prolonged effects on an ecosystem (Wachoki et al., 2001).

Furthermore, when tebuthiuron is used in sage-grouse brood-rearing habitat, a low rate of active ingredient (0.3 kg AI ha^{-1}) that results in partial kill of sagebrush may be more desirable (Dahlgren et al. 2006). Soil texture and depth, sagebrush vigor, precipitation patterns, and other environmental should be considered because they also affect sagebrush kill. Low tebuthiuron AI application rates and treatment widths of ≤120 m are recommended to ensure adequate heterogeneity among mountain sagebrush communities and promote the increase of resource patches that sagebrush obligates are attracted to (Dahlgren et al., 2015). Large reductions in sagebrush canopy cover may negatively impact some sagebrush dependent wildlife species (Davies et al., 2012). Although additional research is needed to document the cumulative effects of tebuthiuron on a larger scale, the cautious application of small brush control treatments may be a viable conservation practice to enhance rangelands for sagebrush obligates and livestock who rely on forbs and grasses. (Dahlgren et al., 2006).

These types of treatments may not be compatible in Wyoming Sagebrush range types especially if cheatgrass (*Bromus tectorum* L.) is present. The treatments in our study were in high elevation mountain sagebrush rangelands without any cheatgrass. Wyoming big sagebrush restoration sites that have significant cheatgrass cover require additional considerations. Cheatgrass may compete for open micro-sites made available by

tebuthiruon thinning, and may compete with herbaceous plants several years after treatment (Olson and Whitson, 2002). Based on the results from the Parker Lake Pasture study, tebuthiuron is superior when compared to mechanical treatments in its ability to reduce mountain sagebrush canopy cover and increase forb and grass cover.

Implications

Tebuthiuron is effective at reducing sagebrush and increasing grass and forb cover. Rangeland managers and land owners can utilize this information to improve sagebrush communities with sagebrush canopy cover that exceeds 35%. Tebuthiuron is the least expensive treatment to apply (aerial application) in a rangeland setting (Dahlgren et al., 2006). For these reasons it makes tebuthiuron one of the most practical options for mountain sagebrush reduction.

Managers should ensure that low site potential (shallow soils) areas avoided and the application rates match soil characteristics. Rangeland managers can use tebuthiuron in high elevation mountain sagebrush ecotypes within the Colorado Plateau as a conservation tool to enhance rangelands for livestock and wildlife.

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Tables and Figures

Table 2.1
Centrocercus urophasianus preferred, mesic, and non-mesic forbs encountered during the duration of the Parker Lake Pastures Experiment (2000 -2009). Sage-grouse forb information was retrieved from Dahlgren et al., 2015, and mesic forb information was retrieved from Lichvar, 2014; Lichvar et al. 2012. Forb categories were analyzed separately.

Common Name	Scientific Name	Sage-Grouse Forb	Mesic Forb	Non-Mesic Forb
Pussytoes	*Antennaria* sp.	X	X	
False Dandelion	*Agoseris* sp.	X	X	
Rockcress	*Arabis* sp.		X	
Milkvetch	*Astragalus* sp.	X	X	
Indian Paintbrush	*Castilleja* sp.		X	
Goosefoot	*Chenopodium* sp.		X	
Thistle	*Cirsium* sp.			X
Cryptantha	*Cryptantha* sp.			X
Springparsley	*Cymopterus* sp.			X
Fleabane	*Erigeron* sp.	X	X	
Buckwheat	*Eriogonum* sp.	X		X
Groundsmoke	*Gayophytum* sp.		X	
Stickseed	*Hackelia* sp.		X	
Alumroot	*Heuchera* sp.			X
Rubberweed	*Hymenoxys* sp.			X
Scarlet Gilia	*Ipomopsis* sp.			X
Prickly Phlox	*Linanthus* sp.			X
Blue Flax	*Linum* sp.			X
Desertparsley	*Lomatium* sp.	X		
Lupine	*Lupinus* sp.	X	X	
Groundsel	*Packera* sp.		X	
Beardtongue	*Penstemon* sp.		X	
Phlox	*Phlox* sp.	X		X
Knotweed	*Polygonum* sp.		X	
Cinquefoil	*Potentilla* sp.		X	
Aster	*Symphyotrichum* sp.		X	
Common Dandelion	*Taraxacum* sp.	X	X	
Mt. Pennycress	*Thlaspi* sp.			X
Clover	*Trifolium* sp.	X		X
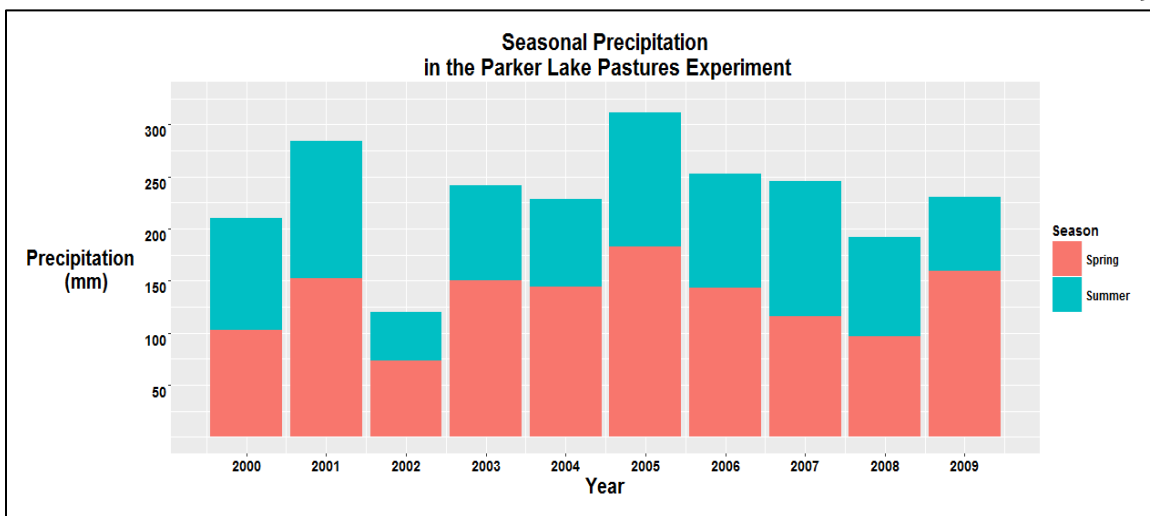
Fig. 2.1. Stacked bar plot of spring (salmon) and summer (turquoise) precipitation (mm) data from Parker Lake during the duration of the study (2000-2009). Datum were derived from Parameter-elevation Regressions on Independent Slopes Model (PRISM) data (2015).
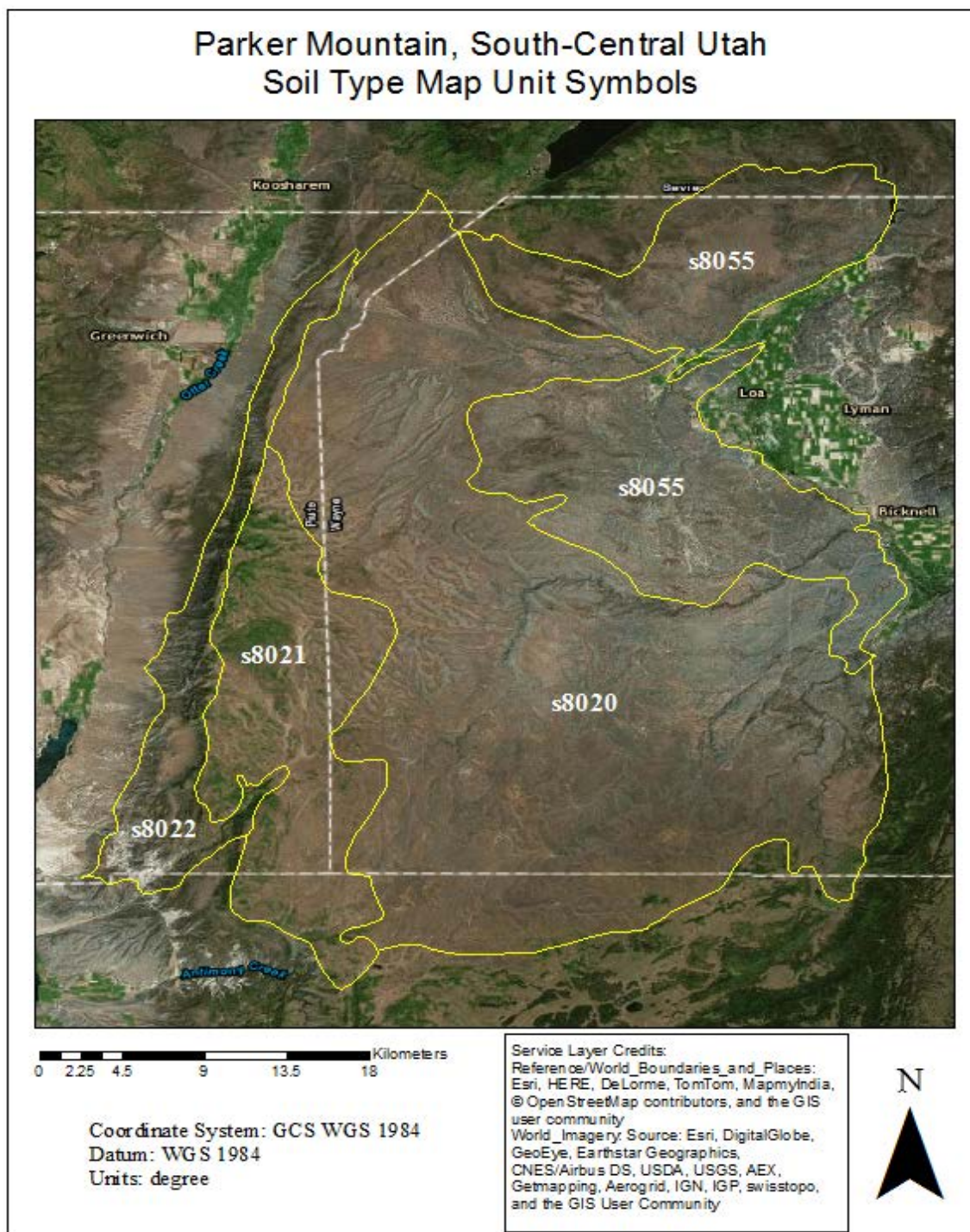
Fig. 2.2. Map of soil map units found on Parker Mountain, Utah (2015). Soil map units are a collection of areas defined and named the same in terms of their soil components (e.g., series).
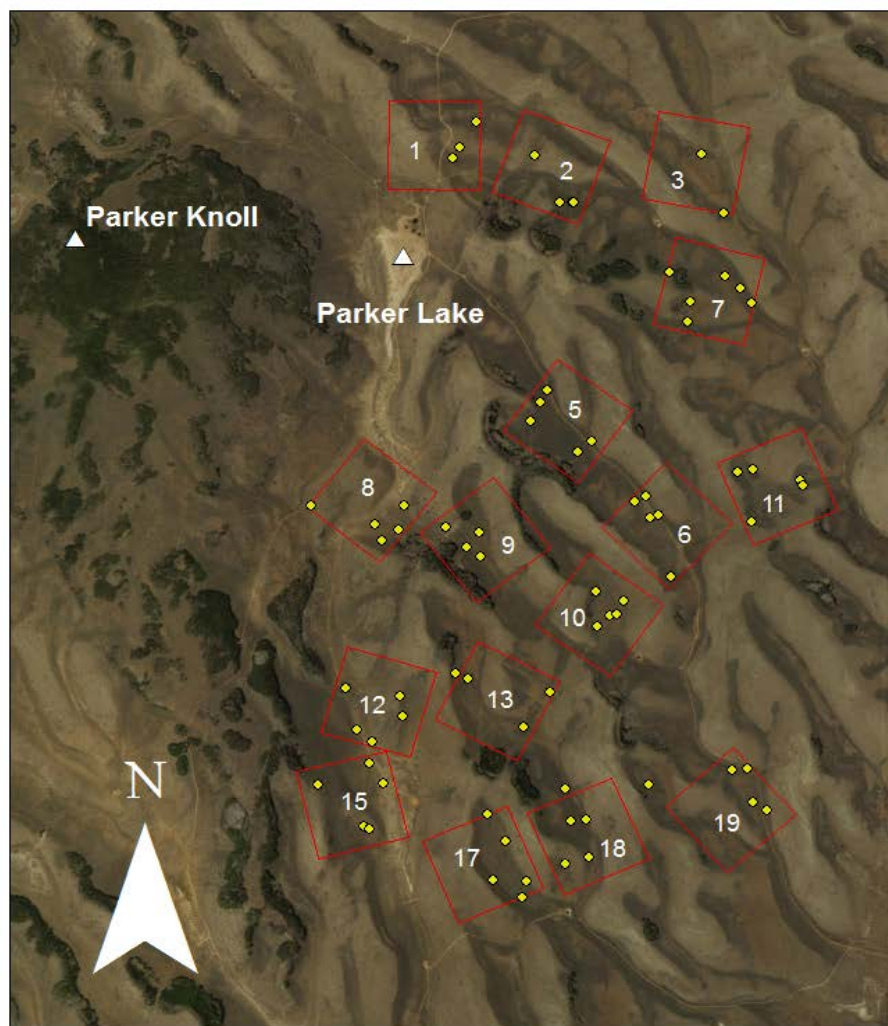
Fig. 2.3. Parker Lake Pastures *Artemisia tridentata* subsp. *vaseyana* treatment experimental design on Parker Mountain, Utah (2000-2009). Numbered red polygons represent randomly located plots and yellow points represent randomly located vegetation transects.
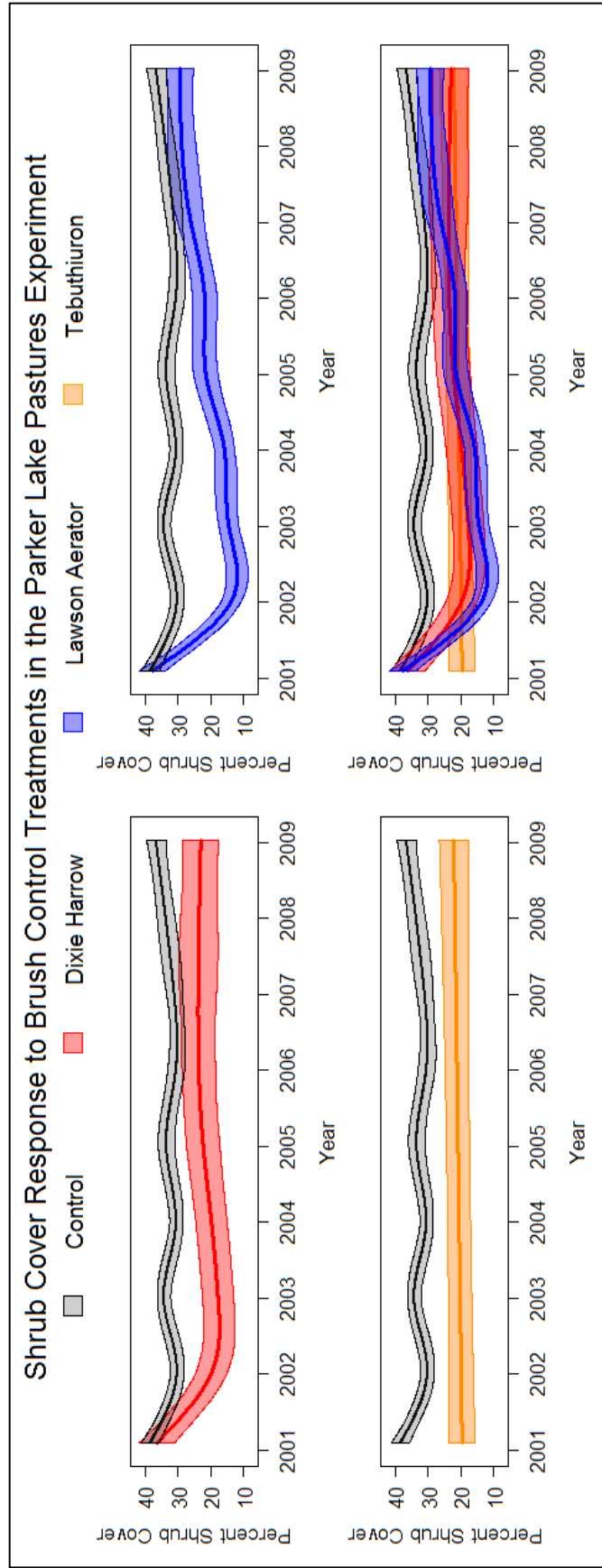
Fig. 2.4. Generalized additive mixed models for percent shrub canopy cover response in the Parker Lake Pastures experiment plots (2001-2009). Parker Mountain, Utah.
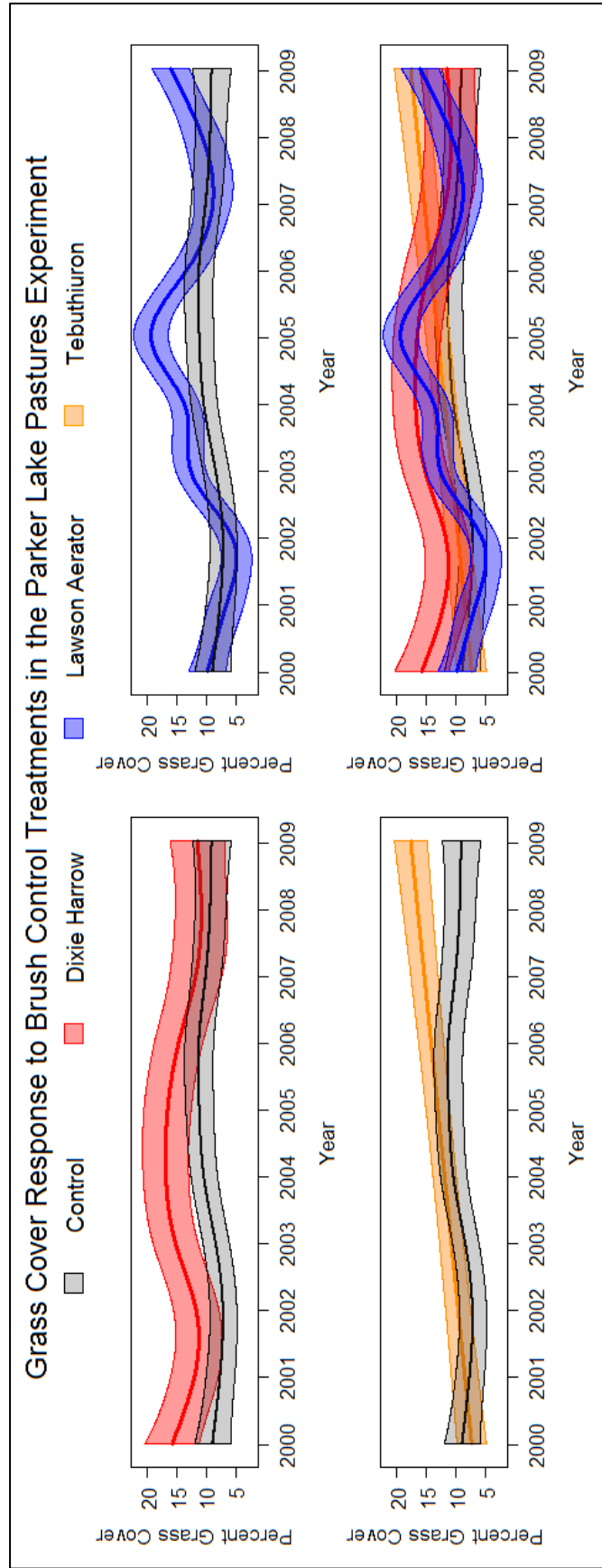
Fig. 2.5. Generalized additive mixed models for percent grass canopy cover response in the Parker Lake Pastures experiment plots (2000–2009). Parker Mountain, Utah.
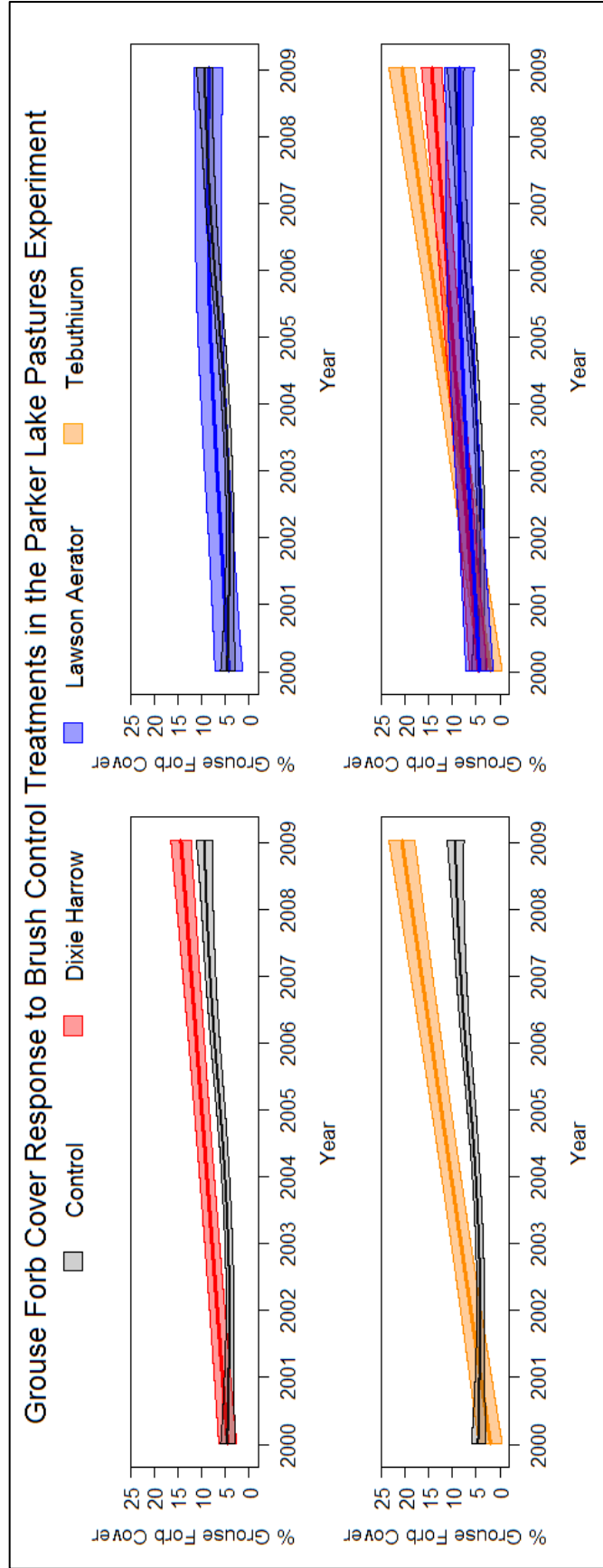
Fig. 2.6. Generalized additive mixed models for percent sage-grouse forb canopy cover response in the Parker Lake Pastures experiment plots (2000-2009). Parker Mountain, Utah.
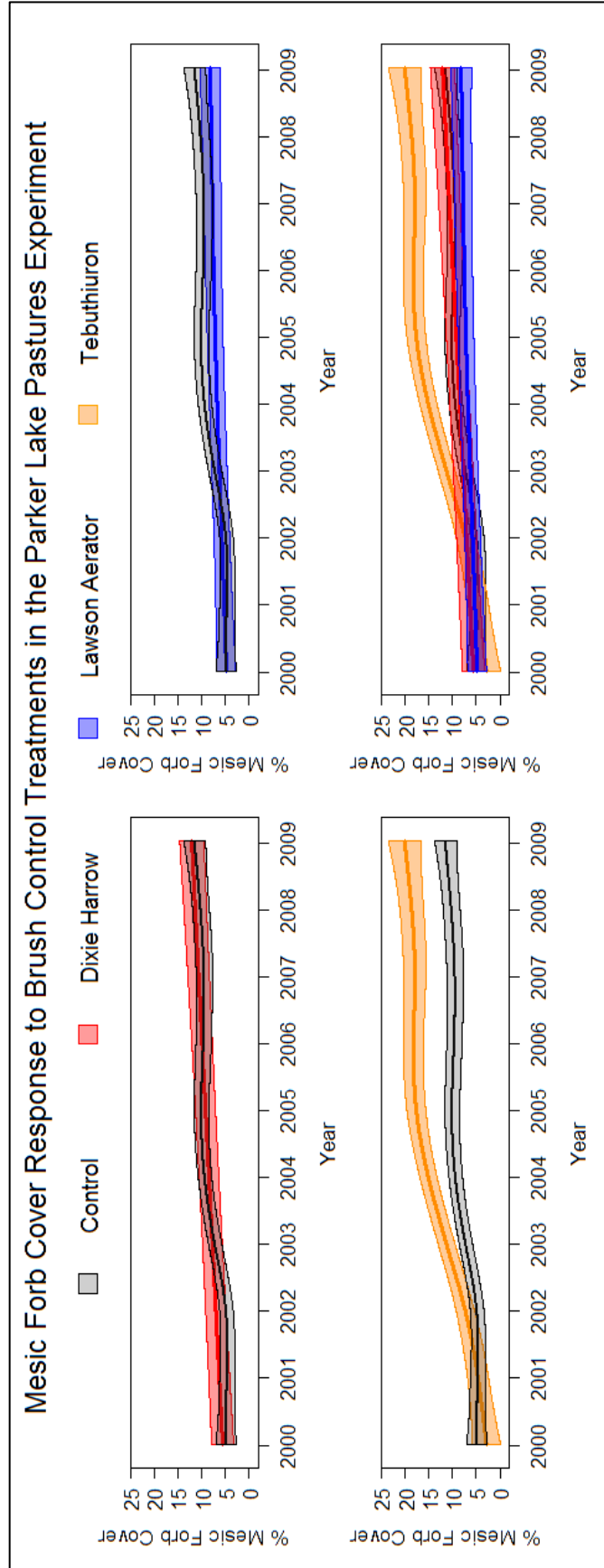
Fig. 2.7. Generalized additive mixed models for percent mesic forb canopy cover response in the Parker Lake Pastures experiment plots (2000-2009). Parker Mountain, Utah.

CHAPTER 3

HERBACEOUS BIOMASS PRODUCTION AND MOUNTAIN BIG SAGEBRUSH

CANOPY COVER RESPONSE TO TEBUTHIURON TREATMENTS

ON PARKER MOUNTAIN IN SOUTH CENTRAL UTAH

Abstract

Dense sagebrush (*Artemisia tridentata L.*) can limit herbaceous biomass production. Many types of treatments to reduce sagebrush canopy have been applied to sagebrush ecosystems in the past. More recently, tebuthiuron has been increasingly used in mountain sagebrush (*A. t.* subsp. *vaseyana* Nutt. [Rydb.] Beetle) communities enhance wildlife habitat and increase forage for domestic livestock. However, scientific evaluations of herbaceous biomass production to tebuthiuron treatments are short-term and limited. My study area was located in south central Utah on Parker Mountain. I evaluated five pastures that were treated with tebuthiuron by measuring biomass production along 45 randomly selected 100 m transects within the treated pastures. The pastures are collectively 2 265 ha and were treated individually from 2006-2012. Sagebrush canopy cover was reduced (P=0.0036) and forb and grass biomass increased (P=0.0334; P=0.0461) compared to untreated mountain sagebrush across pastures I measured on Parker Mountain. The results of my research lends evidence that tebuthiuron has the ability to reduce mountain sagebrush canopy cover for at least 9 years, and increase forage for livestock and wildlife.

Introduction

Herbaceous vegetation generally decreases as sagebrush density increases as a result of interspecific competition for limited resources such as light, water, nutrients, and

space, which can limit herbaceous biomass available to livestock and wildlife (Rittenhouse and Sneva, 1976). When sagebrush stands become too dense and the herbaceous biomass is limited, sagebrush canopy reduction treatments may be necessary to increase herbaceous vegetation in the understory (Connelly et al., 2000; Olson and Whitson, 2002; Crawford et al., 2004; Beck et al., 2009; Davies et al., 2012).

Tebuthiuron treatments of mountain sagebrush ecotypes are a viable option for rangeland managers to reduce mountain sagebrush canopy cover and increase herbaceous biomass for livestock and improve wildlife habitat (Murray 1988; Dahlgren et al., 2006). Tebuthiuron [trade name SPIKE 20P (N-(5-(1,1-dimethylethyl)- 1,3,4-thiadiazol-2-yl)- N,N'-dimethylurea) Dow Agrosciences, Indianapolis, Indiana] a pelleted, soil active herbicide is used to selectively thin mountain sagebrush (Whitson and Alley, 1984; Whitson et al., 1988; Halstvedt, 1994; Johnson et al., 1996; Olson and Whitson, 1996, 2002; Dahlgren et al. 2006). Rangeland managers have been using tebuthiuron to reduce sagebrush for several decades.

Due to inconsistent results within scientific research, rangeland managers should use site specific information on vegetation responses to mountain sagebrush tebuthiuron treatments in their locality if available (Beck et al., 2012). Different vegetation responses may be achieved in mountain sagebrush treatments with different elevations, annual precipitation, soil types/depths, and application rates.

For example, Murray (1988) applied tebuthiuron 20P and 40P at a rate of 0.6 and 1.1 kg AI ha^{-1}, which was effective at reducing canopy cover of mountain sagebrush and increasing grass biomass by ~50% in all treatments when compared to control (Table 1.1). Other research (e.g., Clary et al., 1985) indicated that tebuthiuron treatments of mountain sagebrush did not increase herbaceous biomass at the end of the study (Table

1.1). In another study, mountain sagebrush was reduced, grass biomass increased, and forb biomass decreased when 2, 4-D butyl ester was sprayed on mountain sagebrush stands (Table 1.1; Miller et al., 1980).

Scientific evaluations of herbaceous biomass responses to tebuthiuron treatments are lacking in scientific literature, especially long-term herbaceous biomass responses to tebuthiuron treatments in mountain sagebrush communities. Most scientific literature report results that represent short term (less than four years post treatment) results of herbaceous biomass responses to treatments in mountain sagebrush (e.g., Clary et al., 1985; Murray, 1988), and herbaceous biomass response to sagebrush canopy reducing treatments vary between sites studied (Table 1.1).

The purpose of my research was to quantify biomass response in tebuthiuron treated and untreated mountain sagebrush plots. The scientific research I conducted is part of the adaptive management approach on Parker Mountain to help guide management with scientific findings regarding important biological resources on the mountain.

Study Site

My research was conducted in five high elevation mountain sagebrush dominated pastures in south central Utah, located within 10 km of Parker Knoll on Parker Mountain. The mountain is located in Garfield, Piute, Sevier, and Wayne counties, and is part of the Colorado Plateau (Colorado Plateau, 2015). Parker Mountain is bounded to the north by Fish Lake Plateau, to the west by Grass Valley, to the east by Boulder Mountain, and to the south by the Aquarius Plateau. Parker Mountain is an eastward-sloping mountain that consists of approximately 153 780 ha (Elmore and Messmer, 2006), and has an elevation gradient of approximately 2 134-3 018 m (Chi, 2004).

The study area is influenced by the Arizona monsoonal system, which feeds moisture and summer precipitation from July to September into western North America (Lin et al., 1996; Chi, 2004). Although Parker Mountain receives a negligible amount of precipitation from summer monsoonal precipitation, historically most of the moisture throughout the year comes from snow pack in the late fall, winter, and early spring months.

Climate data provided by parameter-elevation regressions on independent slopes model (PRISM) was used to describe long-term climate conditions on Parker Mountain because weather stations that collect climate data in the area are limited. The climate data indicated over the last 50 years (from January 1, 1964-December, 31, 2014), Parker Lake received 567 mm of average annual precipitation. However, during the duration of this research, Parker Lake received 636 mm of annual precipitation, which is 5.7% higher than the 50-year average. Of the total annual precipitation in 2015, 27% of the annual precipitation came in the spring (March, April, and May) months, while 20% of the precipitation came in summer (June, July, and August) months. The PRISM climate data indicates over the last 52 years (January 1, 1964-January 1, 2016) the Parker Lake on Parker Mountain experienced an average annual temperature of 4.3 C. The average annual for 2015 was also 4.3 C. The 52-year average minimum temperature in January was -11.5 C and the average maximum temperature in August was 22.4 C. However, the minimum temperature in January 2015 was -8.8 C and the average maximum temperature in August was 21.9 C (PRISM, 2004).

Detailed soil information was limited on Parker Mountain. However, the main soil types in the Parker Lake area consist of 70% Pachic Argicryolls, and 30% Xeric Argicryolls (Fig. 2.2; Soil Survey Staff, 2015).

Utah State Institutional Trust and Lands Administration (SITLA) manages 43 863 ha on the western portion of Parker Mountain which includes the study area. The United States Forest Service (USFS) manages 21 685 ha on the southern edge of the study area. On the eastern portion of the sagebrush dominated plateau, the Bureau of Land Management (BLM) manages 36 398 ha, and 5 532 ha are privately owned and managed (Chi, 2004).

Springs and shallow lakes occur above 2621 m elevation on the plateau. In addition, over 80 livestock water developments provide season water sources for livestock and wildlife on Parker Mountain (Chi, 2004). The study area has maintained cattle (*Bos taurus*) herbivory for at least 100 years. Cattle still graze the area at 1.46 ha per animal unit month (AUM) (Chi, 2004).

Within the study area in proximity to Parker Knoll, mountain sagebrush, black sagebrush, and silver sagebrush (*A. cana* Pursh) coexist within pockets of quaking aspens (*Populus tremuloides* Michx.) (Chi, 2004). Other shrubs and sub-shrubs in the high elevation pastures near Parker Knoll include yellow rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.), Wood's rose (*Rosa woodsii* Lindl.), and mountain snowberry (*Symphoricarpos oreophilus* A. Gray). Dominant graminoids include squirreltail (*Elymus elymoides* [Raf.] Swezey), sheep fescue (*Festuca ovina* L.), prairie Junegrass (*Koeleria macrantha* [Ledeb.] Schult.), muttongrass (*Poa fendleriana* [Steud.] Vasey), needle and thread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth), and Letterman's needlegrass (*Achnatherum lettermanii* [Vasey] Barkworth). The most abundant forbs include small-leaf pussytoes (*Antennaria parvifolia* Nutt.), purple milkvetch (*Astragalus agrestis* Douglas ex G. Don), lesser rushy milkvetch (*A. convallarius* Greene), Eaton's fleabane (*Erigeron eatonii* A. Gray), spiny phlox (*Phlox hoodii* Richardson), longleaf phlox (*P.*

longifolia Nutt.), and elegant cinquefoil (*Potentilla concinna* Richardson) (Chi, 2004; United States Department of Agriculture, Natural Resources Conservation Service. 2015).

Methods

My research project was conducted in the mountain sagebrush dominated high elevation pastures near Parker Knoll that were treated with tebuthiuron. The main goal of the research was to evaluate and provide information about management actions. The information from this research will be used by the adaptive management process to improve rangeland habitat for wildlife and livestock. The Utah Department of Agriculture and Food (UDAF), Natural Resources Conservation Service (NRCS), and SITLA funded and implemented the treatment of sagebrush dominated pastures with tebuthiuron in pastures near Parker Knoll based on scientific findings from previous research (Dahlgren et al., 2006).

I evaluated five mountain sagebrush dominated pastures totaling 2 265 ha (Table 3.1). Tebuthiuron was applied aerially with a fixed-wing airplane to mountain sagebrush dominated pastures at a rate between 0.37 kg ha-1 and 0.74 kg ha-1 in the fall of 2006, 2007, 2010, 2011, and 2012 (Fig. 3.1). Each pellet of tebuthiuron is cylinder shaped (2 mm in diameter and 5 mm in length). The chemical is delivered from the airplane that has uploaded shapefiles and global positioning system (GPS) guidance for accurate application of tebuthiuron to a desired area. Once the airplane is loaded with chemical, it can deliver the pelleted tebuthiuron to mountain sagebrush stands in 27.4 m to 30.5 m strips.

Herbaceous biomass production and mountain sagebrush responses were evaluated in each of the five pastures in the summer (July) of 2015. I established 45, 100

m transects to quantify forb and grass biomass production and sagebrush canopy cover
responses in five pastures (Fig. 3.1). Each 100 m transect start point was randomly
selected using ArcGIS (ESRI, 2011) and made permanent with 40 cm rebar. Rebar was
also used to mark the end point of each 100 m transect permanent. If a randomly selected
start point fell outside of a treatment, we relocated to ensure transects were all located
within treated areas. Once inside the treated area a rebar was then thrown behind without
looking to reduce any biases. Each pasture includes five randomly located transects
within the treated areas of each pasture and four randomly located control transects
within the untreated portions of each pasture. Each 100 m transect was installed so the
direction of transects was 0° (north) from the starting point (0 m). If transects did not fit
at a randomly selected location transects were installed at 180° (south).

To quantify herbaceous biomass production, data was collected from three
grazing exclusion cages placed on each transect at the 33 m, 66 m, and the 99 m mark
(Fig. 3.2). Forbs and grass species were clipped at ground level and separated at each
0.56 m^2 cage (Fig. 3.3). The herbaceous biomass samples from each cage were dried at
60° C for approximately 120 hours then weighed and recorded.

To quantify mountain big sagebrush response to tebuthiuron treatments, live and
dead shrub canopy cover (black, silver, and mountain sagebrush) was collected along
each 100 m transect using the line intercept method with 10 cm gaps (Canfield, 1941).
Dead sagebrush canopy was defined as any standing dead sagebrush where branches did
not contain live leaves. Herbaceous biomass production and sagebrush canopy cover data
was collected in South, Nick's, Buttes, Forshea Draw, and Chicken Spring Pasture from
July 9, 2015 to July 29, 2015 (Fig. 3.1).

Data Analyses

I performed a principal component analysis (PCA) on 45 transects across all pastures. Transect datum that was loaded into the PCA ordination included live/dead mountain sagebrush canopy cover, live/dead black sagebrush canopy cover, live/dead silver sagebrush canopy cover, and forb/graminoid biomass. The PCA ordination was performed using the "MASS" package (Venables and Ripley, 2002), the "vegan" package (Oksanen, 2007), and the "labdsv" package (Roberts, 2007) in R 3.2.3 (R Core Team, 2016). Paired t-tests were performed on averaged pasture transect data (biomass response data from within each treated pasture and data from transects in untreated portion of each pasture were averaged) to test differences between vegetation responses in treated and untreated mountain sagebrush communities across all pastures.

A PCA ordination was also performed within each pasture. Two-sample t-tests were performed to test differences between biomass responses in tebuthiuron treated and non-treated mountain sagebrush stands within each pastures measure. All two sample t-tests and paired t-tests were performed in R 3.2.3 (R Core Team 2014).

Results

The results from the PCA ordination across all pastures indicated treated and non-treated pastures were grouped respectively (Fig. 3.4). There was more variation observed within treated pastures compared to non-treated portions of each pasture. Vector strength of the biomass responses indicated that tebuthiuron treatments had more forb biomass ($r^2 = 0.74$; $P = 0.012$), grass biomass ($r^2 = 0.85$; $P = 0.003$), and less live mountain sagebrush canopy cover ($r^2 = 0.92$; $P = 0.002$) when compared to untreated portions of pastures (Fig. 3.4).

Paired t-tests indicated tebuthiuron reduced the percentage of mountain sagebrush canopy cover across all pastures ($P = 0.0036$, $/\mu = 18.57\%$). Forb biomass was higher across all treated pastures when compared to untreated pastures ($P = 0.0334$, $/\mu = 126$ kg ha^{-1}). Grass biomass increased across all pastures treated with tebuthiuron (Table 3.2; $P = 0.0461$, $/\mu = 341$kg ha^{-1}).

Within each pasture biomass responses differed in the treated and untreated mountain sagebrush stands. Principal component analysis ordination within pastures indicated tebuthiuron treated and untreated mountain sagebrush stands exhibited two groupings. Vector strength of the vegetation responses revealed that tebuthiuron treatment areas exhibited more forb and grass biomass and less live mountain sagebrush canopy cover (in four of five pastures) when compared to non-treated areas of all pastures. (Fig. 3.5).

Two sample t-tests within tebuthiuron treated and untreated areas of each pasture indicated that Forshea Draw was the only pasture that live mountain sagebrush canopy cover was not reduced (Table 3.3; $P=0.1330$). There were no differences in forb biomass between treated and untreated sagebrush communities within each of the five pastures assessed in the study area (Table 3.4; $P>0.5$). Grass biomass was greater within all pastures treated with tebuthiuron, except Buttes Pasture (Table 3.5; $P=0.3078$) and South Pasture, which exhibited marginal increases of grass biomass (Table 3.5; $P=0.0791$).

Discussion

Tebuthiuron increased herbaceous biomass production across all pastures. However, upon further investigation, when I compared individual pasture responses to tebuthiuron treatments, I discovered that treated areas of South Pasture and Buttes Pasture did not have more grass or forb biomass than non-treated areas (Table 3.4 and

3.5). The research I conducted suggests that South Pasture being the oldest tebuthiuron treatment has approached or reached untreated conditions suggesting that the community has recovered from the tebuthiuron treatment. Follow up treatments and grazing rest for two years may be a viable option to increase herbaceous biomass to desirable levels in South Pasture.

Reduction of live mountain sagebrush canopy cover occurred across most pastures, however, mountain sagebrush canopy cover in Forshea Draw did not differ when comparing treated to untreated areas within the pasture (Table 3.3). Forshea Draw is dominated by both mountain sagebrush and silver sagebrush and had the lowest mountain sagebrush canopy cover in untreated portions of the pasture. Even though mountain sagebrush cover was reduced by almost 50% (Table 3.2 and 3.3) there were no statistical differences between treated and untreated areas of Forshea Draw (Table 3.3; $P=0.13$). This could suggest that the number of samples collected in Forshea Draw was not adequate to capture the variation within the pasture. This is the only pasture with a high silver sagebrush community component, which would have created a more diverse landscape with greater variability. Whitson and Alley (1984) noted tebuthiuron applications are less effective at reducing canopy cover of silver sagebrush when compared to tebuthiuron treatment of big sagebrush species, which may have led to higher densities of silver sagebrush in Forshea Draw. It is interesting to note that even though mountain sagebrush canopy cover was not reduced significantly, there was an increase in grass biomass (Table 3.5; $P=0.02$) indicating that the treatments did work and that there was a reduction of mountain sagebrush cover even though it was not statistically different.

Forb biomass was not different between treated and untreated areas within each pasture, but forb biomass was different across all pastures (Table 3.2 and 3.4). Forb biomass results across all pastures show a positive response, which coincides with results from Dahlgren et al. (2006), though units of vegetation measurement were different (cover compared to biomass). Results from Dahlgren et al. (2006) indicate tebuthiuron with similar application rates increased forb cover compared to control plots (untreated mountain sagebrush) (Table 1.1).

The results from my research supports the use of tebuthiuron to increase grass biomass in mountain sagebrush stands on Parker Mountain and the Colorado Plateau. Grass biomass in Nick's Pasture, Forshea Draw, and Chicken Spring increased in treated areas when compared to untreated portions within each pasture (Table. 3.5). When live mountain sagebrush canopy cover is reduced, limited resources (light, water, nutrients, and space) become available to grass in the understory, which may translate to increased grass biomass. Murray (1988) also reduced mountain sagebrush canopy cover with similar tebuthiuron 20P application rates (0.60 kg AI ha^{-1}) in mountain sagebrush communities, and reported increases of grass biomass, but forb biomass did not differ from control plots (Table 1.1).

Tebuthiuron treatments in South Pasture and Buttes Pasture did not increase grass biomass when compared to untreated areas within each pasture (Table 3.5; P=0.079, P=0.309 respectively). South Pasture is the oldest treatment (9 years since treatment) evaluated and evidence from this study suggests South Pasture is approaching or has approached untreated conditions based on mountain sagebrush canopy cover and grass biomass measurements in the treated and untreated portions of the pasture. Live mountain sagebrush canopy cover in South Pasture is ~20%, which is as high as non-treated

portions of some pastures. Grass biomass was not different in treated areas of the pasture when compared to untreated areas of the pasture (Table 3.5; P=0.0791). Therefore, it is possible that even though sagebrush cover is not similar to untreated sites in South Pasture, ~20% sagebrush cover may start to limit herbaceous biomass response. This suggests that the sustained thinning effects of mountain sagebrush with tebuthiuron on Parker Mountain is less than 9 years.

In my study there was some variability of treatment responses. This may be attributed to the age of treatment, soil characteristics (soil depth, pH, and texture) or ecological site potential. For example, in Buttes Pasture, tebuthiuron treatments were successful in reducing mountain sagebrush by 80%, however forbs and grass biomass did not differ from untreated portions of the pasture. A possible explanation is that Buttes Pasture had shallower soils with low clay content and organic matter that may have accelerated the uptake of available tebuthiuron (DowElanco, 1994; Olson and Whitson, 2002). Sagebrush cover in Buttes Pasture was the lowest (6%) of any of the treatments, indicating that even though it had the similar application rate of tebuthiuron as other treatments, the sagebrush kill was much higher (80%). Another possible explanation is over application of tebuthiruon, which could have limited grass and forb response. Anecdotal observations in Buttes Pasture suggest the pasture may have shallow rocky soils (Xeric Argicryolls), which would have increased uptake of tebuthiuron by sagebrush and non-target species such as forbs and grasses. This could indicate that tebuthiuron was more active in Buttes Pasture potentially injuring or inhibiting the herbaceous response, especially forbs and grasses that have a broader fibrous rooting system (Murray, 1988; Olson and Whitson, 2002).

Another explanation could be that the site potential may be limiting herbaceous response within each pasture. Based on biotic and abiotic comparisons of South Pasture, Buttes Pasture, and Chicken Springs Pasture, vegetation responses may vary based on age of treatment and soil texture/depth. Chicken Spring Pasture had the least amount of time since treatment (3 years) when I sampled the pasture and appeared to have the deepest soils. Grass biomass responded the most in this pasture when compared to all other pastures. In the future, managers must consider soil conditions and site potential prior to tebuthiuron application because ambient soil conditions may negatively impact herbaceous vegetation response.

Furthermore, if tebuthiuron is used for sage-grouse brood-rearing habitat treatments in mountain sagebrush communities, a low rate of active ingredient that results in partial kill of sagebrush may be most desirable (Dahlgren et al., 2015). Soil texture and depth, sagebrush vigor, precipitation regimes, and other environmental conditions would affect the resulting percentage of sagebrush killed. Pretreatment data measuring these various factors would help guide the best application rate. It is also recommended that tebuthiuron be applied in narrow strips or small patches ($\leq$120 m) in order to promote the increase of resource patches that sagebrush obligates are attracted to (Dahlgren et al., 2015). Large reductions in sagebrush cover may have the potential to negatively impact some mountain sagebrush associated wildlife species if applied to large areas as long as sagebrush cover remains low (Davies et al., 2012).

Implications

My research indicates that tebuthiuron reduced mountain sagebrush canopy cover and increased herbaceous biomass among mountain sagebrush pastures. However, vegetation responses may vary among tebuthiuron treatments from site to site due to

differences in time since treatment, soil characteristics, application rate, and site potential. It is recommended that pretreatment plots be evaluated before large scale applications are implemented. Application of tebuthiuron to mountain sagebrush communities with low herbaceous biomass may be a viable conservation practice for land management agencies to enhance rangelands for wildlife and livestock forage. However, caution should be exhibited because species such as sage-grouse are sensitive to sagebrush loss, especially in wintering and nesting areas. Therefore, managers should avoid treating sagebrush in areas where it may have a negative impact on sagebrush dependent species. Long-term monitoring of tebuthiuron treatments will provide rangeland managers with more information regarding management of mountain sagebrush communities to benefit wildlife and livestock.

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Tables and Figures

Table 3.1
Description of *Artemisia tridentata* subsp. *vaseyana* pastures treated with tebuthiuron on Parker Mountain located in south central Utah, USA. Tebuthiuron treatments where applied from 2006-2012.

Pasture	Treatment Year	Area (ha)	Elevation Range (m)
South Pasture	2006	292.14	2 775-2 845
Nick's Pasture	2007	433.32	2 795-2 852
Buttes Pasture	2010	436.45	2 760-2 824
Forshea Draw	2011	879.14	2 810 – 2 861
Chicken Spring	2012	211.40	2 820-2 921

Table 3.2
Paired t-test results for vegetation responses in tebuthiuron treatment and untreated areas across five pastures on Parker Mountain, Utah (2015). n=10.

Response	t-statistic	p-value	95 % CI	Mean of Differences
Live Mountain Sagebrush Cover (%)	6.12	0.0036	[10.14, 27.0]	18.57
Forb Biomass (kg ha^{-1})	3.19	0.0334	[17.0, 25.0]	126
Grass Biomass (kg ha^{-1})	2.86	0.0461	[9.0, 72.0]	341

Table 3.3
Welch two sample t-test results for live mountain sagebrush canopy cover (%) of transects located in five pastures on Parker Mountain, Utah (2015). n=45.

Pasture	t-statistic	df	p-value	95% CI	mean (treated)	mean (non-treated)
South Pasture	-6.68	4.74	0.0014	[-36.07, -15.77]	19.94	45.86
Nick's Pasture	-2.84	6.82	0.0258	[-21.67, -1.92]	23.56	35.36
Buttes Pasture	-7.73	6.99	0.0001	[-31.66, -16.82]	5.89	30.13
Forshea Draw	-1.73	6.23	0.1330	[-27.4, 4.6]	12.00	23.39
Chicken Spring	-5.54	6.79	0.0010	[-27.88,-11.13]	14.40	33.91

Table 3.4
Welch two sample t-test results for forb biomass (kg ha^{-1}) in tebuthiuron treatments in five pastures on Parker Mountain, Utah (2015). n=45.

Pasture	t-statistic	df	p-value	95% CI	mean (treated)	mean (non-treated)
South Pasture	0.35	4.94	0.7439	[-179.8, 358.8]	247.6	236.8
Nick's Pasture	1.13	6.45	0.3006	[-179.8, 538.2]	538.2	395.0
Buttes Pasture	1.06	5.99	0.3319	[-358.8, 893.4]	645.8	376.7
Forshea Draw	0.45	4.16	0.6768	[-358.8, 538.2]	538.2	484.4
Chicken Spring	1.18	4.89	0.2926	[-179.8, 358.8]	516.7	376.7

Table 3.5

Welch two sample t-test results for grass biomass (kg ha^{-1}) in tebuthiuron treatments in five pastures on Parker Mountain, Utah (2015). n=45.

Pasture	t-statistic	df	p-value	95% CI	mean (treated)	mean (non-treated)
South Pasture	2.15	5.48	0.0791	[-35.5, 394.0]	430.6	251.2
Nick's Pasture	2.62	5.80	0.0407	[17.9, 721.2]	785.8	395.0
Buttes Pasture	1.11	6.33	0.3078	[-161.5, 412.3]	570.5	447.8
Forshea Draw	3.23	5.56	0.0201	[53.8, 322.9]	699.7	484.4
Chicken Spring	3.58	4.36	0.0200	[179.8, 1399.3]	1108.7	322.9
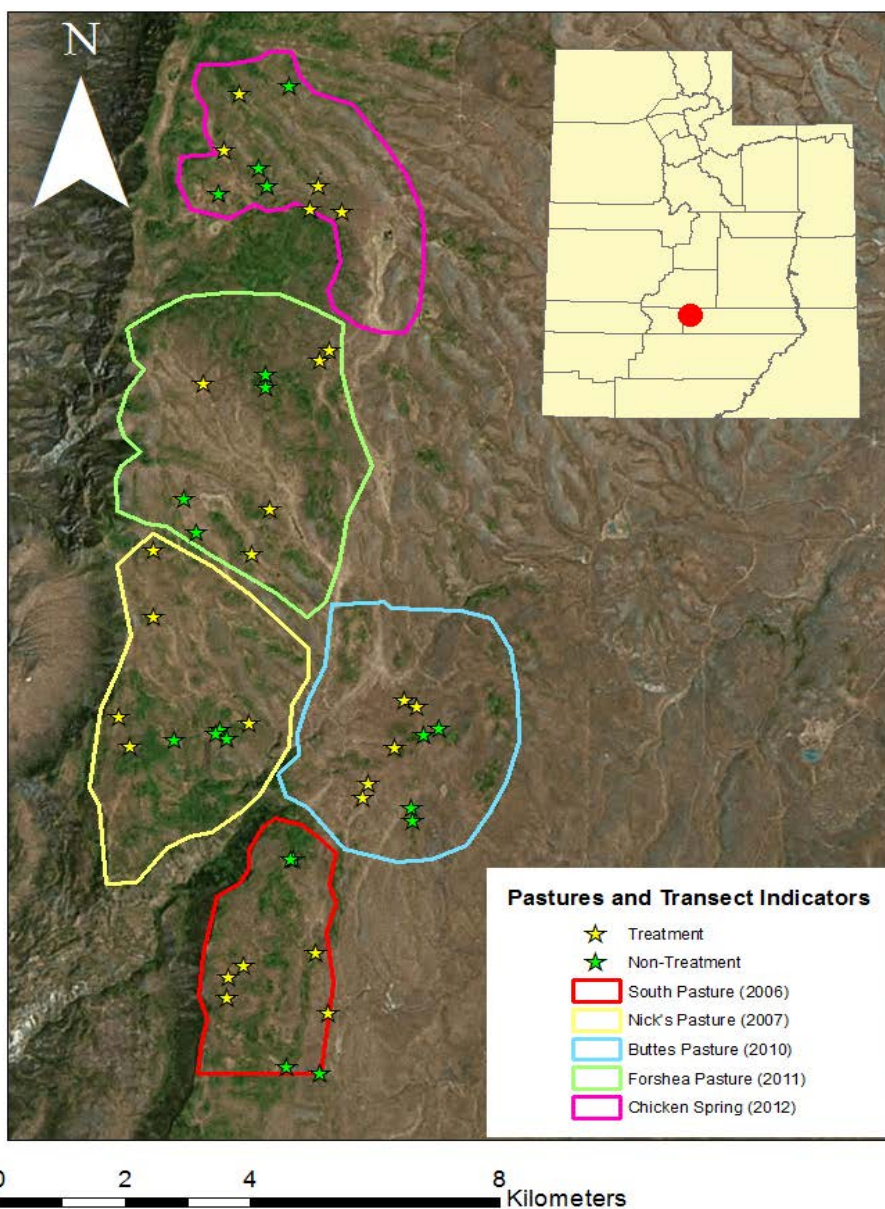
Fig. 3.1. Map of *Artemisia tridentata* subsp. *vaseyana* tebuthiuron treatment areas on Parker Mountain, Utah. Treated areas are spatially and temporally separated (2006-2012).

Fig. 3.2. Transect data collection method used to quantify herbaceous biomass and *Artemisia tridentata* subsp. *vaseyana* canopy cover in five pastures on Parker Mountain, Utah (2015). Transect design includes 100 m transect with three utilization exclosure cages centered on the 33 m, 66 m, and 99 m mark. Transects are oriented north or south.

Fig. 3.3. Photo of the utilization exclusion cages used to collect herbaceous biomass measurements in *Artemisia tridentata* subsp. *vaseyana* dominated pastures on Parker Mountain, Utah (2015). Utilization exclusion cage dimensions are ~91 cm X 61 cm X 91 cm.

Fig. 3.4. Principal component analysis ordination displaying tebuthiuron treated and untreated pastures across Parker Mountain, Utah (2015). Red dots represent untreated pastures and black squares represent tebuthiuron treated pastures. Blue vectors represent vegetation responses.
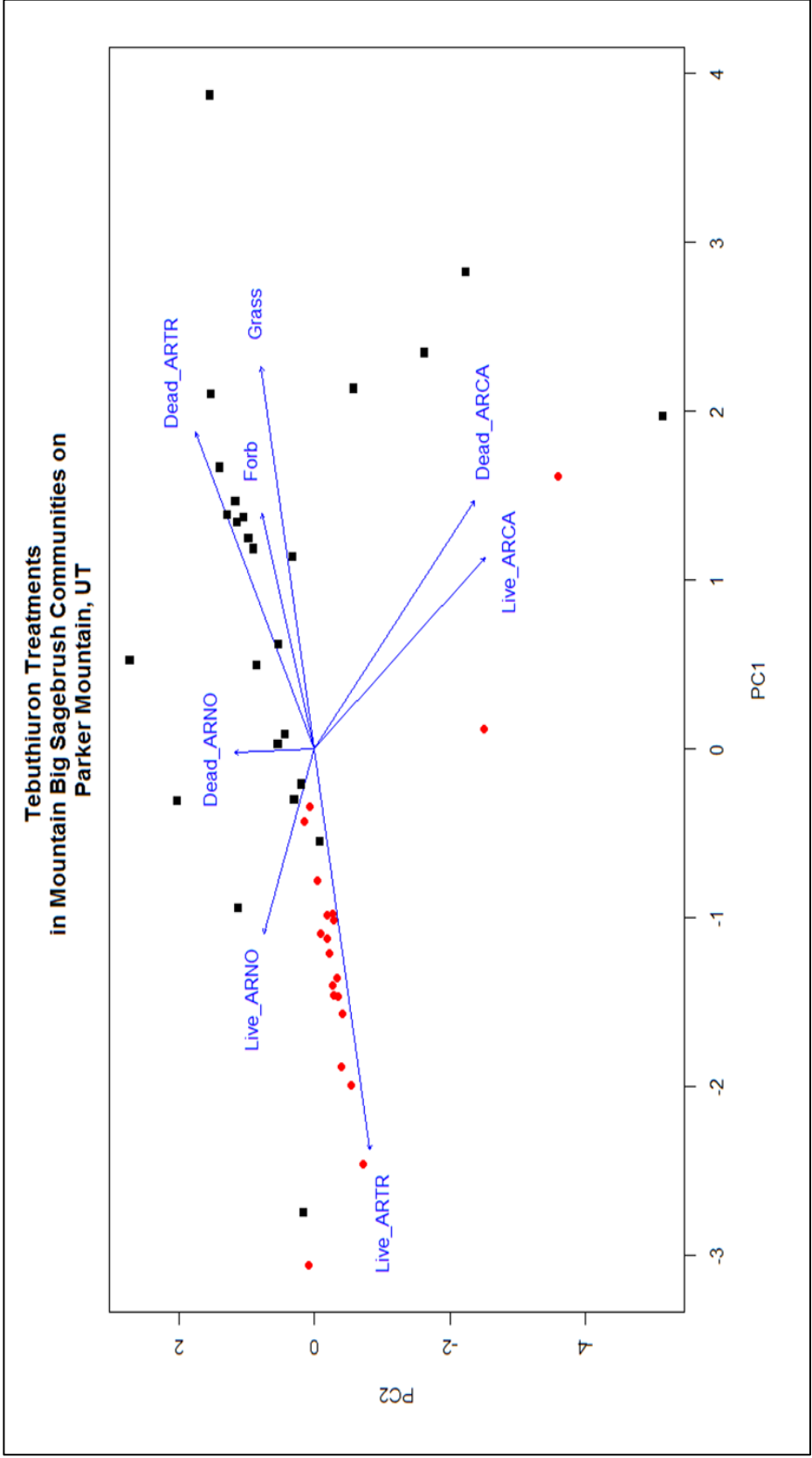
Fig. 3.5. Principal component analysis ordination of 45 transects located in tebuthiuron treated and untreated areas within five pastures on Parker Mountain, Utah (2015). Red dots represent non-treated transects and black squares represent tebuthiuron treated transects. Blue vectors represent vegetation responses.

CHAPTER 4

HIGH ELEVATION BLACK SAGEBRUSH COMMUNITY COMPOSITION OF

PARKER MOUNTAIN IN SOUTH CENTRAL UTAH

Abstract

Black sagebrush (*Artemisia nova* Nelson) is the most common and widely

distributed shrub species on Parker Mountain and has strong spatial patterning associated

with topography, elevation, and soil depth. Information on high elevation (2 135-2 891

m) black sagebrush community composition of Parker Mountain is limited. I described

the spatial variability and vegetation of black sagebrush community phases, and separated

black sagebrush community phases contingent on canopy cover of shrubs, graminoids,

and forb species. The hierarchical cluster analysis supported evidence that two black

sagebrush community phases exist on Parker Mountain. Other results of the analysis

suggest higher elevation black sagebrush phases with ~20% canopy cover had ~14%

mean grass cover and ~5.9% mean forb cover. In lower elevation black sagebrush phases

with ~30% canopy cover, grass cover was 9.1%, and forb cover was ~4.5%. Results from

a non-metric multidimensional scaling ordination suggests that a major influence on

black sagebrush community phase distribution in species space is strongly dispersed by

species evenness and richness. I also provided a black sagebrush canopy cover predictive

map provided a landscape level, 30 m resolution that displayed five canopy cover classes

of black sagebrush (0%, 10%, 20%, 30%, and ≥40%) on Parker Mountain. The

information provided by my research on Parker Mountain will help assist future research

projects and guide adaptive management of livestock, sage-grouse (*Centrocercus

urophasianus*), Utah prairie dog (*Cynomys parvidens*), and pronghorn antelope

(*Antilocapra americana*) habitat on Parker Mountain.

Introduction

Black sagebrush (*Artemisia nova* Nelson) communities typically form wide, often continuous bands along elevational zones that separate black sagebrush from other plant ecotones. The elevational distribution of black sagebrush in western North America can occur from ~1 400 m-3 400 m (Table 4.1; Kartesz, 1999; Flora of North America Association, 2009). On Parker Mountain black sagebrush occurs on an elevation gradient from approximately 2 134-3 018 m, which is considered high elevation mountainous country or "montane".

Black sagebrush communities form pure and mixed shrub stands, with a sparse herbaceous understory. However, montane black sagebrush communities, mixed stands on Parker Mountain are composed of other shrubs such as mountain big sagebrush (*A. tridentata* subsp. *vaseyana* Nutt. [Rydb.] Beetle), yellow rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.), and broom snakeweed (*Gutierrezia sarothrae* [Pursh] Britton & Rusby) that have higher herbaceous production (Fryer, 2009).

The black sagebrush on Parker Mountain like most in western North America tolerates and is most common on xeric soils, but can also be found growing on soils in mesic sites (Hironaka, 1963; West, 1979; Shultz, 1986). The soils supporting black sagebrush communities are usually relatively drier for most of the growing season because the shallow soils have lower water holding capacity than soils that support big sagebrush subspecies, and most of the annual precipitation comes in the winter and spring (Schultz and McAdoo, 2002; Goodrich, 2005; Kitchen and McArthur, 2007; Fryer, 2009). Most of the sites on Parker Mountain where black sagebrush is found growing are considered cold-desert climates.

Generally black sagebrush is the dominant species over areas it occupies and influences many organisms in the community (Baker et al., 1976; Knick et al., 2003; Connelly et al., 2011). Black sagebrush communities on Parker Mountain provides forage for sagebrush obligates and wildlife species, which may be highly selected by greater sage-grouse (*Centrocercus urophasianus*) as winter-feeding areas (Gullion, 1964; Thacker, 2010).

This research was conducted to provide a description of high elevation black sagebrush communities on Parker Mountain. Specifically, we sought to describe black sagebrush plant community phases on Parker Mountain and describe what plant species coexist in each phase. Evidence from my research supports that two black sagebrush community phases exist on Parker Mountain. A predictive surface map of black sagebrush canopy cover on Parker Mountain was also produced via my research. Detailed species composition of sites across Parker Mountain provided by my research will help guide adaptive management of livestock, greater sage-grouse, Utah prairie dog (*Cynomys parvidens*), and pronghorn antelope (*Antilocapra americana*) seasonal habitat.

Study Site

Parker Mountain is located in Garfield, Piute, Sevier, and Wayne counties. The plateau is part of the High Plateaus portion of the Colorado Plateau (Colorado Plateau, 2015). Parker Mountain is bounded to the north by Fish Lake Plateau, to the west by Grass Valley, to the east by Boulder Mountain, and to the south by the Aquarius Plateau. Parker Mountain is an eastward-sloping plateau that consists of approximately 153 780 ha and has an elevation gradient of approximately 2 134-3 018 m. From north to south and east to west, the mountain is approximately 48 km long and 33 km wide respectively (Chi, 2004; Elmore and Messmer, 2006).

Parker Mountain is influenced by the Arizona monsoonal system, which feeds

summer precipitation from July to September into western North America (Lin et al.,

1996; Chi, 2004). Parker Mountain receives a small amount of precipitation from summer

monsoonal precipitation, historically most of the moisture throughout the year comes

from snow pack in late fall, winter, and early spring months. I chose to represent long-

term climate conditions of Parker Mountain with parameter-elevation regressions on

independent slopes models (PRISM) gridded climate data because weather station

climate data in the area is limited and does not represent climatic condition ranges of the

entire mountain.

In the lower elevations (~2438 m) of Parker Mountain, PRISM climate data

indicated Sage Flat (selected due to being a representative of lower elevation black

sagebrush dominated communities on Parker Mountain) received 312 mm of average

annual precipitation over 50-year (January 1, 1964-December, 31, 2014). However,

during the duration of this research (2014-2015), Sage Flat received 364 mm of average

annual precipitation, which is 14.3% higher than the 50-year average. Of the average total

annual precipitation in 2014-2015, 25% of the annual precipitation came in the spring

(March, April, and May) months, while 30% of the precipitation came in summer (June,

July, and August) months. PRISM gridded climate data indicates Sage Flat experienced

an average annual temperature of 5.6 C over 50 years (January 1, 1964-January 1, 2014).

The average annual temperature for 2014-2015 was 6.7 C, which is a 16.4% increase.

The 50-year average minimum temperature in January is -11.7 C, and the average

maximum temperature in August is 24.6 C. However, at Sage Flat the average minimum

temperature in January 2014-2015 was -8.3 C, which is a 29% increase, and the average

maximum temperature in August 2014-2015 was 23.4 C, which is 4.9% decrease (PRISM 2004).

In the upper elevation (~2743 m) of Parker Mountain, PRISM data indicates Parker Lake (representative of higher elevation black sagebrush dominated communities on Parker Mountain) received 568 mm of average annual precipitation over 50-year (from January 1, 1964 to December, 31, 2014). However, during this research (2014 – 2015), Parker Lake received 527 mm of average annual precipitation which is 7.2% less than the 50-year average. Of the average total annual precipitation in 2014-2015, 28% of the annual precipitation came in the spring (March, April, and May) months, while 22% of the precipitation came in summer (June, July, and August) months. Climate data provided by PRISM indicated Parker Lake experienced an average annual temperature of 4.3 C over the past 50 years (January 1, 1964-December, 31, 2014). The average annual for 2014-2015 was 5.1 C, which was 15.7% higher. The 50-year average minimum temperature in January was -11.6 C, and the average maximum temperature in August was 22.4 C. However, the minimum temperature at Parker Lake in January 2014-2015 was -9 C, which was a 22.4% increase, and the average maximum temperature in August 2014-2015 was 20.8 C, which was a 7.1% decrease (PRISM, 2004).

Information on soil types on Parker Mountain is limited. However, the lower elevation soil types are composed of 60% Ustic Argicryolls, 30% Lithic Argicryolls, and 10% Pachic Argicryolls. The soil types in the mid-elevations are composed of 65% Xeric Argicryolls, 30% Faim Pachic Argicryolls, and 5% rock outcrop. The soil types in the upper elevations are composed of 70% Pachic Argicryolls, and 30% Xeric Argicryolls (Fig. 4.2; Soil Survey Staff, 2015).

Springs and shallow lakes occur above 2 621 m elevation on Parker Mountain. In addition, over 80 livestock water developments provide season water sources for livestock and wildlife on the plateau (Chi, 2004). There are 10 grazing allotments on Parker Mountain ranging in size from 302-2 475 ha. The plateau has maintained cattle and sheep herbivory for at least 100 years. Sheep (*Ovis aries*) and cattle (*Bos taurus*) still graze the area at 1.46 ha per animal unit month (AUM). In addition to grazing, the area is considered "multiple use" for hunting, motorized vehicle use, hiking, camping, and sightseeing (Chi, 2004, Dahlgren et al., 2006).

Black sagebrush is the dominant vegetation across most of the lower to mid elevations, and extends to the higher elevations, on exposed slopes, ridges, and flats. At the higher elevations of Parker Mountain, mountain sagebrush is more prevalent in the drainages and mountain top pastures. Silver sagebrush (*A. cana* Pursh) occurs in the upper elevation pastures and wetter drainages. The higher elevations of Parker Mountain also provide habitat for quaking aspens (*Populus tremuloides* Michx.) (Chi, 2004). Other shrubs and sub-shrubs that coexist with black sagebrush on Parker Mountain include yellow rabbitbrush, slender buckwheat (*Eriogonum microthecum* Nutt.), sulfur-flower buckwheat (*E. umbellatum* Torr.), and broom snakeweed (Chi, 2004; United States Department of Agriculture, Natural Resources Conservation Service., 2015).

The graminoid portion of the black sagebrush community assemblage on Parker Mountain consists of blue grama (*Bouteloua gracilis* [Willd. ex Kunth] Lag. ex Griffiths), obtuse sedge (*Carex obtusata* Lilj.), squirreltail (*Elymus elymoides* [Raf.] Swezey), sheep fescue (*Festuca ovina* L.), prairie Junegrass (*Koeleria macrantha* [Ledeb.] Schult.), muttongrass (*Poa fendleriana* [Steud.] Vasey), Letterman's

needlegrass (*Achnatherum lettermanii* [Vasey] Barkworth), and mat muhly

(*Muhlenbergia richardsonis* [Trin.] Rydb.). (Chi, 2004; USDA, NRCS. 2015).

The most common forbs of the black sagebrush community assemblage on Parker

Mountain include small-leaf pussytoes (*Antennaria parvifolia* Nutt.), Holboell's

rockcress (*Arabis holboellii* Hornem.), Eaton's fleabane (*Erigeron eatonii* A. Gray),

shaggy fleabane (*E. pumilus* Nutt.), redroot buckwheat (*E. racemosum* Nutt.), mat

penstemon (*Penstemon caespitosus* Nutt. ex A. Gray), Watson's penstemon (*P. watsonii*

A. Gray), spiny phlox (*Phlox hoodii* Richardson), longleaf phlox (*P. longifolia* Nutt.),

elegant cinquefoil (*Potentilla concinna* Richardson), lobeleaf groundsel (*Packera*

multilobata [Torr. & A. Gray ex A. Gray] W.A. Weber & Á. Löve), and alpine

pennycress (*Noccaea fendleri* [A. Gray] Holub subsp. *glauca* [A. Nelson] Al-Shehbaz &

M. Koch) (Chi, 2004; USDA, NRCS., 2015).

Methods

I sampled 89 random points across ~96 000 ha of Parker Mountain to quantify

percent canopy cover by species and describe vegetation composition of the black

sagebrush community. The black sagebrush sites that I sampled were determined by

generating random points across Parker Mountain in ArcGIS 10.2.2 (ESRI, 2011). If a

randomly selected site was another vegetation type besides black sagebrush, the reference

point was moved to the nearest black sagebrush site. When the new site was determined,

a new reference point was selected by throwing a piece of rebar blindly to reduce biases.

Black sagebrush vegetation was sampled in the late spring (May) and summer (June,

July, and August) of 2014 and 2015. Each black sagebrush site included four 25 m

transects radiating from each site center. Transects at each site are oriented in the four

cardinal directions (0°, 90°, 180°, 270°). Each transect started one meter from the study

site center point (Fig. 4.1).

I used a modified Daubenmire method to collect species cover data (Daubenmire,

1959). Daubenmire frames were placed at the 0 m, 5 m, 10 m, 15 m, and 20 m mark on

the left side of each transect for a total of 25 frames per site. Discrete percentages for

each species and ground cover was recorded. (Fig. 4.1). To quantify and describe live

shrub canopy cover, species cover data were collected along each transect utilizing the

line intercept method using 5 cm gap criteria (Canfield, 1941). Each black sagebrush site

included 100 m of line intercept. Other abiotic information such as date, location (using

UTM [Universal Transverse Mercator] NAD [North American Datum] 83 coordinate

system), elevation, and aspect was collected. Additionally, digital photographs were

taken of each transect at each site. Slope and heat load (potential direct incident radiation

calculated from slope, aspect, and latitude) values were also added to the data frame,

which were derived from the black sagebrush site locations, using 10 m digital elevation

models (DEM) and ArcGIS 10.2.2 (McCune and Keon, 2002; ESRI, 2011).

Data Analyses

A species accumulation curve across all black sagebrush sites was performed

using the "vegan" package (Oksanen, 2007) in R 3.2.3 (R Core Team, 2014) to determine

how well species diversity was sampled in black sagebrush communities across Parker

Mountain. (Appendix C1). To determine how many black sagebrush community phases

are found on Parker Mountain, I performed a hierarchical cluster analysis on the species

level data (cover was transformed to abundance) utilizing calculation of Bray-Curtis

dissimilarity. The black sagebrush sites where clustered with an agglomerative

hierarchical clustering algorithm using the "vegan" package (Oksanen, 2007) in R 3.2.3

(R Core Team, 2014). Sum of squared error (utilizing kmeans) within clusters scree plot (Appendix C2), internal and stability measures (connectivity, silhouette width, and average proportion of non-overlap [APN] values) validated two clusters should be identified in the hierarchical cluster analysis using the "clValid" package (Brock et al., 2008) in R 3.2.3 (Fig. 4.2; Appendix C2 and C3; R Core Team, 2014).

To determine how species composition and environmental variables influence distribution of black sagebrush community phases on Parker Mountain, a non-parametric multidimensional scaling (NMDS) ordination analysis was performed on species cover data (transformed to abundance in order to achieve the best solution and lowest stress value) (Appendix C4). Bray-Curtis dissimilarity distances where utilized in the NMDS ordination analysis. Environmental variables (elevation, slope, and heat load) and species diversity measures (richness, evenness, and diversity) where then fitted as vectors in the NMDS ordination. The NMDS ordination with fitted vectors was analyzed using the "vegan" package (Oksanen, 2007) in R 3.2.3 (Fig. 4.3; R Core Team, 2014).

The two black sagebrush phases from the hierarchical cluster analysis were then subsetted from the black sagebrush inventory data frame. Means of all environmental variables, species diversity measures, functional group cover, and species cover were derived from each of the subset black sagebrush phase data frames. The subset data was used to describe how the vegetation differs in each black sagebrush community phase (Table 4.2).

After the vegetation within each black sagebrush phase was described, a black sagebrush canopy cover prediction map of Parker Mountain was produced. ERDAS Imagine 2015 was used to perform a supervised classification (utilizing cloudless [<10% cloud cover] Landsat 8 OLI imagery [Path 39/Row 31] from June 18, 2014 [retrieved

from http://earthexplorer.usgs.gov/ on November 11, 2015]) of black sagebrush stands on

Parker Mountain. The classified imagery was then used to produce a black sagebrush

cover predictive map that was trained with the black sagebrush inventory data. The

predictive cover map was built utilizing the ModelMap package (Freeman et al., 2014) in

R 3.2.3 (R Core Team, 2014). The ModelMap package created a random forest model of

training data and black sagebrush canopy cover as the response variable (Liaw and

Wiener, 2002). The training data were composed of predictor variables such as elevation,

aspect, slope, Landsat 8 Operational Land Imager (OLI) bands (one, three, four, five, six,

and seven), and normalized difference vegetation index (NDVI). The random forest

model was validated with out of bag (OOB) predictions on the training data (Appendix

C5). The ModelMap package created graphs of the model validation results, which was

implemented through the randomForest package (Liaw and Wiener, 2002; Freeman et al.,

2014) in R 3.2.3 (R Core Team, 2014). Variable importance plot, and a scatter plot of

observed verses predicted values with slope and intercept of the linear regression line

(labeled with Pearson's and Spearman's correlation coefficients) were also used to

validate the accuracy of the random forest model (Appendix C6, C7; Freeman et al.,

2014).

Results

My analysis revealed that there were two black sagebrush community phases on

Parker Mountain. The NMDS ordination indicated site locations in species space from

each of the black sagebrush community phases have some overlap. Fitted vectors in the

NMDS ordination lends evidence that sites in black sagebrush community Phase 1 are

strongly dispersed by species richness, species evenness, species diversity, and elevation.

Sites in black sagebrush Phase 2 are strongly dispersed by rock and soil cover.

Black sagebrush phase 1 sites are found at higher elevations, on steeper slopes, which had higher heat loads. Phase 1 exhibited lower soil (2.8% less), rock (0.9% less), and litter (2.7% less) cover than phase 2. However, phase 1 had higher cryptogram cover (0.8% more) than phase 2 (Table 4.2).

Mean species diversity measures indicated phase 1 had higher richness (five more species), evenness (0.11 more even), and diversity (0.16 more diverse) than phase 2. Shrub canopy cover in phase 1 was lower (6.9% less) than phase 2. Phase 1 also had higher grass cover (5% more) and forb cover (1.4% more) than phase 2. Shrub abundance in phase 1 was 13.8 % less than phase 2. Phase 1 also had 10.8% higher abundance of grass and 3.1% higher abundance of forbs than phase 2 (Table 4.2).

A. nova was the most abundant species in both phases. In phase 2, *Artemisia nova* was 16.2% more abundant than observed in phase 1, and had 7.8% more canopy cover. In phase 1, *C viscidiflorus* was 2.8% more abundant than observed in phase 2. *Lianthus pungens* was evenly abundant among phase 1 and phase 2 (1.7% and 1.7% respectively) (Table 4.2).

P. fendleriana was the most abundant grass in both black sagebrush community phases, however in phase 1, *P. fendleriana* was 12.9% more abundant than observed in phase 2. *A. lettermanii* was evenly abundant in both phase 1 and phase 2 (3.6% and 3.6% respectively). In phase 1, *E. elymoides* was 2.7% more abundant than observed in phase 2 (Table 4.2).

E. pumilus was the most abundant forb (2.97%) in both black sagebrush phases. In phase 2, *E. pumilus* was 1.3% more abundant than observed in phase 1. In phase 1, *P. concinna* was 1.6% more abundant than observed in phase 2. In phase 2, *P. caespitosus* was 0.8% more abundant than observed in phase 1 (Table 4.2).

The black sagebrush canopy cover predictive map provided a landscape level, 30 m resolution TIFF (tagged image file format) image that displayed five canopy cover classes of black sagebrush (0%, 10%, 20%, 30%, and ≥40%) on Parker Mountain (Fig.4.4).

Discussion

Black communities seem relatively homogenous across the landscape, but as many as 38 species of plants can be found in one location. My data revealed biotic as well as abiotic environmental differences between the black sagebrush phases that existed on Parker Mountain.

The relationship between black sagebrush canopy cover and herbaceous species cover/abundance observed in each phase described in this study may also be driven by elevation and annual precipitation regimes on Parker Mountain. Higher elevation black sagebrush sites had lower average black sagebrush cover and higher herbaceous cover when compared to sites in lower elevations. Vegetation patterns in semi-arid shrub lands like those on Parker Mountain, have been shown to be limited by water availability, slope, and soil texture patterns (Table 4.2; Billings, 1949; Beatley, 1975; West, 1979; Burke et al., 1989).

Black sagebrush communities are highly competitive and appear to be resistant to displacement by other shrubs. However, in some locations black sagebrush is highly selected by ungulates, and heavily browsed sagebrush stands are thinned and replaced by shrubs more resistant to grazing (Hutchings and Stewart, 1953; Holmgren and Hutchings, 1972; Clary, 1986). If black sagebrush is severely reduced by ungulate over use, mechanical treatments, chemical treatments, or fire, black sagebrush may return to pre-disturbance conditions within 20 years if the stressor is removed. Additionally, lower

elevation cold desert stands of black sagebrush are highly subject conversion to cheat grass systems, as higher elevation montane black sagebrush stands appear to be more resistant to invasion and displacement by cheat grass (Goodrich, 2005).

On Parker Mountain, black sagebrush communities are used by ungulates and wildlife throughout the year because black sagebrush has a rather wide elevational range (2135 – 2891 m). Mule deer (*Odocoileus hemionus*), pronghorn antelope, and sage-grouse utilize black sagebrush dominated habitat in the winter and early spring. Though these communities have low value for nesting sage-grouse, they are important for winter survival, especially if the lower elevation black sagebrush communities are adjacent to more productive mountain or Wyoming sagebrush sites that provide protective cover (Goodrich, 2005).

The higher elevation black sagebrush communities I studied exhibited greater forb and grass cover than lower elevation black sagebrush communities on Parker Mountain. High elevation black sagebrush communities provide forage for ungulates and wildlife throughout the summer. The higher elevation black sagebrush communities are important because they are adjacent to sage-grouse brood-rearing habitat in mountain sagebrush communities. These high elevation black sagebrush communities may provide forage for these birds (Dahlgren, 2006). Generally, abundance of forbs are commonly much lower in black sagebrush communities when compared to mountain sagebrush communities. Though some stands of black sagebrush have height and crown cover that meets the requirements indicated by Connelly et al. (2000), the short stature of black sagebrush and lower abundance of forbs indicates that stands of this shrub have lower value than stands of mountain sagebrush for sage-grouse nesting and winter habitat (Goodrich, 2005; Dahlgren, 2009).

The ability to identify what type of black sagebrush phase a black sagebrush stand is, based on the abundance and cover of vegetation present, and other abiotic factors would aid management of wildlife habitat and livestock grazing on more than 96 000 ha of rangeland on Parker Mountain. Phase 2 black sagebrush stands on the mountain exhibit high black sagebrush canopy cover, which provide late fall, winter, and early spring habitat for sage-grouse, antelope, deer, and sheep. It is important these black sagebrush dominated communities be sustained because sagebrush obligate species depend on these black sagebrush community phases as part of their life cycles. Phase 1 black sagebrush stands provide late spring, summer, and fall habitat for sage-grouse, brewer sparrows (*Spizella breweri*), pronghorn, deer, elk (*Cervus canadensis*), sheep, and cattle (*Bos taurus*). These types of phases provide higher forb and grass species cover essential for sage-grouse brood rearing. Conservation of black sagebrush community phase 2 habitat types are important for supporting healthy populations of sage-grouse, which is a species of conservation concern.

Implications

The results of my research suggest that there are two distinct plant community phases within the black sagebrush communities that are generally separated by elevation. The results of this research will help managers better understand the diversity and composition of black sagebrush communities as they relate to important wildlife and livestock. This data will also be useful as baseline data to inform important management and research questions about livestock, sage-grouse, and pronghorn habitat in the future.

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Tables and Figures

Table 4.1
Elevational ranges of *Artemisia nova* across its geographic distribution in western North America (2015).

Area	Range (m)
Arizona	1 829-2 438
California	1 524-3 353
California (White Mountains)	2 134-2 896
Colorado	2 134-2 500
Nevada	1 524-3 353
New Mexico	2134-2 438
Utah	1 402-3 033
Great Basin	1 524-2 438
Intermountain West	1 402-3 033

Table 4.2
Mean environmental measures, effective ground cover, species diversity measures, functional group percent canopy cover, and species percent canopy cover values of two black sagebrush community phases on Parker Mountain, Utah (2014-2015).

	Community Phase 1	Community Phase 2
Environmental Measures		
Elevation (m)	2675	2607
Slope (%)	6.98	5.75
Heat Load	1.63	1.41
Effective Ground Cover	Cover	Cover
Soil	24.75	27.54
Rock	21.87	22.72
Litter	28.29	31.00
Cryptogram	5.75	4.95
Species Diversity Measures		
Richness	24	19
Evenness	0.61	0.50
Diversity	0.74	0.58
	% Canopy Cover	% Canopy Cover
Functional Groups		
Shrub	26.60	33.50
Herbaceous	20.00	13.60
Grass	14.10	9.10
Forb	5.90	4.50

Plant Species-Shrub/Sub-Shrub	% Canopy Cover	% Canopy Cover
Artemisia frigida	0.04	0.37
Artemisia nova	21.27	29.10
Artemisia tridentata subsp. *vaseyana*	0.85	0.07
Chrysothamnus vaseyi	0.01	0.28
Chrysothamnus viscidiflorus	3.09	1.82
Ericameria parryi	0.03	0.00
Eriogonum microthecum	0.11	0.32
Gutierrezia sarothrae	0.23	0.51
Juniperus scopulorum	0.04	0.00
Linanthus pungens	0.85	0.86
Purshia tridentata	0.00	0.06
Tetradymia canescens	0.08	0.07

Plant Species-Grass/Grass-Like	% Canopy Cover	% Canopy Cover
Achnatherum hymenoides	0.07	0.04
Achnatherum lettermanii	1.75	1.73
Bouteloua gracilis	0.34	1.73
Carex obtusata	0.93	0.72
Carex sp.	0.12	0.02
Elymus elymoides	0.93	2.18
Festuca ovina	0.56	0.67
Hesperostipa comata	0.07	0.08
Koeleria macrantha	1.04	0.16
Muhlenbergia richardsonis	0.02	0.01
Pascopyrum smithii	0.22	0.35
Poa fendleriana	7.36	1.41
Poa secunda	0.17	0.01
Psuedoroegneria spicata	0.47	0.01

Plant Species-Forb	% Canopy Cover	% Canopy Cover
Androsace septentrionalis	0.19	0.06
Antennaria parvifolia	0.59	0.05
Arabis drummondii	0.01	0.00
Arabis holboellii	0.28	0.32
Astragalus agrestis	0.02	0.10
Astragalus consibrinus	0.02	0.01
Astragalus convallarius	0.10	0.04
Astragalus sp.	0.13	0.03
Calochortus nuttallii	0.02	0.00
Castilleja chromosa	0.03	0.04
Chaenactis douglasii	0.09	0.01
Cryptantha bakeri	0.20	0.05
Cymopterus purpurascens	0.01	0.02
Descurainia pinnata	0.01	0.01
Draba rectifructa	0.01	0.00

Erigeron eatonii	0.49	0.07
Erigeron pumilus	0.40	0.95
Eriogonum alatum	0.02	0.01
Eriogonum ovalifolium	0.00	0.14
Eriogonum racemosum	0.08	0.05
Eriogonum umbellatum	0.17	0.07
Erysimum asperum	0.00	0.01
Gayophytum ramosissimum	0.01	0.01
Hymenoxys richardsonii	0.03	0.15
Lappula occidentalis	0.00	0.02
Lesquerella montana	0.00	0.01
Linum lewisii	0.12	0.09
Lotus utahensis	0.01	0.02
Lygodesmia spinosa	0.07	0.01
Noccaea fendleri	0.15	0.03
Oenothera caespitosa	0.02	0.00
Opuntia fragilis	0.01	0.02
Packera multilobatus	0.15	0.08
Packera neomexicana	0.03	0.01
Pediocactus simpsonii	0.01	0.03
Penstemon caespitosus	0.22	0.59
Penstemon watsonii	0.08	0.04
Petradoria pumila	0.01	0.01
Phlox griseola	0.11	0.07
Phlox hoodii	0.34	0.19
Phlox longifolia	0.45	0.74
Polygonum douglasii	0.01	0.00
Potentilla concinna	0.97	0.12
Potentilla hippiana	0.01	0.11
Sphaeralcea coccinea	0.01	0.02
Streptanthus cordatus	0.03	0.01
Taraxacum officinale	0.03	0.01
Trifolium gymnocarpon	0.20	0.08
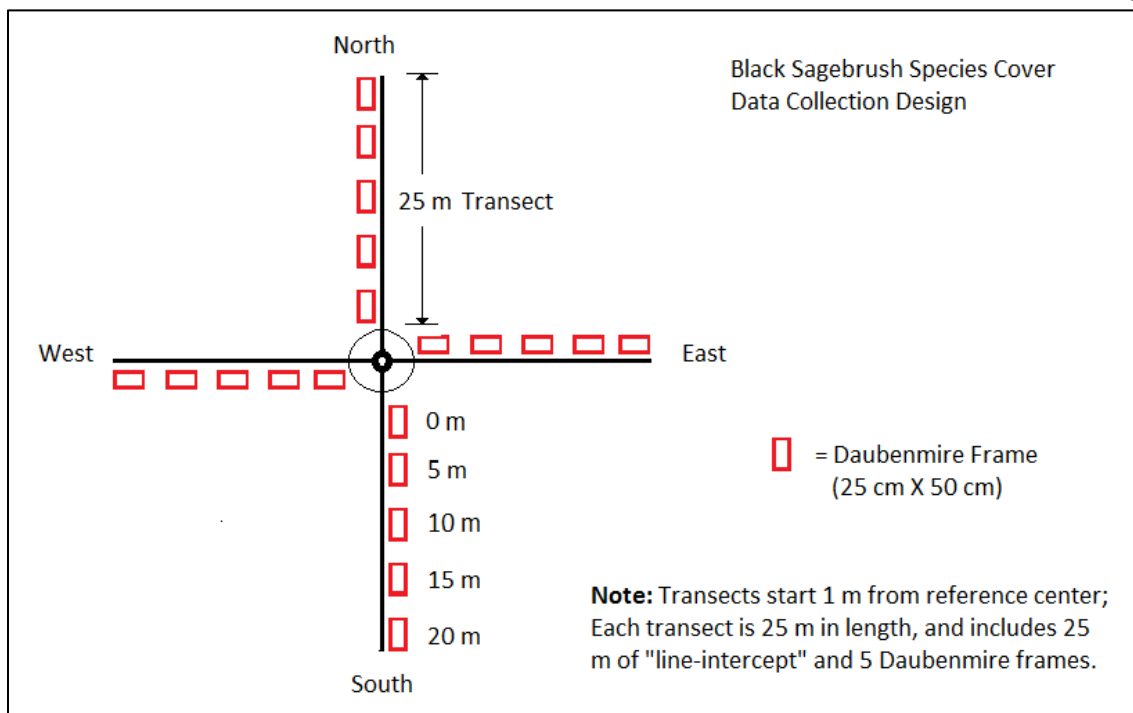
Fig. 4.1. Species canopy cover data collection design. Parker Mountain, Utah (2014-2015).
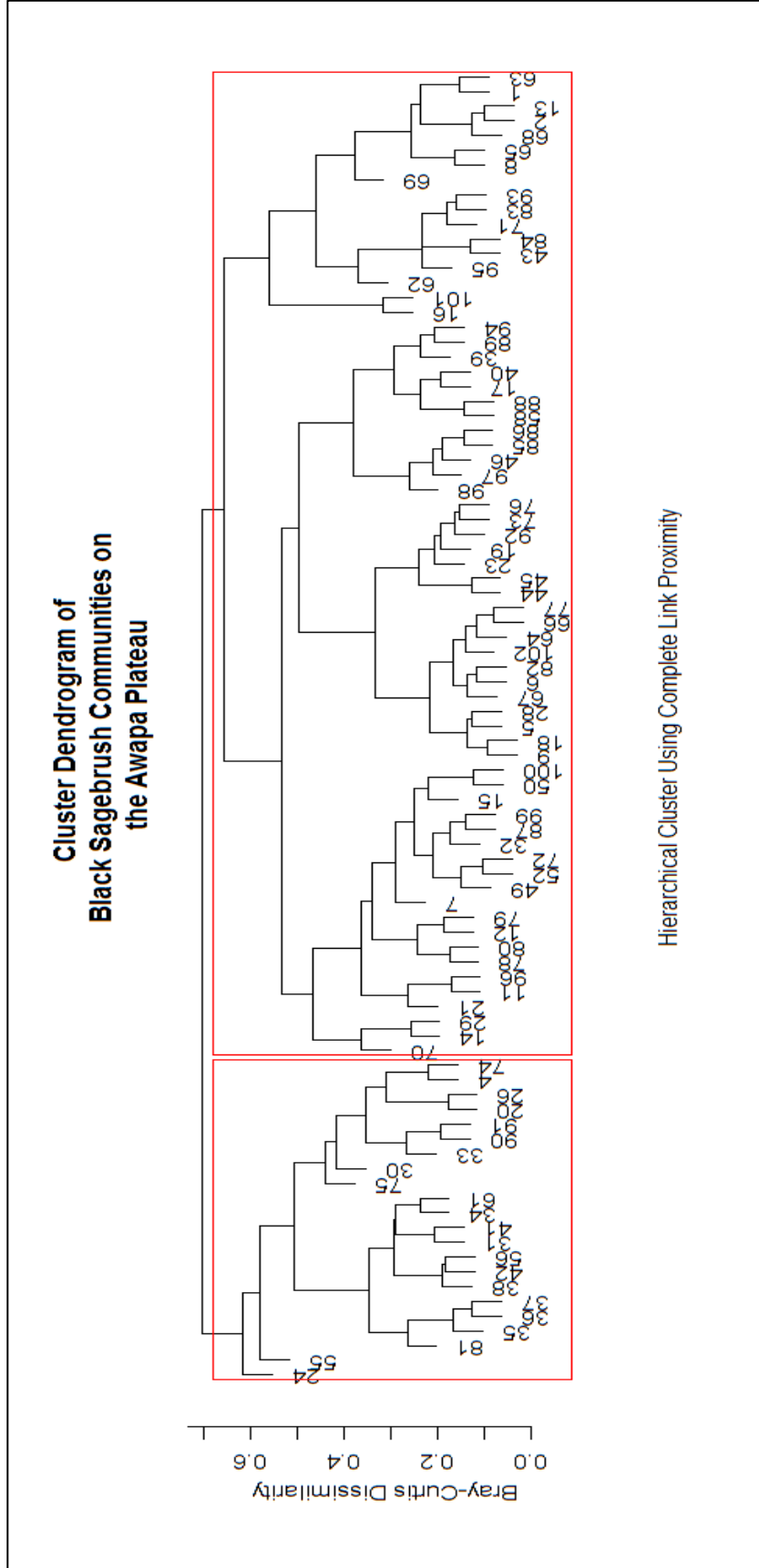
Fig. 4.2. Cluster dendrogram of *Artemisia nova* phases on Parker Mountain (Awapa Plateau), Utah (2014-2015). The red polygons indicate phases (2), which each site (leaflet) is contained.
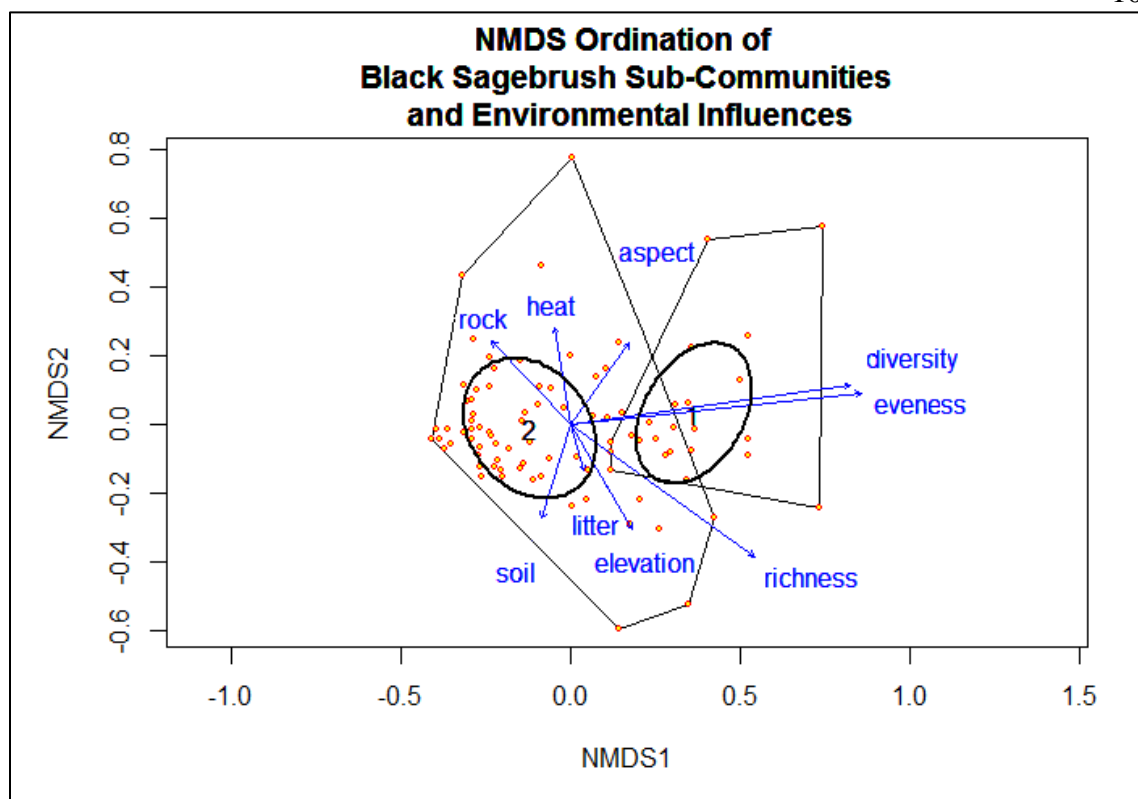
Fig. 4.3. Non-metric multidimensional scaling ordination of black sagebrush community phases on Parker Mountain, Utah (2014-2015). Yellow filled red dots represent individual black sagebrush stands inventoried, black poly-circles represent the two black sagebrush phases identified in the hierarchical cluster analysis, black polygons represent the distribution of all inventory points in each phase. Blue vectors represent environmental variables and biotic measures of diversity. Longer vectors indicate stronger influences on black sagebrush site distribution.
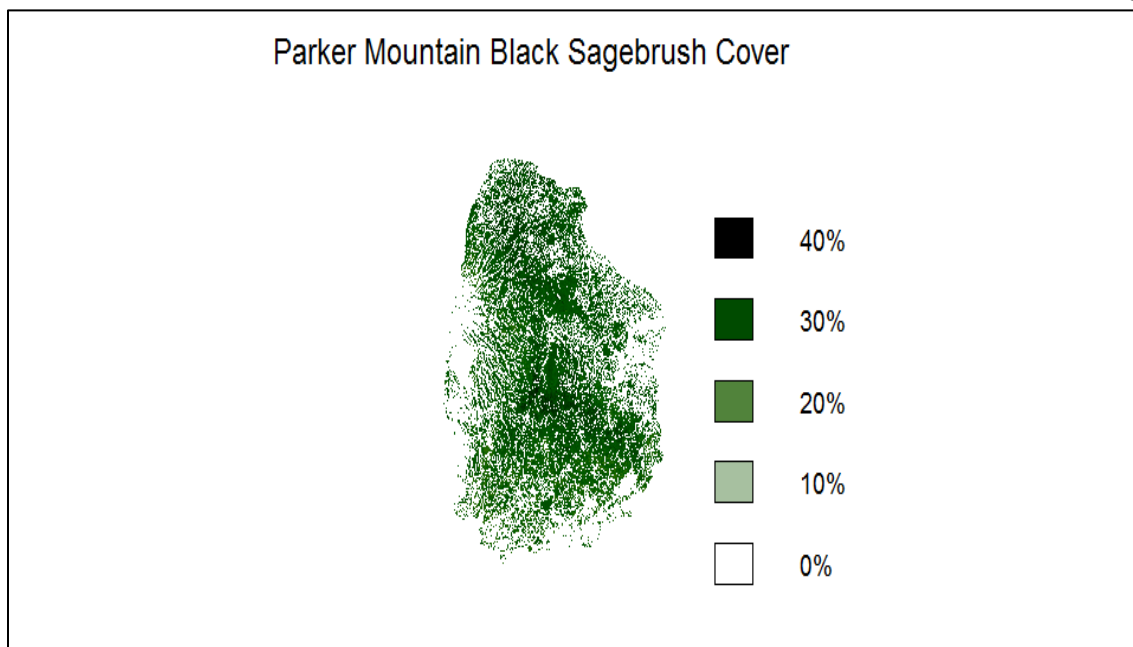
Fig. 4.4. Detailed prediction surface of *Artemisia nova* canopy cover on Parker Mountain, Utah (2015).

CHAPTER 5

SUMMARY AND CONCLUSIONS

On Parker Mountain, tebuthiuron treatments have been applied to high elevation mountain sagebrush ecosystems as part of an adaptive resource management approach to improve wildlife habitat for sage-grouse and increase forage for livestock. This approach combines contemporary knowledge of habitat needs of sagebrush obligates within sagebrush ecosystems with landscape level grazing practices that will provide managers with the information needed to provide a sustainable ecosystem (Dahlgren et al., 2006).

I evaluated mechanically and chemically treated mountain sagebrush pastures, and black sagebrush communities to study sagebrush ecology of Parker Mountain.

Based on the long-term (9 years) vegetation cover response, tebuthiuron treatments were superior when compared to Dixie harrow and Lawson aerator treatments to reduce mountain sagebrush cover and increase the cover of grasses and forbs for at least 9 years. My results provide managers an understanding of the long-term impacts of mechanical and chemical treatments on grass and forb cover. The information from my research may be used by local and regional rangeland managers to help guide decisions in the implementation of mountain sagebrush reduction treatments that improve forage production for livestock and improve habitat for wildlife.

Results from my research quantified the impacts of tebuthiuron on forage production. My results indicate that tebuthiuron is a viable option to increase forage for livestock and wildlife. My results showed that grass cover was significantly increased in treated areas. However, vegetation biomass responses may vary from site to site due to differences in, soils and site potential. Therefore, I recommend that pre-treatment plots be evaluated to ensure application rates match soil characteristics and avoid areas with low

site potential. Cautious application of tebuthiuron to mountain sagebrush communities with limited herbaceous understory may be a viable conservation practice for land management agencies to enhance rangelands for wildlife and livestock grazing. Continued monitoring of tebuthiuron treatments will provide managers with more information regarding management of high elevation mountain sagebrush communities to benefit wildlife and livestock.

Across Parker Mountain, black sagebrush communities exhibited ~32% shrub cover, ~10% grass cover, and ~5% forb cover. The relationship between black sagebrush canopy cover and herbaceous species cover/abundance observed in each phase described in this study may also be driven by elevation and annual precipitation regimes on Parker Mountain. Higher elevation black sagebrush sites had lower average black sagebrush cover and higher herbaceous cover when compared to sites in lower elevations.

The ability to identify what phase type a black sagebrush stand is, based on the abundance and cover of vegetation present, and other abiotic factors would aid management of wildlife habitat and livestock grazing on more than 96 000 ha of rangeland on Parker Mountain. Black sagebrush stands on the plateau that exhibit high black sagebrush canopy cover, which provide late fall, winter, and early spring habitat for sage-grouse, antelope, deer, and sheep are important and should be sustained because sagebrush obligate species depend on these black sagebrush community phases as part of their diet. Other black sagebrush stands provide late spring, summer, and early fall habitat for sage-grouse, brewer sparrows, antelope, deer, elk, sheep, and cattle. These types of black sagebrush communities provide higher forb and grass species cover essential for sage-grouse brood rearing. Conservation of black sagebrush communities may be

important for supporting healthy populations of wildlife and sage-grouse, which is a

species of conservation concern.

Literature Cited

Dahlgren, D.K., Chi, R., Messmer, T.A., 2006. Greater sage-grouse response to
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APPENDICES

APPENDIX A

Appendix A1. Generalized additive mixed model annotation used in Parker Lake Pasture experiment vegetation response analysis, Parker Mountain, Utah. Data collected from 2000-2009.

$$Vegetation\ Response_{\text{Treatment Type}\ ij} \approx \alpha + a_i + f(Day\ of\ Research_{ij}) + \varepsilon_{ij}$$

where $\varepsilon_i \sim N(0, \sigma^2)$ and $a_i \sim N(0, \sigma^2)$
where a_i is the random intercept of plot identification

Appendix A2. Model validation for the percent shrub canopy cover response model in control plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2001-2009.
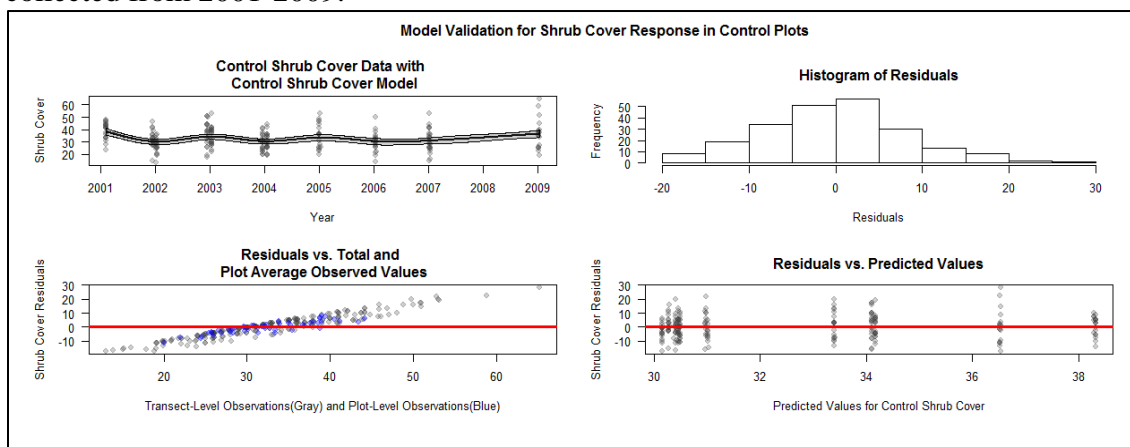
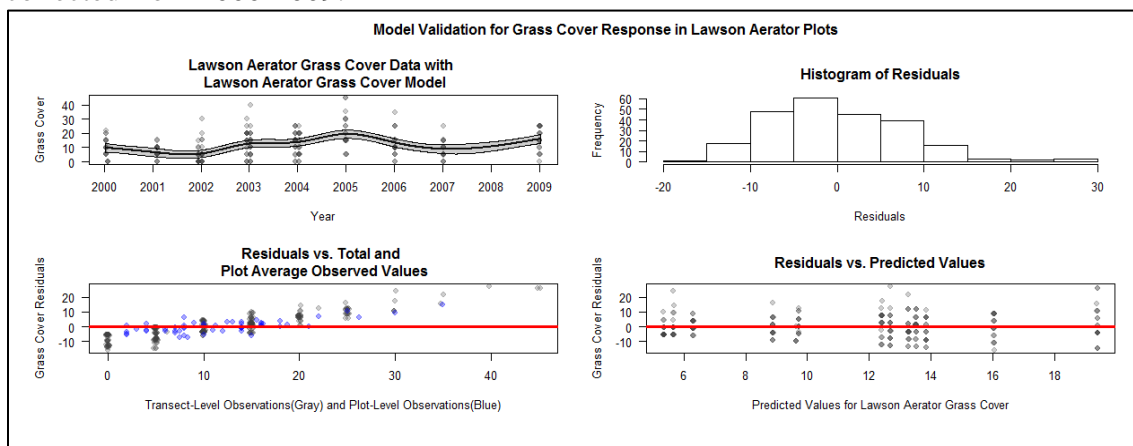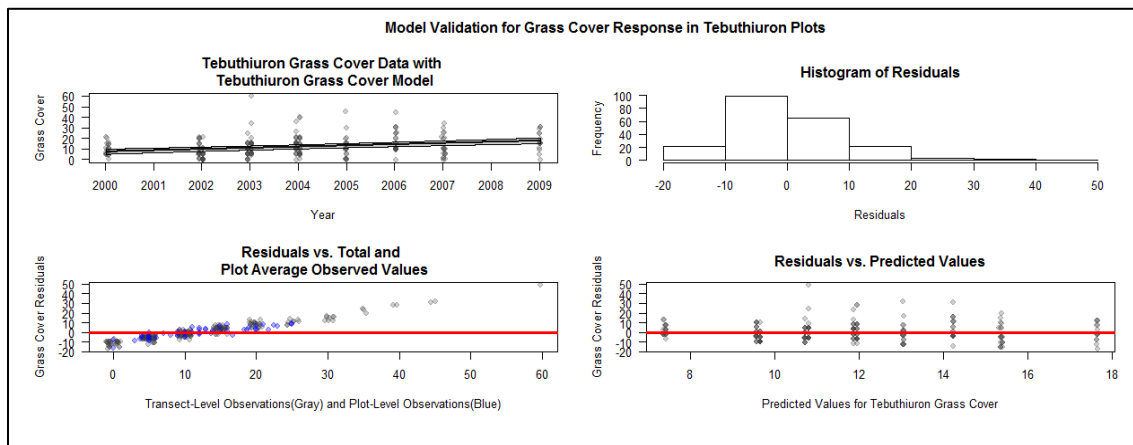**Appendix A3.** Model validation for the percent shrub canopy cover response model in Dixie harrow plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2001-2009.
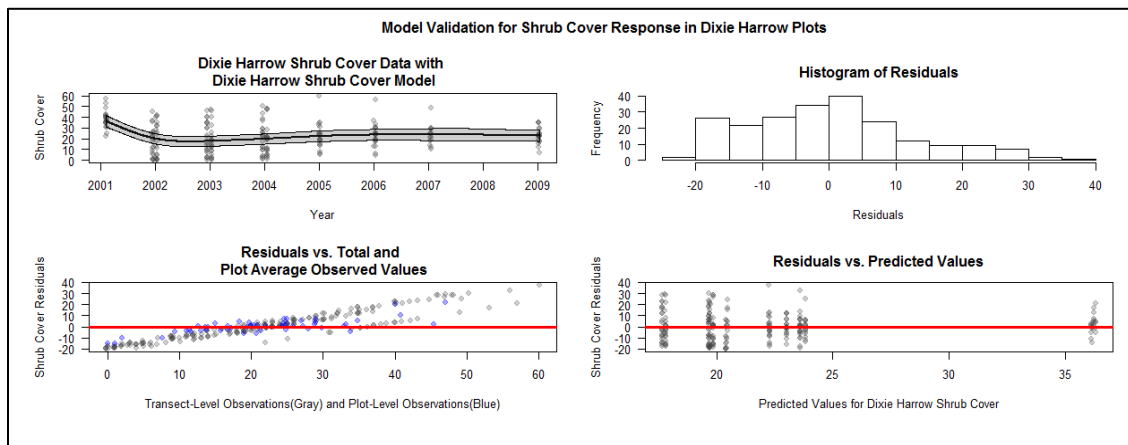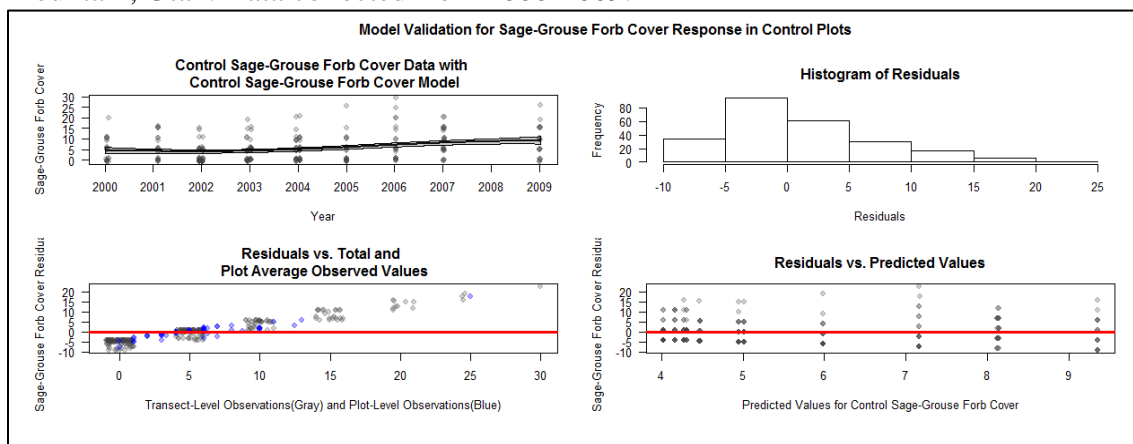

Appendix A4. Model validation for the percent shrub canopy cover response model in Lawson aerator plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2001-2009.
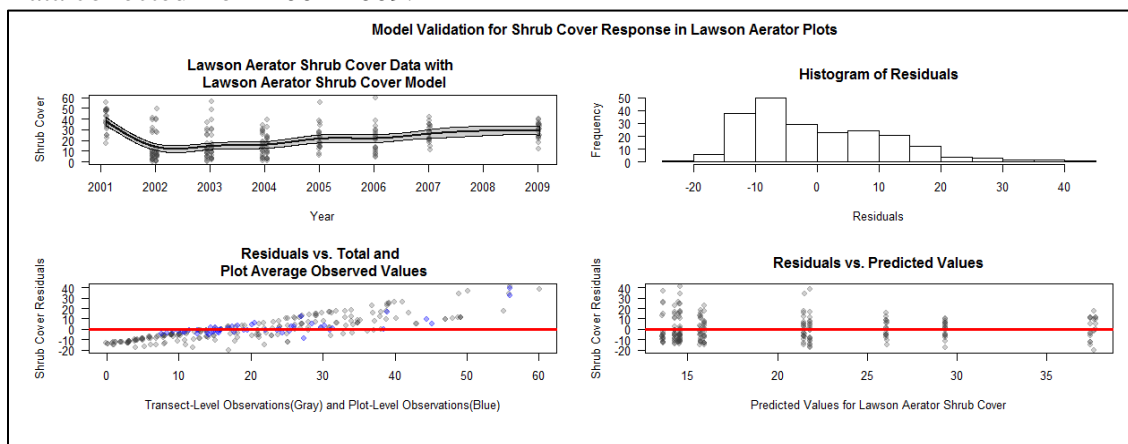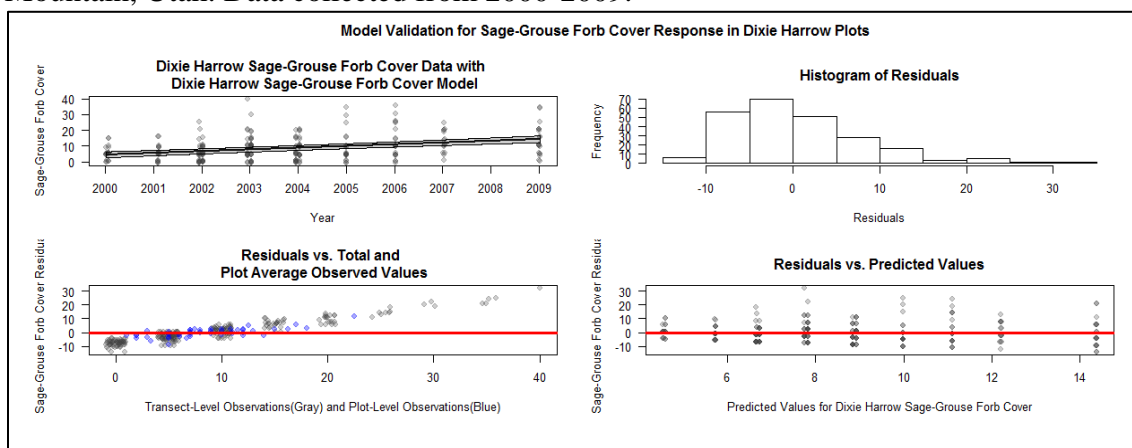
Appendix A5. Model validation for the percent shrub canopy cover response model in tebuthiuron plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2001-2009.
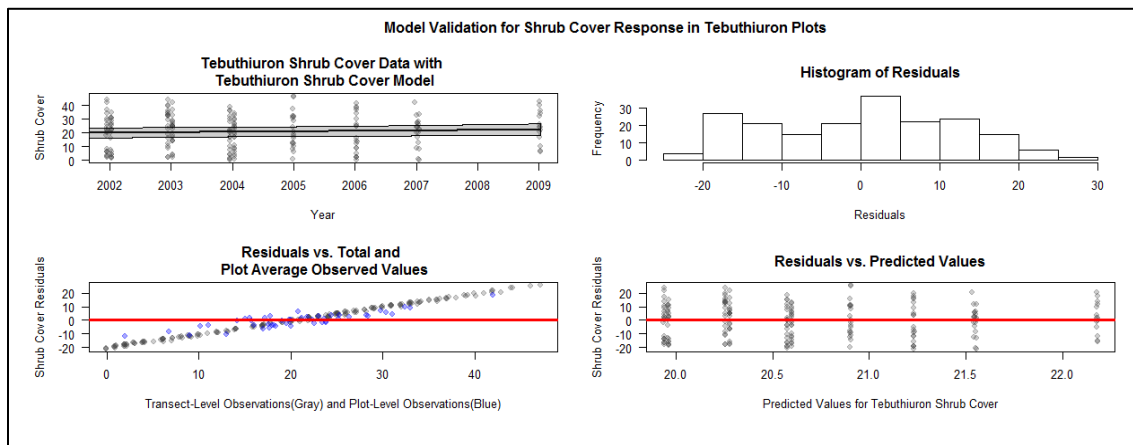
Appendix A6. Model validation for the grass canopy cover response model in controls plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2000-2009.
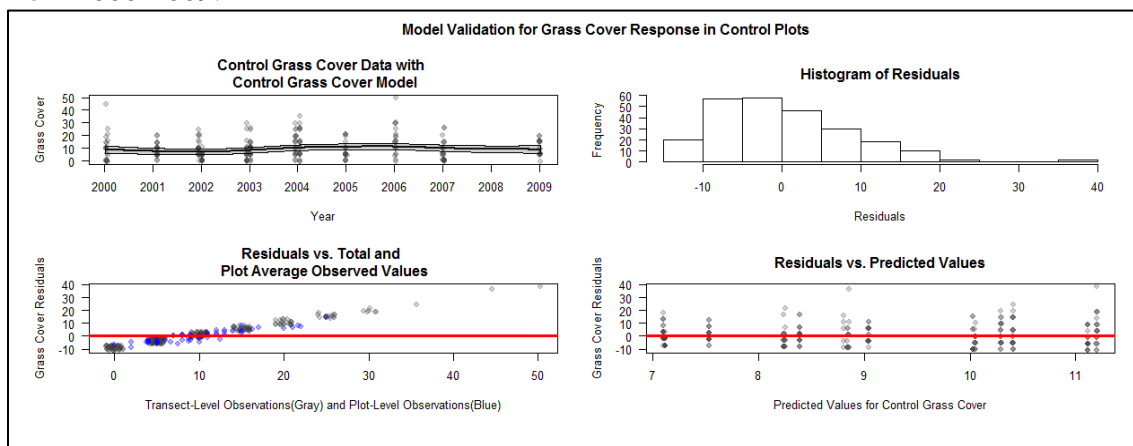
Appendix A7. Model validation for the grass canopy cover response model in Dixie harrow plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2000-2009.
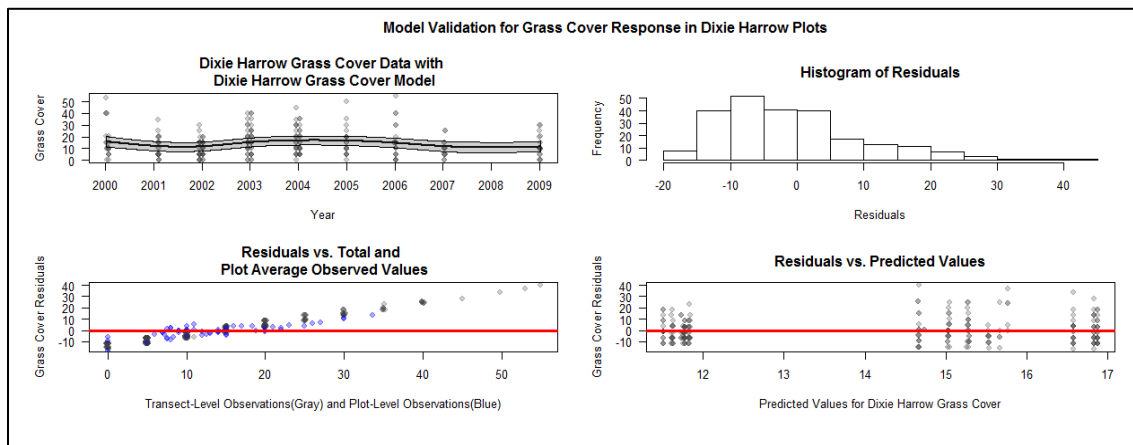
Appendix A8. Model validation for the grass canopy cover response model in Lawson aerator plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2000-2009.

Appendix A9. Model validation for the grass canopy cover response model in tebuthiuron plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2000-2009.
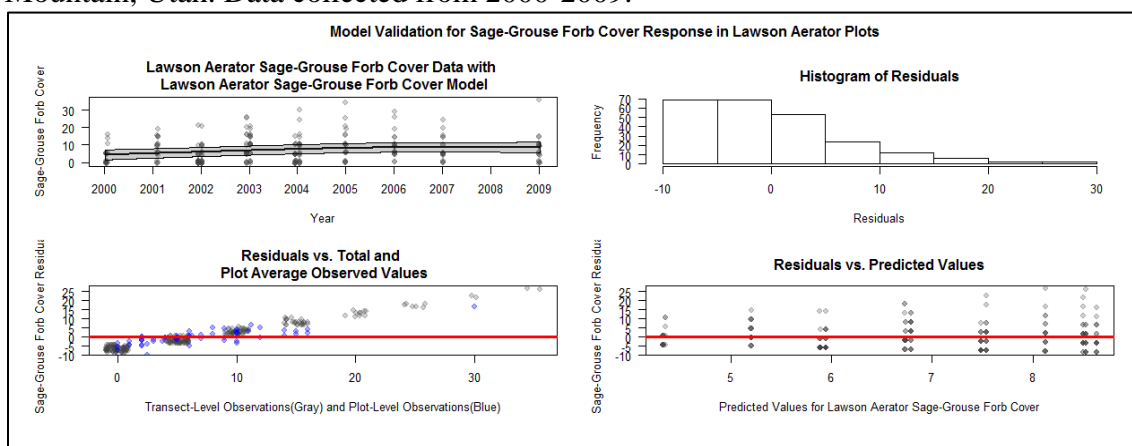

Appendix A10. Model validation for the *Centrocercus urophasianus* forb canopy cover response model in control plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2000-2009.
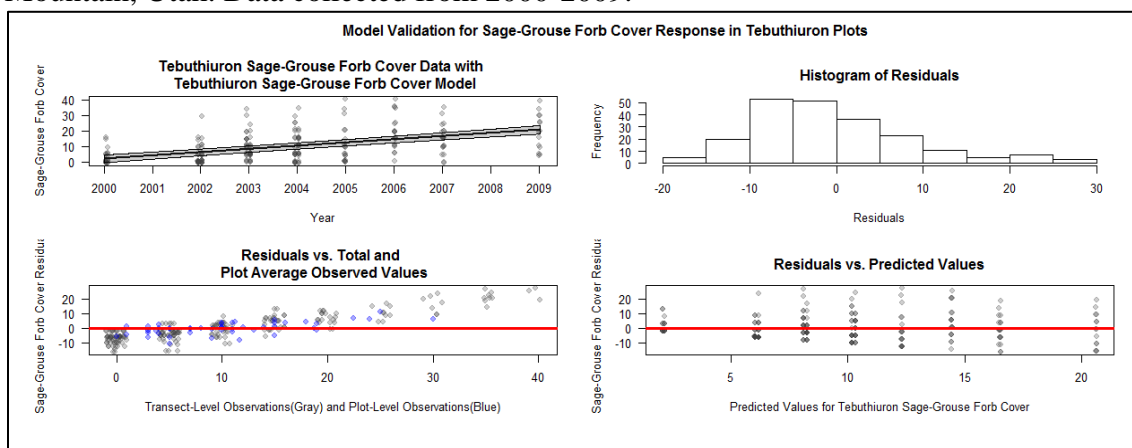
Appendix A11. Model validation for the *Centrocercus urophasianus* forb canopy cover response model in Dixie harrow plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2000-2009.
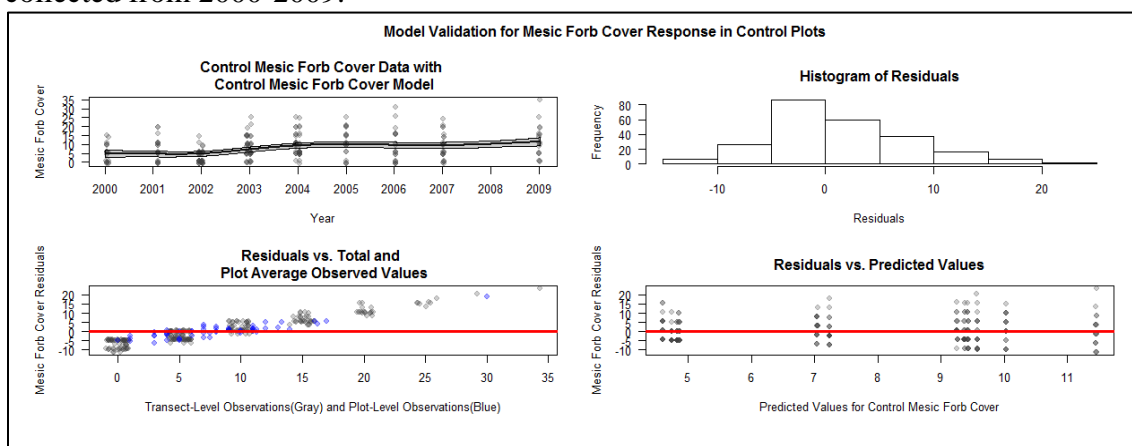

Appendix A12. Model validation for the *Centrocercus urophasianus* forb canopy cover response model in Lawson aerator plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2000-2009.

Appendix A13. Model validation for the *Centrocercus urophasianus* forb canopy cover response model in tebuthiuron plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2000-2009.
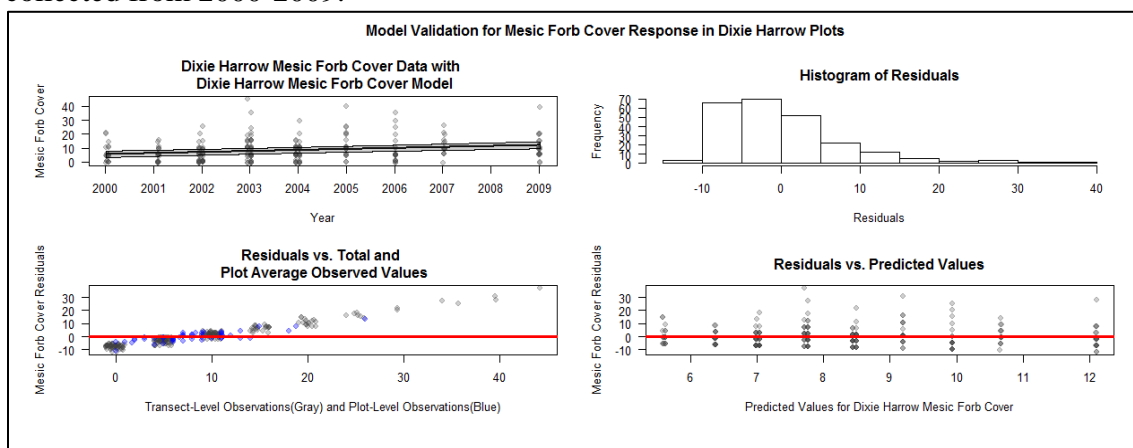

Appendix A14. Model validation for the mesic forb canopy cover response model in control plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2000-2009.
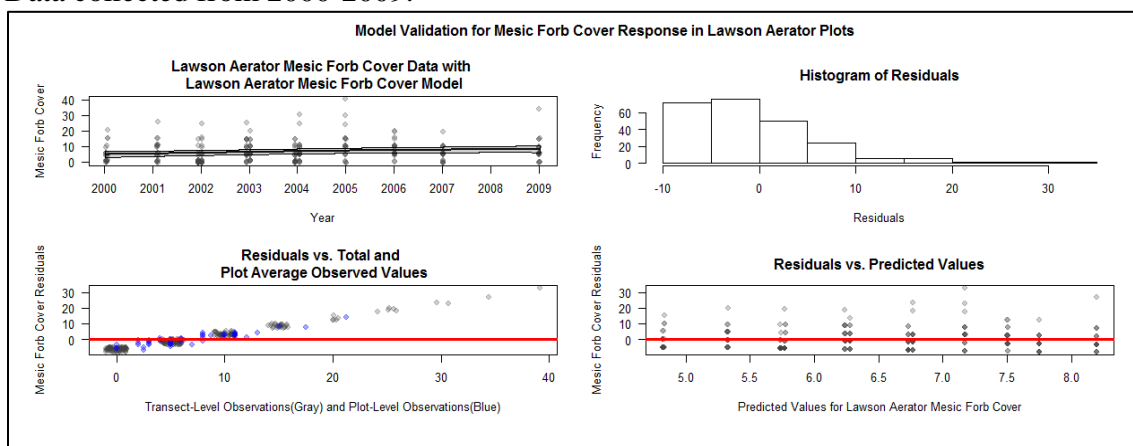
Appendix A15. Model validation for the mesic forb canopy cover response model in Dixie harrow plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2000-2009.

Appendix A16. Model validation for the mesic forb canopy cover response model in Lawson aerator plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2000-2009.

Appendix A17. Model validation for the mesic forb canopy cover response model in tebuthiuron plots of the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2000-2009.
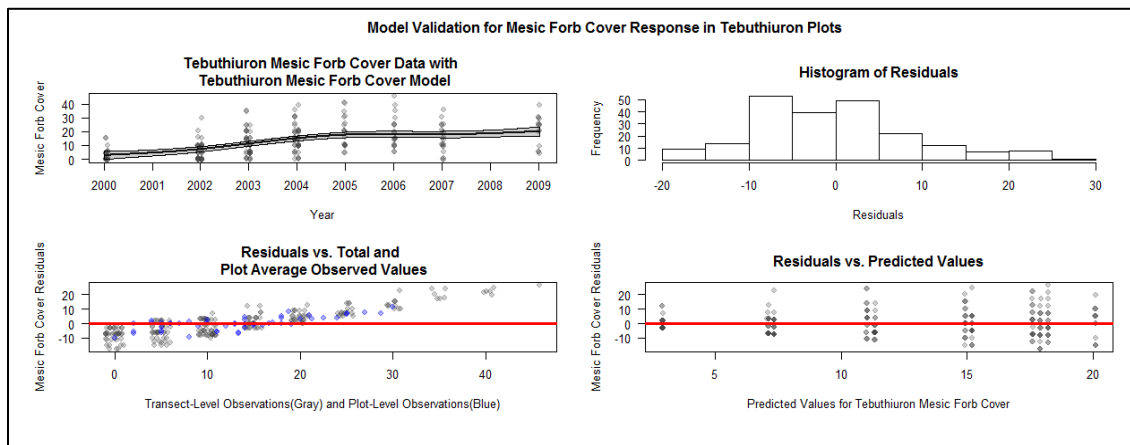
Appendix A18. Generalized additive mixed models statistics for vegetation responses in the Parker Lake Pastures Experiment, Parker Mountain, Utah. Data collected from 2001-2009. Bold values indicate statistical significance ($P<0.05$).

| Parker Lake Pasture Vegetation Response GAMM Statistics									
				Coefficients				Smoother Significance	
Vegetation Response	Treatment Type	n	Adj. R^2	Mean (%)	Std. Error	t value	p value	edf	p value
Shrub Cover									
	Control	223	0.11	32.6	0.95	34.3	**<2e-16**	6.2	**3e-3**
	Dixie	215	0.14	22.1	3.08	7.2	**1.11e-11**	5.3	**4.25e-7**
	Lawson	216	0.29	20.4	1.49	13.7	**<2e-16**	6.1	**2.12e-14**
	Teb.	194	-0.003	20.7	2.47	8.4	**1.16e-14**	1.0	0.432
Grass Cover									
	Control	243	0.028	9.1	1.43	6.4	**7.94e-10**	3.7	0.102
	Dixie	235	0.039	14.2	2.53	5.6	**5.57e-8**	4.5	**0.0246**
	Lawson	236	0.22	11.4	1.52	7.5	**1.26e-12**	6.9	**9.24e-11**
	Teb.	214	0.066	11.9	1.41	8.4	**5.15e-15**	1.0	**4.32e-5**
Grouse Forb Cover									
	Control	243	0.077	5.5	0.42	13.3	**<2e-16**	2.5	**2.1e-4**
	Dixie	237	0.104	8.7	1.10	7.9	**1.3e-13**	1.0	**9.65e-8**
	Lawson	237	0.035	7.0	1.83	3.8	**1.9e-4**	2.0	**4.9e-3**
	Teb.	214	0.219	10.2	1.45	7.0	**2.74e-11**	1.0	**3.65e-14**
Mesic Forb Cover									
	Control	243	0.112	7.7	0.78	9.8	**<2e-16**	4.1	**4.44e-6**
	Dixie	237	0.046	8.3	1.48	5.6	**5e-8**	1.0	4e-4
	Lawson	237	0.017	6.5	1.13	5.8	**2.67e-8**	1.4	**0.052**
	Teb.	214	0.246	12.9	1.03	12.6	**<2e-16**	3.5	**1.27e-12**

APPENDIX B

Appendix B1. Welch two sample t-test results for dead *Artemisia tridentata* subsp. *vaseyana* canopy cover (%) of transects located in five pastures on Parker Mountain, Utah. n=45. Data collected in 2015.

Pasture	t-statistic	df	p-value	95% CI	mean (treated)	mean (non-treated)
South Pasture	1.35	4.71	0.2381	[-2.62, 8.21]	7.33	4.54
Nick's Pasture	2.10	6.66	0.0759	[-0.32, 4.99]	7.25	4.91
Buttes Pasture	9.18	5.85	0.0001	[6.19, 10.73]	13.12	4.67
Forshea Draw	4.77	5.27	0.0044	[4.32, 14.07]	12.42	3.22
Chicken Spring	5.56	5.02	0.0026	[6.12, 16.65]	16.27	4.89

APPENDIX C

Appendix C1. Species accumulation curve from *Artemisia nova* sites sampled across Parker Mountain (Awapa Plateau), Utah. Data collected from 2014-2015.
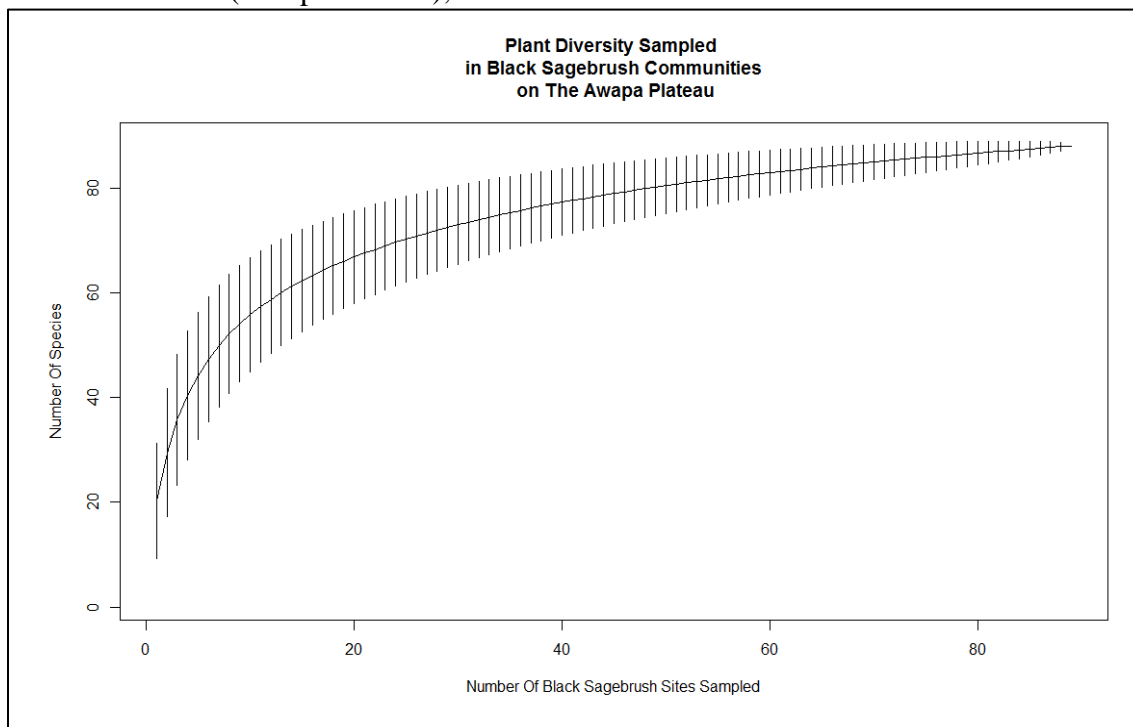

Appendix C2. Sum of squared error scree plot used to validate the number of clusters found within a hierarchical clustering analysis of *Artemisia nova* sites on Parker Mountain, Utah. Data collected from 2014-2015.
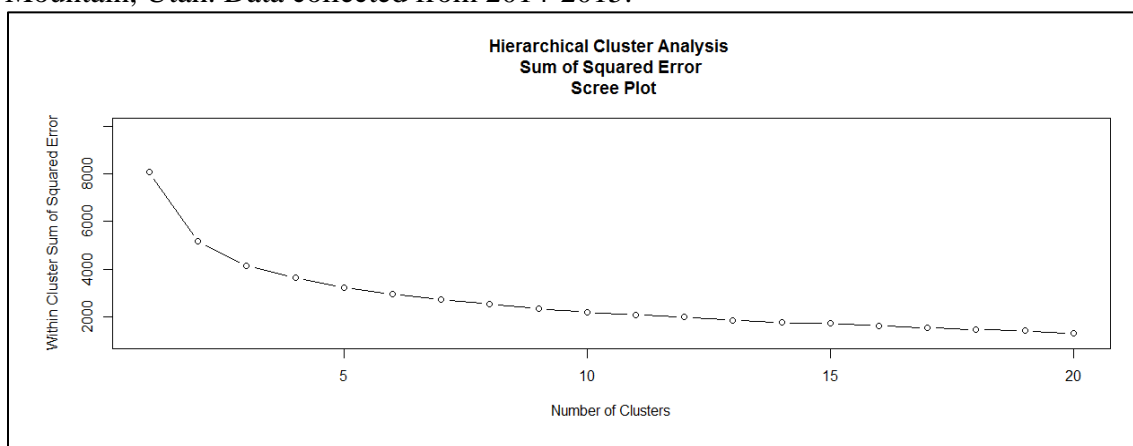
Appendix C3. Internal and stability measures used to determine the number of clusters (*Artemisia nova* phases) in the hierarchical cluster analysis of *Artemisia nova* sites across Parker Mountain, Utah (2014-2015). Higher scores are desired with connectivity, while both the silhouette width and APN should be minimized. These measures indicated two groups are represented in the hierarchical cluster analysis of *Artemisia nova* sites.

|	Measure	Score
Internal	Connectivity	8.15
	Silhouette Width	4.98e-1
Stability	APN (Average Proportion of Non-Overlap)	5.30e-3
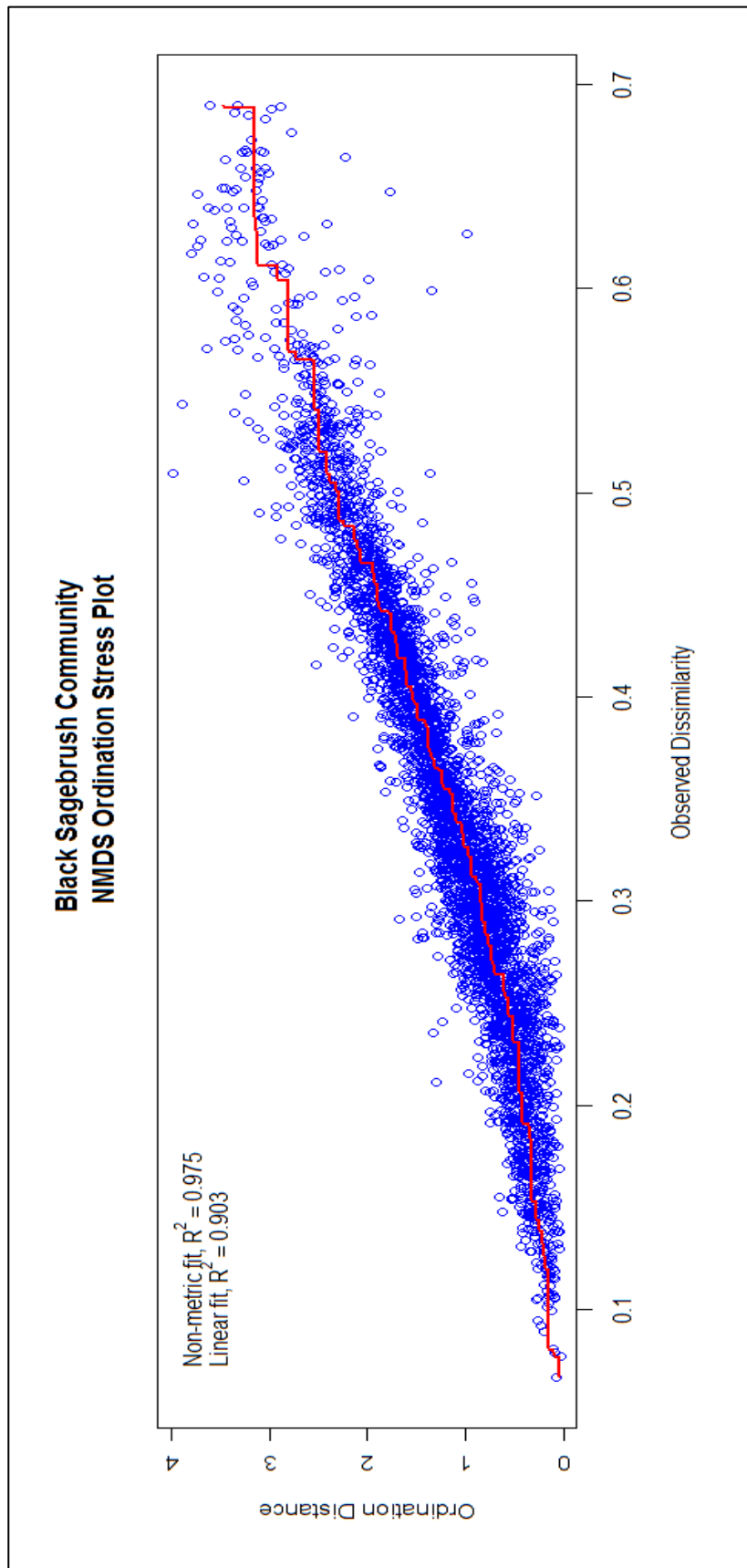
Appendix C4. *Artemisia nova* (black sagebrush) community non-metric multidimensional scaling ordination stress plot for black sagebrush sites on Parker Mountain, Utah. Data collected from 2014-2015. The NMDS ordination found the optimal solution to the black sagebrush dissimilarity matrix on run 16 and the stress value to for the solution is 0.159.

Appendix C5. Out of bag mean standard error as a function of number of trees for *Artemisia nova* canopy cover random forest model. Random forest model used to produce and validate *Artemisia nova* canopy cover predictive surface of Parker Mountain, Utah. Data collected from 2014-2015.
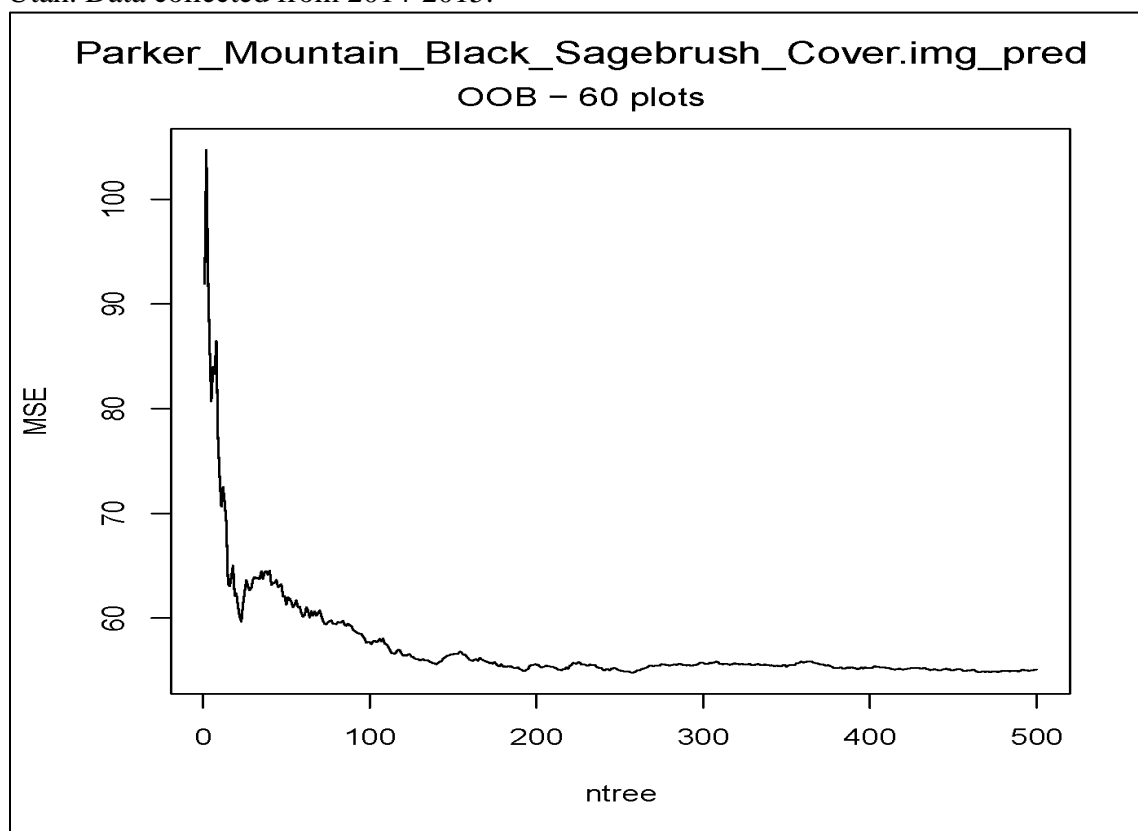
Appendix C6. Variable importance plots for the *Artemisia nova* canopy cover random forest model used to produce and validate *Artemisia nova* canopy cover predictive surface of Parker Mountain, Utah. Data collected from 2014-2015.
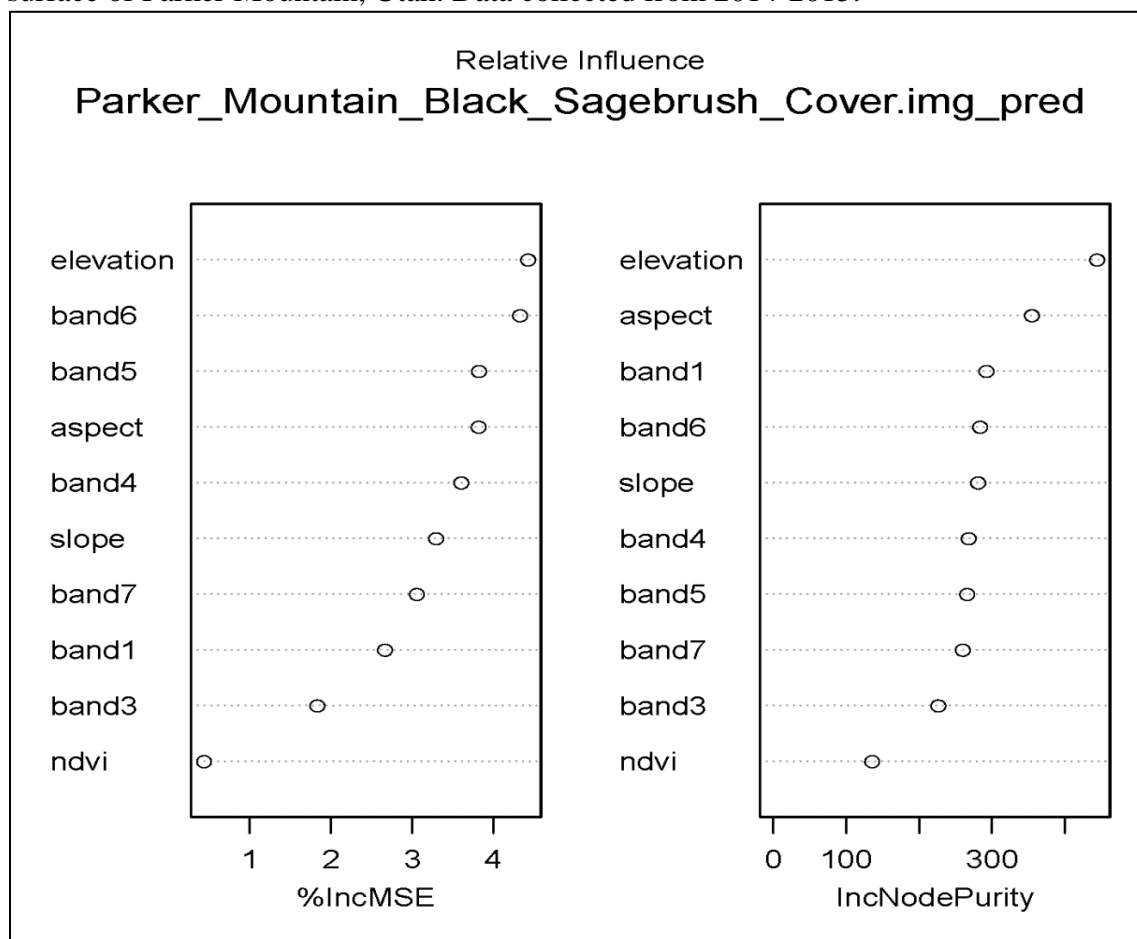
Appendix C7. Observed versus predicted values for *Artemisia nova* cover in the random forest model used to produce and validate *Artemisia nova* canopy cover predictive surface of Parker Mountain, Utah. Data collected from 2014-2015. Pearson's and Spearman's correlation is equal to 0.72 and 0.70 respectively.

Parker_Mountain_Black_Sagebrush_Cover.img_pred

RMSD:4.29
pearson's cor: 0.72
spearman's cor: 0.7
obs = 1.54(pred) + −16.66