5-2004

Influence of Fall Grazing by Sheep on Plant Productivity, Shrub Age Class Structure and Herbaceous Species Diversity in Sagebrush Steppe

Ryan Duncan Woodland
Utah State University

INFLUENCE OF FALL GRAZING BY SHEEP ON PLANT

PRODUCTIVITY, SHRUB AGE CLASS STRUCTURE AND HERBACEOUS

SPECIES DIVERSITY IN SAGEBRUSH STEPPE

by

Ryan D. Woodland

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

of

MASTER OF SCIENCE

in

Range Science

Approved:

Dr. Neil E. West Major Professor	Dr. Fred Provenza Committee Member
Dr. Kenneth C. Olson Committee Member	Dr. Byron R. Burnham Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2007

ABSTRACT

Influence of Fall Grazing by Sheep on Plant

Productivity, Shrub Age Class Structure, and Herbaceous

Species Diversity in Sagebrush Steppe

by

Ryan D. Woodland, Master of Science

Utah State University, 2004

Major Professor: Neil E. West
Department: Wildland Resources

Traditional chemical and mechanical treatments of Wyoming Big Sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) are costly and have typically focused solely on increasing forage for livestock production. Managing these systems biologically with grazing can potentially reduce costs and increase both biodiversity and understory production as well as rejuvenate Wyoming Big Sagebrush (ARTRWY). This experiment was conducted on Deseret Land and Livestock Ranch in northern Utah in October 2003. One hundred and twenty sheep (dry ewes) grazed 3, 60m x 40m plots ($40 \text{ sheep} \cdot \text{plot}^{-1}$). Sheep were provided a protein-energy supplement to facilitate use of the secondary metabolites found in ARTRWY forage. I used the reference unit method to estimate ($\text{g} \cdot \text{m}^{-2}$) phytomass in the following plant categories immediately before, immediately after, and one year following grazing: total phytomass, current annual growth (CAG) of ARTRWY, the woody portion of ARTRWY, CAG of other shrubs, the woody portion of other shrubs, grasses, forbs, litter (woody and herbaceous), and standing dead (woody and herbaceous). I also measured plant species richness and abundance, as well as estimates of the age class structure of sagebrush. Sheep used 98% of the total available forage. One year following grazing, total phytomass decreased by 43% relative to pre-graze levels, due primarily to the reduction in biomass of ARTRWY. The CAG of ARTRWY decreased by 66%, while grasses increased by 43%, forbs increased 60%, and the number of species encountered in the grazed plots increased 42%. While caution should be exercised, considering the short time frame of my study, fall grazing by sheep supplemented with nutrients may be a useful way to enhance shrub age class structure and increase herbaceous species richness, dominance, and production in sagebrush steppe.

(133 pages)

ACKNOWLEDGMENTS

This research has been supported by a grant to Fred Provenza from the U.S. Department of Agriculture, IFSAS. This was also a contribution to Utah Agricultural Experiment Project 924. Both institutions support an effort known as BEHAVE.

The members of my committee, Dr. Neil E. West, Dr. Fred Provenza, and Dr. Ken Olson, have each been invaluable to the completion of this thesis by providing their assistance and support. I consider them not only to be my mentors, but also my friends. I offer many thanks to Ms. Susan Durham and Dr. Juan Villalba for their input and help on the statistical analysis of the data. Jocelyn Haskell, a fellow graduate student, was a great help in the data collection and field work.

Thanks to everybody at Deseret Land & Livestock! Firstly for allowing us to conduct this research on their land and secondly for the sincere interest they have shown, and continue to show, in research projects such as this that give us new insights into land management. Projects such as this would not get very far without progressive people like Bill Hopkin and Rick Danvir. My interactions with Deseret have extended beyond the scope of this research and I will be forever grateful for my associations with them.

Members of the BEHAVE consortium, as well as the other graduate students I associated with on a daily basis, were always a great source of knowledge, experience, and support for me.

I am grateful to my family for raising me in an environment where I grew to love the outdoors and wide-open spaces and for teaching me the importance of learning.

Most of all, my most sincere and heartfelt thanks go to my wife, LaBretta, my daughters Kaylee and Corinne, and my two sons Noah and Payton. While I have been engaged in this endeavor, they have often gone without a husband and dad. There truly are no words that accurately reflect my gratitude for them. I can never fully repay their sacrifice and support other than to say, “Bretta, kids, I love you!”

I have been blessed to be around great people doing great things. I will forever treasure the experiences, associations, and friendships that I have gained from being involved with this project. Thank you all so very much.

Ryan D. Woodland

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Sagebrush steppe is a type of rangeland with roughly equivalent dominance by sagebrush (woody *Artemisia* spp.) and herbaceous species (bunchgrasses and forbs) when the land is free from human disturbance (West 1983, 1989). Thus, sagebrush steppe is a naturally occurring intermediate system between grassland and desert shrubland.

Distribution

Sagebrush steppe occurs primarily in the northern portion of the Intermountain Region and at one time occupied more area than any other semidesert vegetation type in North America (West and Young 2000). It is still considered the largest vegetation type in the Western United States, covering approximately 60 million ha (Wambolt and Hoffman 2001).

Climate

The climate of sagebrush steppe is classified as semiarid, temperate and continental (West 1983) such that this vegetation type is found in areas where the winters are cold and summers are hot and dry with extreme temperatures ranging from -46°C in the winter to 39°C in the summer. The mean of the warmest month is 20.4°C and the mean for the coldest month is -2°C with an overall mean temperature of 7.8°C (West 1983). Most precipitation occurs during winter in the form of snow (Knight 1994), with a lesser amount from rain in early spring and late fall. The average annual precipitation for this vegetation type is 246 mm (West 1983).

Soils

Most soils in the sagebrush steppe are Mollisols or Aridisols (Knight 1994), with depths from very shallow (less than 1m) to quite deep. These soils often vary from deep deposits of loess and alluvium to fairly shallow profiles along ridgetops; they are classified taxonomically from Ustolls and Xerolls to Orthids and Argids (West 1983). The soils throughout sagebrush steppe have a strong influence on what vegetation is found, its productivity and capacity for renewal following disturbance.

Vegetation

Due to its wide accessibility, I am using the taxonomic nomenclature from the USDA Plants Database (USDA-NRCS 2003). However, I used Shaw (1993) occasionally to identify plants throughout the study. The woody shrubs, particularly big sagebrush (*Artemisia tridentata*) and its various subspecies, dominate the shrub component in sagebrush steppe. Other species of *Artemisia* include Black sagebrush (*A. nova*), Low sagebrush (*A. arbuscula*), and Three-tip sagebrush (*A. tripartita*). Other shrubs associated with this vegetation type are Rabbitbrush (*Chrysothamnus* spp.), Antelope bitterbrush (*Purshia tridentata*), Horsebrushes (*Tetradymia* spp.), Winterfat (*Krascheninnikovia lanata*), and Mormon tea (*Ephedra* spp.). These shrubs typically share dominance with an herbaceous understory often consisting of grasses such as Western wheatgrass (*Pascopyrum smithii*), Bluebunch wheatgrass (*Pseudoroegneria spicata*), Bottlebrush squireltail (*Elymus elymoides*), Indian ricegrass (*Stipa hymenoides*), Junegrass (*Koeleria macrantha*), Needle-and-Thread grass (*Stipa comata*), Sandberg's bluegrass (*Poa secunda*), and Basin wildrye (*Leymus cinereus*).

Though perennial forbs are not as abundant, they are an important part of this system. Commonly occurring forbs include Scarlet Globemallow (*Sphaeralcea coccinea*), Arrowleaf balsamroot (*Balsamorhiza sagittata*), Western yarrow (*Achillea millefolium*), Low pussytoes (*Antennaria dimorpha*), Locoweeds (*Astragalus* spp.), Sego Lilies (*Calochortus* spp.), Hawksbeards (*Crepis* spp.), Larkspurs (*Delphinium* spp.), Daisies (*Erigeron* spp.), Buckwheats (*Eriogonum* spp.), Lupines (*Lupinus* spp.), Biscuitroot (*Lomatium* spp.), Foxgloves (*Penstemon* spp.), Phloxes (*Phlox* spp.), Groundsels (*Senecio* spp.), Violets (*Viola* spp.), Mulesear (*Wyethia amplexicaulis*) and Deathcamases (*Zigadenus* spp.) (Blaisdell et al. 1982, Knight 1994, Holechek et al. 2001).

Sagebrush Steppe Plant Growth Forms and Autecology

When looking at the abundance and richness of the species in sagebrush steppe vegetation, it is crucial to understand the autecology of the various plants. Sagebrush has several adaptations that enable it to successfully compete with herbs. A deep taproot enables sagebrush to use deep soil water, originating from snowmelt, some of which has percolated past the reach of the fibrous roots of the grasses and forbs. Sagebrush also has a network of fine fibrous roots near the soil surface, which allow it to take advantage of early spring, summer and fall rains and compete with the herbs for soil moisture and nutrients.

The dimorphic leaf structure of sagebrush is also an advantage (Miller and Shultz 1987). Sagebrush has both evergreen, persistent leaves that remain on the plant year round and ephemeral leaves that grow each spring and drop off as soil water availability decreases during the summer, allowing the plant to more efficiently use limited soil moisture. These “extra” leaves help sagebrush maximize leaf area for photosynthesis early in the growing season, thus taking advantage of spring moisture for growth (Miller et al. 1994). Sagebrush has the ability to photosynthesize at very low temperatures and has been noted to do so even when leaf temperatures are at or near 0°C (Caldwell 1979). This is important because these low temperatures typically occur when grass and forb species are either dormant or under snow. The bulk of sagebrush’s growth, however, occurs in the summer, with flowering and fruit dispersal in the fall.

The structure of sagebrush is also an advantage, as it is larger and taller than herbaceous competitors. As a result, snow (Frischknect and Harris 1973) and sediment often accumulate near the plant as wind blows across the landscape. This accumulation of snow and sediment benefits both sagebrush and herbaceous species.

Finally, the chemical makeup of sagebrush is also advantageous. Sagebrush contains many secondary metabolites that typically make it less palatable to large herbivores than the herbaceous species, especially during spring, summer, and early fall. As a result, it is grazed less heavily by domestic livestock, particularly when they are given an opportunity to exercise high selectivity regarding their diets. I will discuss this particular characteristic of sagebrush in further detail later in the thesis.

Disturbance

In the absence of the herbivory of the Pleistocene megafauna, which heavily used sagebrush steppe (Burkhardt 1996), fire has probably been the most prevalent natural disturbance, excluding grazing by domestic livestock, in these systems over the last 10,000 to 12,000 years. During pre-settlement times, fire return intervals were between 12-110 years or longer, depending on the site (Miller and Eddleman 2001, BLM 2002).

Most species of sagebrush do not sprout from roots, so they are highly susceptible to fire. Perennial grasses and forbs, however, are normally able to sprout from roots, thus gaining a temporary advantage over the shrubs following a fire. In essence, these fires reset the successional clock by creating a mosaic of old, young and middle aged sagebrush plants across a landscape. This mosaic prevented the dominance of old, large shrubs, allowing the co-dominance of both the herbaceous and shrubby species, and providing a better mix of habitat for the total fauna (West 1996). These fires were often caused by lightening; however, Native Americans also actively burned areas to attract wildlife for future hunting opportunities among other things (Pyne 1982).

As Europeans began to settle these areas, fire was viewed as a threat to their livelihood and they began aggressive fire suppression that has prevailed to the present. We have only recently realized the vital roles of fire in these systems (Miller and Eddleman 2001). In the absence of natural disturbances by fire and megafauna herbivory, sagebrush has a competitive advantage, often to the detriment of rest of the plant community.

Land Use

The sagebrush steppe has had a varied history of land use (Young et al. 1979, Young 1994, BLM 2002). Native Americans used these lands for hunting and gathering food prior to the arrival of European settlers, except where horses were reintroduced. In these instances, horses allowed the Native Americans to range further to more productive lands to meet their needs. When settlers began to arrive, the areas with the highest potential for crop production were settled first, leaving the rest unused for a time. Soon the settlers discovered these lands were very different from those they farmed in the

Eastern U.S. or Europe in as much as scant rainfall supports very little crop production without flood irrigation. Settlers used un-irrigated uplands for grazing horses and cattle initially and later for sheep as well. As food and fiber production were the main thrust in agriculture during the 1800's and the first half of the 1900's, much of the science involved with these systems focused largely on increasing forage production (Morris 1931, Pickford 1932, Mueggler 1950, Miller 1957, Laycock 1961).

After World War II, there was a surge in land management to eradicate sagebrush in an attempt to establish grasslands, which would favor cattle that were replacing sheep as the predominant domestic grazer in sagebrush steppe. Attempts to eradicate sagebrush, through the use of fire, chemical, or mechanical means, were common from the mid 1940's to the 1970's. In its place people planted easily established, productive forages such as Crested Wheatgrass (*Agropyron cristatum*).

Sprinkler irrigation and more powerful pumps allowed more rolling sagebrush plains to be subjected to intensive agriculture since about 1970. Rangeland livestock production was then shifted to steeper, rockier, higher elevation locales. Broader environmental concerns have emerged from the 1970's onward as people began to recognize the part these systems play in issues such as water quality, carbon sequestration, soil stabilization, and wildlife habitat. In recent years, much attention has been given to the value of these systems to wildlife. Mule deer (*Odocoileus hemionus*), Pronghorn (*Antilocarpus americana*), Elk (*Cervus elaphus*), and Sage grouse (*Centrocercus urophasianus*), as well as numerous non-game animals, all use sagebrush steppe at different times of the year (Welch 2005). Interventions focused on livestock now have to consider potential impacts on wildlife, especially on publicly managed lands.

Rationale for Conducting This Research

As stated earlier, sagebrush steppe was widely used for the grazing of domestic livestock and various species of wildlife including sage grouse, mule deer, pronghorn and elk depend heavily on these lands during certain parts of the year. Prior to the Taylor Grazing Act of 1934, livestock grazing on the publicly-owned lands was unregulated and was open to all on a first come, first served basis. The unregulated grazing, along with low levels of precipitation, led to the eventual overstocking of these ranges which in turn resulted in severe overgrazing and deterioration in condition (Clapp 1936, McArdle et al. 1936). The combination of lack of fire, grazing practices and climatic conditions puts these systems in a state of flux that can potentially have 1 of 2 outcomes. Lack of fire and heavy grazing during spring results in dense stands of sagebrush with a depleted understory, and if conditions are favorable, a shift to a system dominated by annuals with sagebrush present mainly as seedlings (Laycock 1991). With a change in grazing practices, these systems hold the potential, often with the assistance of some human-directed disturbance, to return to open stands of sagebrush with a productive perennial herbaceous understory (Laycock 1991). Many of these systems have followed the first path – dominance of dense sagebrush with little or no perennial understory – and humans have attempted to return them to a more productive state through various treatments.

Since the post World War II time of killing brush, we have learned it is not ecologically wise to remove the brush completely from these systems. One may then ask the question, "Why treat sagebrush at all, why not leave it alone?" In these systems, as individual sagebrush plants near senility, their production of current annual growth (hereafter referred to as "CAG"), seeds, flowers, and green foliage is much less than that of juvenile and adult plants. That makes them less valuable to both livestock and wildlife. The total cover of brush can dominate for decades (West et al. 1984).

As plants become decadent, a large portion of the resources is tied up in the woody tissues. Juvenile and adult plants have less woody tissue, leaving more resources available for use by other plant species, resulting in greater biodiversity within the plant community. More diverse communities are typically more productive, aesthetically pleasing, economically beneficial, more resistant to environmental perturbations, and more stable in relation to the ecosystem processes and services they render, all of which have an impact on human welfare (West 1993, Naeem et al. 1999).

Historically, natural disturbances such as wildfire and megafaunal herbivory prevented shrub dominance. Today, considering the absence, decline, or unpredictable nature of natural disturbance, the land manger faces the challenge of how to deal with these systems to meet modern management objectives; whether they be increasing forage production and biodiversity, improving wildlife habitat, protecting watershed values and soil resources, or increasing recreational opportunities.

Historically, land managers have used fire, chemicals, and mechanical treatments to reduce the abundance of sagebrush. Current and past literature is replete with examples evaluating the effectiveness of these methods (Morris 1931, Blaisdell and Mueggler 1956, Britton and Ralphs 1979, Evans et al. 1979, Parker 1979, Blaisdell et al. 1982, Sturges 1986, Johnson et al. 1996, Aoude 2002, BLM 2002, Olson and Whitson 2002, West and Yorks 2002, Wirth and Pyke 2003). However, for any management option to be sustainable, it must be 1) economically viable, 2) ecologically sound, and 3) socially acceptable. While the aforementioned methods are generally effective in controlling sagebrush in the short-term, none of them meet all three criteria. Moreover, with growing concerns over human-induced climate change and ever increasing costs of fossil fuels, the use of fire, chemical and mechanical treatments is likely to decrease dramatically in the coming decades.

Fire, if timed correctly, is an extremely effective and relatively inexpensive way to reduce sagebrush, and though it is generally innocuous to grasses and forbs, it is not without fault. Fire can be unpredictable and difficult to control, making it onerous to achieve the desired level of treatment with the added risk of not being able to contain it in the desired treatment area. There are also increasing concerns with air quality, especially when burning near large human populations.

Chemicals such as 2,4-D (2,4-dichlorophenoxyacetic acid) and tebuthiuron are also very effective at reducing sagebrush, but they can have negative impacts on herbaceous species. Chemicals are somewhat more costly than burning, but they are easier to control. One of the most negative aspects of chemical application is that of public perception (BLM 2002).

Following World War II, inexpensive fuel and military surplus heavy machinery became more readily available on a broad scale. This made the use of mechanical treatments feasible. Federal programs geared to enhancing red meat production also underwrote the costs. Some of the mechanical treatments applied to sagebrush steppe in the past include disking, chaining, roller chopping, Dixie harrow, and the more recent use of the Lawson™ pasture aerator. While mechanical treatments can be precise, controlled, and effective (Summers 2005) they are also very expensive. In fact, when comparing fire, chemicals, and mechanical treatment, Aoude (2002) found that mechanical treatments were the most costly. Along with the cost, disturbance of archeological values and aesthetics must be considerations when dealing with public land, which adds additional costs. While mechanical treatments can be effective, their visual appearance is a concern to many people.

Managers need options. By exploring the use of biological agents, sheep in this case, we hope to add another option to the manager's "tool box" for rejuvenating sagebrush steppe. From past research, we feel that sheep show great potential for controlling sagebrush (Mueggler 1950, Laycock 1967, Wright 1970, Frischknecht 1979, Bork et al. 1998). While our experiment does not explore the economics of sheep grazing, we feel they may play a surrogate role for natural disturbance, achieving similar ecological results while potentially being more socially and economically acceptable than other alternatives in many contexts. However, with this approach comes a unique challenge, the generally unpalatable nature of sagebrush.

Plant-herbivore Interactions

Many plants produce what are known as secondary metabolites. These chemical compounds are not used to meet growth requirements. Once viewed as waste products of plant metabolism (Provenza et al. 2003b), we now know they play a vital role in a plant's ability to defend itself against herbivory and decay, thus increasing its chance of survival.

When we refer to chemical defense systems in plants, we often associate them with poisonous plants that, if consumed, can cause extreme sickness or death, such as cicutoxin, the toxic compound in Water hemlock (*Cicuta* spp.) (Panter et al. 1996). However, many other compounds present in plants in the sagebrush steppe, such as the terpenes, oxalates and tannins found in sagebrush and other shrubs, while dramatically less lethal, can limit intake by herbivores (Dziba 2006). This in turn encourages the consumption of other plants on the landscape and can potentially lead to a high degree of selectivity in an animal's diet. Plants that possess these compounds have a higher likelihood of survival and hence they too must be considered part of chemical defense.

When an herbivore eats a plant, it receives postingestive feedback, either positive or negative, from that plant. If the feedback is positive, the herbivore is likely to eat the plant again; if the feedback is negative, the herbivore is likely to avoid that plant, or eat it in limited quantities. It is through this process that herbivores either develop preferences or aversions for certain foods (Provenza 1995). It is also through these postingestive feedback loops that herbivores are able to self-regulate their intake and thus avoid being lethally poisoned by toxic compounds (Provenza et al. 2003a). It is advantageous for a plant to contain these secondary metabolites in some concentration in order to avoid being consumed at levels beyond the point of recovery. If herbivores are allowed to be highly selective and avoid the less palatable species, there is potential for landscapes to eventually be depleted of the palatable species and dominated by the less palatable, and often highly defended, species such as sagebrush. People do not realize animals learn foraging behaviors. Thus, Provenza (2003) suggests managers have inadvertently trained animals to forage selectively by allowing them to "eat the best and leave the rest," rather than by teaching them to "mix the best with the rest." There are, however, many management strategies that can be used to "get around" the chemical defenses in plants (Provenza et al. 2003a,b), including grazing management and supplements.

In the case of sagebrush, we are dealing with a suite of terpenes that animals must excrete in urine. This process requires substrate (protein) and fuel (energy), which are diverted from maintenance and growth (Provenza et al. 2003a). By supplying extra protein and energy in the form of supplements, there is the potential to give animals the tools required to metabolize terpenes without depriving them of valuable resources (Villalba et al. 2002). Supplements also increase use of sagebrush by sheep and goats (Villalba et al. 2002). While this is admittedly a simplified explanation, it gives basis for some of the methods we used for this experiment.

Objectives

This study had four objectives. The first objective was to determine if grazing by sheep would increase plant species richness by reducing the abundance of Wyoming Big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) (hereafter referred to as ARTRWY). The second objective was to determine if grazing by sheep would increase the relative abundance of perennial herbaceous plants, also by reducing the abundance of ARTRWY. The key words in these first two objectives (richness and abundance) are encapsulated in the often misused term "biodiversity" (West 1993). The third objective was to determine if grazing by sheep would alter the age class structure of ARTRWY. With the decrease of natural disturbances, such as fire, these communities of big sagebrush often have become old, even-aged, monotypic stands dominated by brush, resulting in the decline of perennial herbaceous species found in the understory due to shading, water competition and nutrient sequestration. Part of this third objective was to determine if grazing by sheep would create a mosaic in the age class structure of the ARTRWY that would hopefully reestablish the co-dominance of shrubs with herbaceous species. The fourth objective was to examine the initial indications of resilience of ARTRWY and herbaceous plants following heavy fall utilization by sheep grazing.

My hypothesis was that by reducing the abundance of ARTRWY, through fall sheep grazing, species richness and abundance of desirable perennial herbaceous plants would increase while creating a desired mosaic in the age class structure of the ARTRWY.

Previous treatments of this nature, such as Bork et al. (1998), Laycock (1967), Wright (1970), and Mueggler (1950), involved *A. tripartita*. However, it is important for us to observe the response of the most widespread dominant *Artemisia* taxon in sagebrush steppe, ARTRWY, by exposing it to similar treatments. The treatments took place in the fall, at the conclusion of the herbaceous plant growing season so the herbs would escape negative impacts. I observed the responses of plants to grazing by sampling during the month of July, following the grazing during the previous October. July was a good time to observe the plants as the majority of plant growth in sagebrush steppe takes place between May and June then begins to decline as temperatures rise and soil moisture is depleted during mid to late summer. While working towards these objectives, we hoped to answer four questions: What is the effect of fall grazing by sheep supplemented with energy and protein on 1) forage production, 2) plant species richness, 3) plant species abundance, and 4) the age class structure of ARTRWY?

METHODS AND MATERIALS

Description of the Study Area

This research was conducted during 2003 and 2004 on Deseret Land and Livestock (DLL), a privately owned and operated ranch located in Rich County, northern Utah. Most of the eastern half of this ranch is occupied by sagebrush steppe, an ecosystem type whose southern border occurs here (West 1983).

DLL's land use history is typical of many other areas in sagebrush steppe (Washington-Allen 2003). The earliest inhabitants of the area were most likely the Shoshone and Bannock peoples (Shobans) dating back to pre-Columbian times. They were a hunting/gathering society and probably used prescribed burning to help meet their needs. The primary herbivores during Shoban occupancy were horses, pronghorn, deer and bison. The Shobans continued to be the primary land users up until the 1860's when Mormon settlers began to arrive.

Mormon settlers arrived in the nearby Salt Lake Valley in 1847. Their settlements slowly expanded, and in 1891 a group of prominent Mormon pioneer families formed what is now considered DLL to be used primarily as summer range for sheep. Although DLL has changed owners and managers several times from 1891 to the present (Washington-Allen 2003), it has been used primarily for raising livestock. Sheep were the primary grazers for about the first 100 years of ranching, with numbers reaching a peak of approximately 65,000 in the early to mid 1900's (B. Hopkin pers. comm., Deseret Land and Livestock 2004). Sheep remained the dominant grazer on DLL until nearly 1970 when the emphasis switched to cattle (Washington-Allen 2003, Deseret Land and Livestock 2004). DLL now uses both wild and domestic ungulates to make a profit while striving to maintain or enhance their resources. Deer and pronghorn trespass permits were first sold as early as the 1960's. Elk and moose have been added to the harvestable wildlife in recent decades.

My study area is located just above the Barney Pond in the West Stacey Pasture (41°20'31" N. Latitude, 111°6'10" W. Longitude) at approximately 2042m elevation. The soils are designated as the LBC map unit with a typical pedon of the Lariat fine sandy loam series (NRCS 1982) and slopes of 2-15 % (NRCS 1994). The representative soil of this series is moderately deep, well drained coarse-loamy, mixed frigid Xerollic Calciorthid, found on the uplands and foothills and derived primarily from colluvium and alluvium of mixed sedimentary material. The mean annual precipitation ranges from 203 to 304 mm with a mean annual air temperature of 5 to 9.4°C and an average frost-free period of 55 to 80 days (NRCS 1994).

My study took place on the "Semidesert Loam" ecological site (NRCS 1994). The ecological site guide (NRCS 1994) suggests that the potential plant community, by air-dry weight of current annual growth, is composed of approximately 50% perennial grasses, 10% forbs, and 40% shrubs. The major perennial grasses include Indian ricegrass (*Stipa hymenoides*), Bottlebrush squirreltail (*Elymus elemoides*), Needle-and-Thread grass (*Stipa comata*), Western wheatgrass (*Pascopyrum smithii*), Bluebunch wheatgrass (*Pseudoroegneria spicata*), and Sandberg's bluegrass (*Poa secunda*). The major forbs species include Scarlet Globemallow, Wooly milkvetch (*Astragalus mollissimus*), Sego lily (*Calochortus nuttallii*), Mountain pepperweed (*Lepidium montanum*), Longleaf phlox (*Phlox longifolia*), Western tansymustard (*Descurania pinnata*), and Arrowleaf balsamroot (*Balsamorhiza sagittata*). Shrubs in the potential natural vegetation include (in approximate order of abundance) ARTRWY, Low rabbitbrush (*Chrysothamnus viscidiflorus*), Fourwing saltbush (*Atriplex canescens*), Winterfat (*Kraschennikovia lanata*), Central Plains pricklypear (*Opuntia polyacantha*), and Horsebrush (*Tetradymia canescens*) (NRCS 1982, 1994). These rankings reflect compositions that may have been present during pre-settlement times and not necessarily the current status of the site.

The potential forage production for this ecological site ranges from approximately 567 $kg \cdot ha^{-1}$ (dry weight) in unfavorable years to 1,021 $kg \cdot ha^{-1}$ in favorable years, with an average of approximately 765 $kg \cdot ha^{-1}$ (NRCS 1994). As is typical of many other sites in sagebrush steppe (West 1983), the majority of plant growth takes place between the months of March and June. There are occasional late fall "green ups" but they are the exception (NRCS 1994). The site guide further suggests the potential canopy cover of this site consists of grasses (30%), perennial forbs (5%), and shrubs (25%), and bare ground (40%). Observations at the site at the beginning of the study, however, showed shrubs occupied more than the potential 25%, while grasses were far below their respective potentials.

Experimental Design

This experiment was initially set up in 2001 as a randomized complete block design with three replicates; each 80m x 120m replicate was split into 2, 40m x 120m plots (Fig. 1). Insignificant impacts were observed on the vegetation during the first grazing trial (Staggs 2006). Thus in 2003 we "split blocked" these plots into four, 40m x 60m plots per block to accommodate my study (Fig. 2). The 2 treatments -- control (no

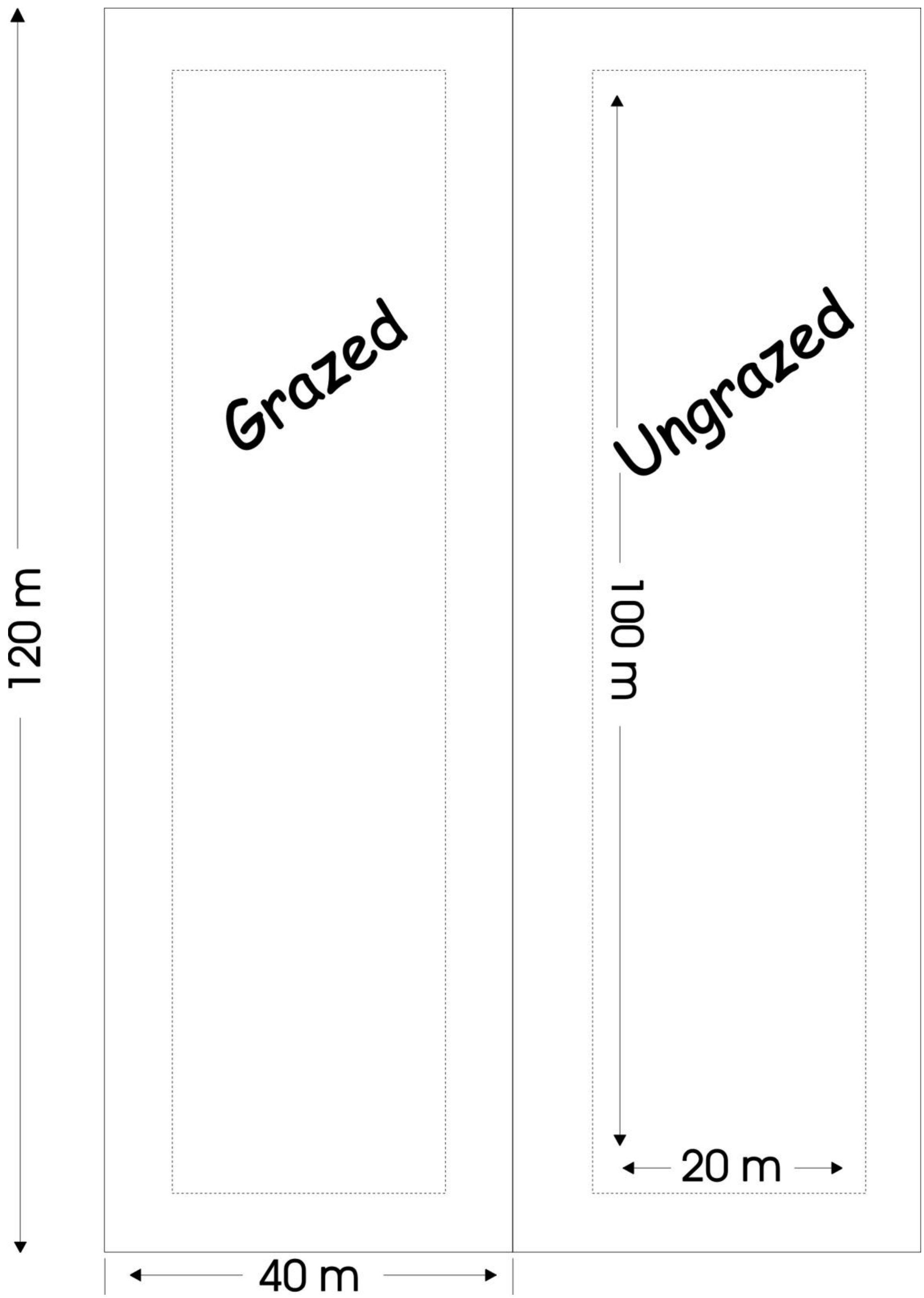


Figure 1 – Plot layout in 2001.

sheep grazing) and supplemented fall sheep grazing in 2001 & 2003 -- were replicated in each of the 3 blocks.

For this experiment, we used the 3 exclosures constructed in 2001. The exterior fences of the exclosures are approximately 4m tall. The bottom 1.3m is fenced with sheep netting and chicken wire, while the remaining top 2.7m is strictly barbed wire (10 strands). These perimeter fences were constructed with the goal of excluding both large (cattle, elk, deer, and pronghorn) and small (rabbits) vertebrate herbivores. The interior fences separating the plots within each block are fenced with sheep netting and are approximately 1.3m tall.

In the fall of 2001, forty dry ewes grazed each 40m x 120m treatment area ($120\,\mathrm{m}^2 \cdot \mathrm{ewe}^{-1}$) for 15 days in each of the 3 replicates (Figs. 1 & 3); a total of 120 ewes grazed the three replicates. Using the following equation, I calculated 1,250 sheep-days $\cdot\,\mathrm{ha}^{-1}$ were applied in each of the 3 replications in 2001:

$$120m \times 40m = 4{,}800m^2 \Rightarrow \frac{4{,}800m^2}{10{,}000m^2 \cdot ha^{-1}} = 0.48\,ha \Rightarrow \frac{40hd}{0.48ha} = \frac{83.3hd}{ha} \times 15\,days\,.$$

Assuming that 5 sheep are equal to 1 animal unit, I calculated that an equivalent of 8.3 AUMs $\cdot$ ha^{-1} (3.4 AUMs $\cdot$ acre^{-1}) were used in the each of the 3 replications in 2001.

In the fall of 2003, I randomly assigned one of the halves in each of the previously grazed plots to be re-grazed with 40 dry ewes ($60\,\mathrm{m}^2 \cdot \mathrm{ewe}^{-1}$) (Figs. 2 & 3) grazing simultaneously in each plot, for a total of 120 ewes over the 3 replications. However, for my experiment, the grazing period was shortened to approximately 10 days.

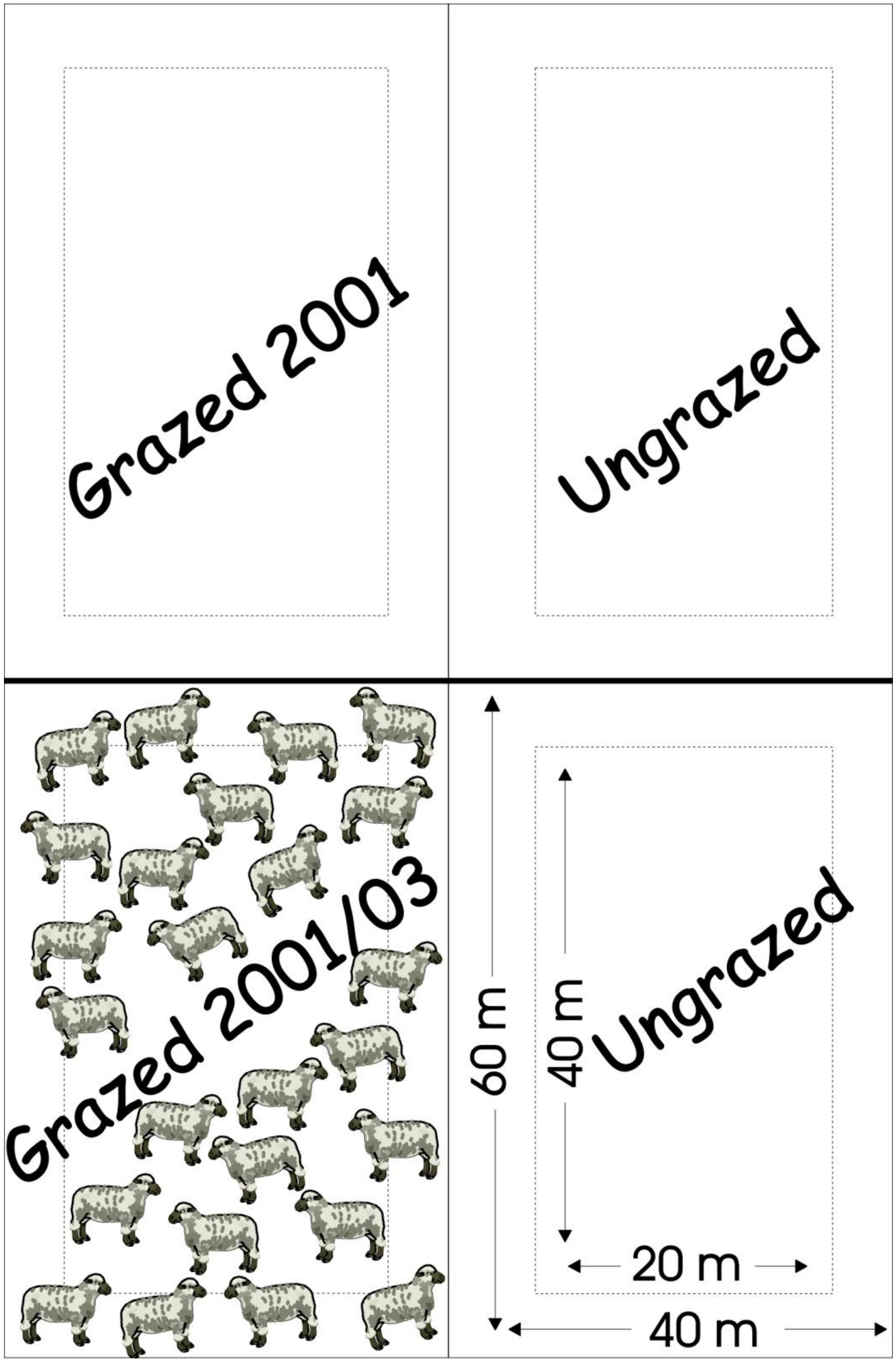


Figure 2 – Plot layout in 2003.

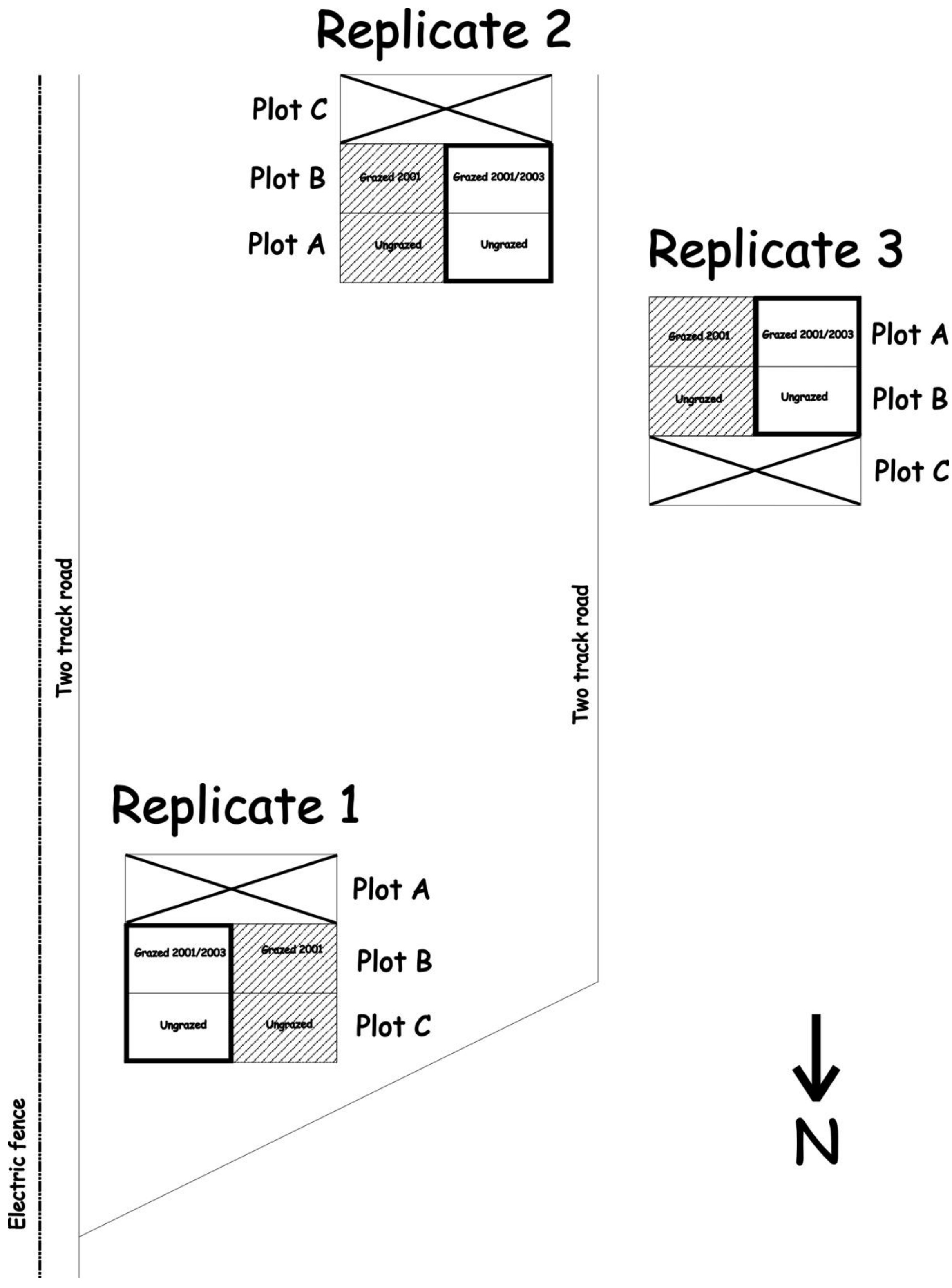


Figure 3 – Layout of study area, approximately 41º20'31" N. Latitude, 111º6'10" W. Longitude.

Using the following equation, I calculated that a total of 1,666 sheep-days $\cdot\,\mathrm{ha}^{-1}$ were applied in each of the 3 replications during the 2003 study:

$$60m \times 40m = 2400m^2 \Rightarrow \frac{2{,}400m^2}{10{,}000m^2 \cdot ha^{-1}} = 0.24\,ha \Rightarrow \frac{40hd}{0.24ha} = \frac{166.6hd}{ha} \times 10\,days.$$

Assuming that 5 sheep are equal to 1 animal unit, I calculated that an equivalent of 10.8 AUMs $\cdot$ ha^{-1} (4.4 AUMs $\cdot$ acre^{-1}) were used in each of the three replications during my 2003 study.

For my study, the treatment area is defined as the entire 40m x 60 plot and the study area is defined as the centrally positioned 20m x 40m area within the plot (Fig. 2). The sheep had unrestricted use of the entire treatment area, but plant measurements were taken only within the study area. This approach created a buffer zone approximately 10m wide around the inside perimeter of each treatment to reduce the likely confoundments from influences such as sheep trails and snow accumulation near the fencelines.

The sheep used in this experiment were dry ewes, ranging in weight from 26 to 44kg, borrowed from a local producer who leases grazing rights from DLL. On October 7, 2003, 40 sheep were placed in each of the plots (120 sheep total) and left there for 10 days. Each morning, I fed each group of sheep approximately 22.7kg of supplement for approximately 30 minutes beginning at 0730 hrs. After the 30-minute supplementation period, the sheep were moved out of the holding pen into the plot where they grazed until approximately 1700 hrs, at which time they were brought back into the holding pen for the night where they received an additional 11.4kg of supplement. Following these guidelines, each ewe received an average of $0.85\,\mathrm{kg}\cdot\mathrm{day}^{-1}$ of the supplement. The supplement used was a custom mix of 50% beet pulp, 30% corn, 5% soybean meal, and

15% alfalfa. This mix contained 3.41 $\text{Mcal} \cdot \text{kg}^{-1}$ and 12% crude protein (J. Villalba, pers. comm.). Using data from the first and third samplings, I calculated the sheep diets consisted of approximately 39% onsite-forages and 61% supplement.

The rationale behind this supplementation schedule has both physiological and behavioral underpinnings. I anticipated the sheep would completely use the herbaceous understory within the first 3 to 4 days, which they did, after which their diets consisted almost completely of sagebrush. Supplementing them in the morning put them on a plain of nutrition needed to physiologically cope with the terpenes in sagebrush, which can potentially limit intake. Supplementing them in the afternoon gave sheep a nutritious "break" from eating sagebrush during the day and a chance to recover throughout the night (Provenza et al., 2003a). Behaviorally, supplementing the sheep in the afternoon gave them an incentive to return to the holding pen for the night – making them easier to handle. After the sheep ate the majority of the herbaceous understory, they came by themselves into the pens when supplemented at night. They were kept overnight in holding pens to avoid creating bedding areas within the treatment area. They had free access to water in the paddocks during the day, but no access to the paddocks at night.

A block of iodized salt was also placed in each of the replicates for the sheep to access during the day. Trace minerals, such as salt, assist in the animal's ability to utilize energy and carbohydrates from food sources (Ensminger et al. 1990).

Fall was chosen as the time to run the grazing portion of the experiment, rather than other times of the year, due to the growth habits of the dominant plants. During the spring and early summer, the herbaceous understory is actively growing (NRCS 1994), thus heavy grazing at that point can be detrimental to those species and would favor grazing by sheep of herbs in preference to ARTRWY. Most of the perennial herbaceous species found in the understory are done growing by about July 1 (NRCS 1994). Some put on additional growth later in the fall, but this "regrowth" is usually minimal (Laycock 1961). By early fall, most of the herbaceous species in the understory are more or less dormant, thus the chances of causing irreparable harm to them by heavy grazing is greatly reduced. Fall clipping of Bluebunch wheatgrass resulted in the highest total production and the least damage, as measured by death losses (Stoddart 1946).

On the other hand, I wished to take advantage of fall grazing to reduce the abundance of ARTRWY. The concentration of terpenes in sagebrush, which potentially limit intake, declines during fall and winter (Kelsey et al. 1982). This decline, combined with the effects of supplementation, was expected to increase consumption of sagebrush by the sheep (Provenza et al. 2003a). Early work looking at the effects of grazing on sagebrush steppe (Mueggler 1950, Laycock 1967, Wright 1970) found that heavy utilization of Three-tip sagebrush in the fall reduced sagebrush yields more than spring and summer, without damaging the herbaceous understory. This in turn increased the production of the perennial herbs due to the decreased competition from the shrubs. Later work by Bork et al. (1998) concluded that these trends were enduring. Considering much of this earlier work was conducted in plant communities dominated by Three-tip sagebrush, it is important to know whether or not similar impacts can be made on the much more widespread ARTRWY by exposing it to comparable utilization.

Sampling

To measure the effects of the grazing treatments, total aboveground phytomass was sampled in 16 subplots randomly located within each treatment (grazed & ungrazed).

The current annual growth fraction can be viewed as a conservative proxy for net annual aboveground primary production (Andrew et al. 1987). All phytomass estimations were calculated on a $g \cdot m^{-2}$ basis utilizing estimates from 3 sample periods: pre-graze, post-graze, and 1 year after grazing. These periods will hereafter be referred to as first sampling/first sample period, second sampling/second sample period, and third sampling/third sample period. The vegetation was measured immediately before (first sampling) and after (second sampling) the sheep grazing in the fall of 2003 and then again in 2004 (third sampling) at the end of the peak growth period of the shrubs and herbs. Due to an early snowstorm in October 2003, the second sampling had to be divided into 2 parts, a portion (54%) of the data were collected immediately after the sheep left but the remainder were collected the following March, as soon as we had regained access to the study area. That 54% is broken down as follows: in the each of the grazed replicates (1B, 2A, and 3A) (Figure 3) all 16 subplots were sampled immediately after the sheep left in October 2003 while in each of the ungrazed replicates (1C, 2B, and 3B) 5 of the 16 subplots were sampled in the fall of 2003 and data from the remaining 11 subplots were collected the following March, as was previously mentioned.

I used circular, $16m^2$ (radius of 2.26m), subplots for the measurements due to their extensive use in measuring the vegetation in shrub-dominated communities and minimization of boundary error (Bonham 1989). The centers of our subplots were permanently marked previously with a piece of concrete reinforcement bar driven flush to the ground with a piece of PVC pipe, extending mostly aboveground, on the outside of the bar, for ease in relocating them. While measuring each subplot, the boundary was temporarily marked with 3 stakes connected by a 2.26m chain. One stake was driven in the center of the subplot while the other 2 stakes marked the 4 quadrants within the subplot (Fig. 4). A handheld compass was used to demarcate equal quadrant sizes of $4m^2$ each. The NE quadrant was established as number one, the SE quadrant number two, the SW quadrant number three, and the NW quadrant was designated as number 4.

For this study, aboveground phytomass is defined as all plant material found on or projecting above the soil surface within the outside vertical boundaries of the plots. This includes all live growing plants, all standing dead plant material and all plant litter. For my measurements, I divided phytomass into the following categories: shrubs by species (the foliage and woody portions of *Artemisia* were measured separately while those of all other shrubs were not), herbs by species (grasses and forbs), standing dead (woody, grass and forb) and litter (woody and herbaceous). Data were not collected for the woody portions of other shrubs (Low rabbitbrush, horsebrush, and winterfat) as I expected sheep would eat all aboveground phytomass, including the chlorenchyma-bearing stems, associated with those shrub and half-shrub species. For practical reasons, data on herbs were only recorded in one of the four, $4m^2$ quadrants (randomly selected) within each subplot. However, data for the other categories were recorded for all four quadrants.
As destructive sampling (clipping and weighing) was not feasible in this experiment, which involved recording phytomass at multiple times in the same locations, I used the reference unit method (Andrew et al. 1979, 1987). This method has been used in several studies on rangeland vegetation in this region (Kirmse and Norton 1985, Cabral and West

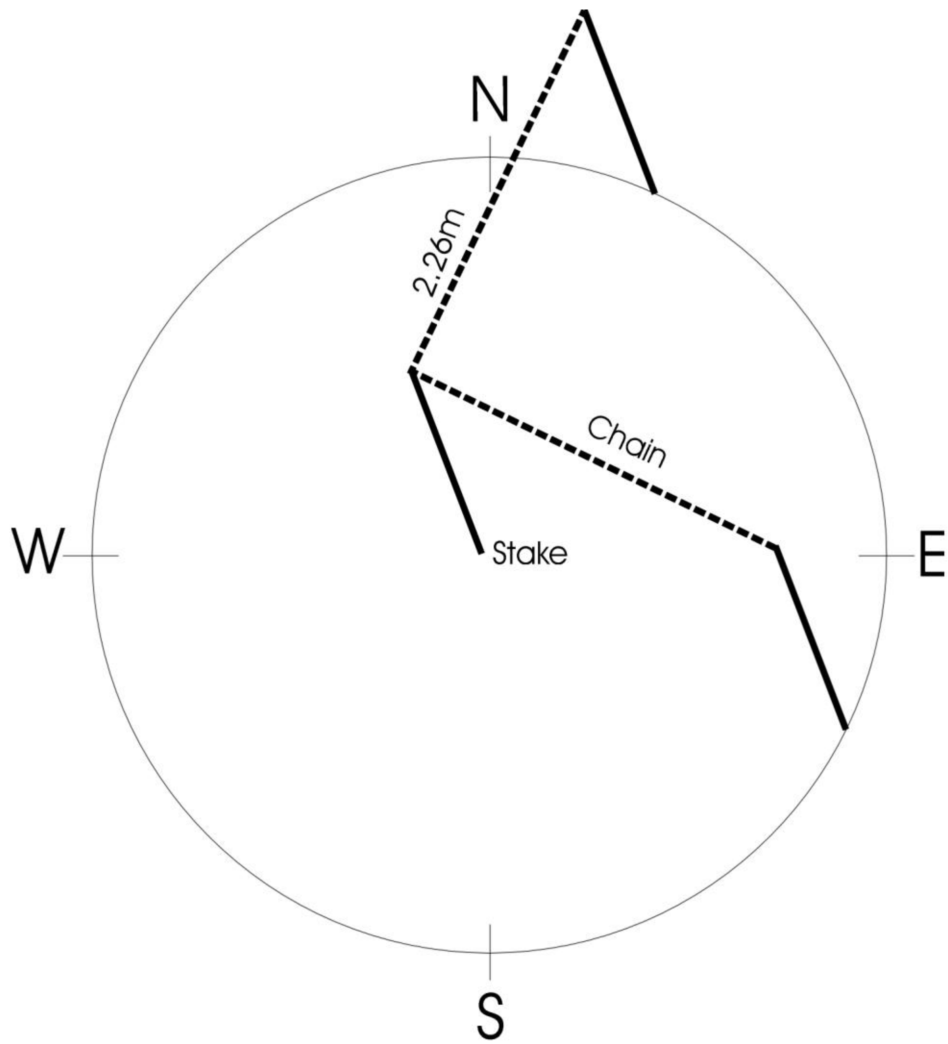


Figure 4 – Depiction of individual subplot.

1986, Carpenter and West 1987), and has produced statistically adequate results. To use this method, a representative sample of each category was harvested from outside the treatment area. This reference unit (RU) is ideally10%-20% of the mass of the average individual to be measured (Andrew et al. 1979). RU's were replaced as needed, due to wilting or mechanical damage. The RU was then visually compared to the phytomass occurring within each subplot and the multiples or fractions of the RU found therein were estimated and recorded. These steps were followed for all categories of phytomass aforementioned and individual species in the case of living plants.

The RU's were also compared against 5 other individual, "calibration units," (10 in the case of ARTRWY) of the appropriate category, which were also harvested from outside the study area. The reference and calibration units were oven dried at 80°C for 24 hrs. (Sharif and West 1968) at the end of the day of use and then weighed within 3 days. These results were then used to create linear regression models from which I derived a multiplier to estimate phytomass for each category. Use of this method allowed me to non-destructively estimate the relative contribution of each species and categories within some species to the total phytomass in each plot. These data also allowed me to estimate species richness and abundance. To minimize any effect the sampler might create by walking back and forth, a small, portable wooden scaffold was used for standing on while recording data from each subplot (Fig. 5).

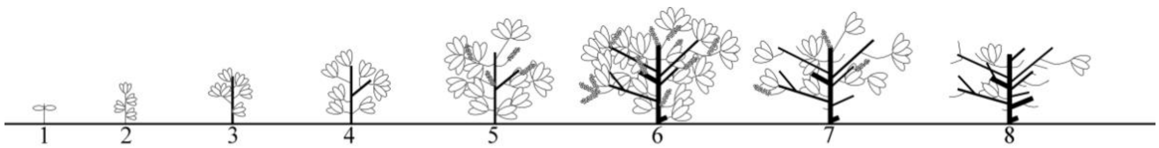
Since one of my objectives was to alter the age class structure of the ARTRWY it was necessary to measure the effect of grazing on this component of the vegetation. To do so, I first determined the age classes of the plants. Thus, I assigned one of the age

Figure 5 – Scaffolding and plot boundary marker.

classes developed for shrubs by Gatsuk et al. (1980) to each of the ARTRWY plants in the subplots. These classes are based on the developmental and reproductive stages of the individual shrubs (Fig. 6). The class designations range from 1 to 8, with 1 being the youngest plants having green cotyledons present, 5 to 6 are plants having the most green foliage and leader growth, and 8 being the most mature plants consisting mostly of dead, woody tissue with little or no green foliage. Gatsuk et al. (1980) further describe how to aggregate these states into 3, coarser categories, pre-reproductive (juvenile), reproductive (adult), and post-reproductive (senile).

Because net primary production in these semiarid systems is primarily water-driven (Noy-Meir 1973), I decided to collect on-site precipitation data over the water or crop year, which is defined as extending from September to June (Sneva and Britton 1983) prior to summer vegetation data collection. This time frame was used because precipitation received in July and August does not contribute significantly to the growth of cool season plants (Sneva and Britton 1983). I also collected precipitation data for July and August to assess the possible effect of any additional herbaceous plant growth at the beginning of the autumn pre-graze sampling.

My precipitation gauges were patterned after those used by Cook (1971). The gauges were bottom-capped cylinders constructed of galvanized sheet metal, standing approximately 76cm tall having an open top of 20cm diameter. I placed a gauge in the center of 2 of the replicates (1 in replicate 1, plot B and 1 in replicate 3, plot B; Fig. 3). Prior to the first measurement in September 2001, each gauge was “charged” with approximately 0.9 L of motor oil and approximately 0.9 L of antifreeze. The oil helped prevent evaporation of the water throughout the year because oil floats on the water. The



1- cotyledons still green
2- cotyledons dry, assimilating leaves present
3- presence of woody stem
4- appearance of persistent branches
5- presence of few reproductive stalks
6- many reproductive stalks, little or no dead material
7- few reproductive stalks with some dead material
8- most branches dead, little or no green foliage

Figure 6 – Age class designations for shrubs.

antifreeze mixes with the water in the precipitation received, preventing the precipitation from freezing, as well as melting the incoming snow, thus preventing the gauges from filling up and only collecting a portion of the precipitation.

After the gauges were charged, an initial gross weight was taken using a common dairy scale hung from a tripod. Subsequent weights were recorded twice a year, June and September. The net weights were then used to indirectly calculate how much precipitation was received at the study site during the winter/spring months and how much came in the summer/fall. Each fall, in September, when the precipitation data were collected, the gauges were emptied out and recharged with new oil and antifreeze.

Data Collection

To ease collection of data involving vegetation and to reduce transcription error, a Panasonic Toughbook CF-P1® handheld computer was used to collect all data. The data were transferred daily from the Toughbook onto a laptop computer and then hard copies printed to avoid the loss of data in the event of a computer malfunction.

Data Analysis

Precipitation. Following Cook (1971), we used the following equation to convert the weight (measured in pounds) of precipitation collected at each gauge into inches of precipitation received between each collection period:

$\frac{net\ weight\ (lbs)}{1.75} = inches\ of\ \ precipitation\ received$. The values for these calculations are in Table 1. We then converted these values to millimeters. Winter/spring precipitation was defined as the precipitation received from September through June and summer/fall precipitation was defined as the precipitation received between the months of July and August. The values for winter/spring and summer/fall precipitation were totaled for each plot to calculate the total precipitation for the water year at each gauge. The total values for the 2 replicates where the gauges were located were then averaged to calculate the mean total precipitation received at the study area for each water year. The percent of winter/spring precipitation was calculated by averaging the appropriate values for each water year and dividing by the mean total precipitation received that year. The percent of summer/fall precipitation was calculated by averaging the appropriate values for each water year and dividing by the mean total precipitation received that year.

Phytomass. The end of growing season mean total phytomass was calculated by finding the average of the total phytomass for each of the 3 replications. This was followed by calculating the mean total for each of the categories making up the total phytomass. Using mean values, I calculated the percent increase or decrease of total phytomass, and all contributing categories, across the three sample periods, with the following equation:

Table 1 - Precipitation at the study area. Primary units are in millimeters and inches are in parentheses.

Plot	1B	3B	1B	3B	1B	3B
Water Year	2001 - 2002		2002 - 2003		2003 - 2004	
Winter/Spring Precipitation	170.2 (6.7)	185.4 (7.3)	309.9 (12.2)	322.6 (12.7)	317.6 (12.5)	320.0 (12.6)
Summer/Fall Precipitation	33.0 (1.3)	33.0 (1.3)	55.9 (2.2)	55.9 (2.2)	33.0 (1.3)	38.1 (1.5)
Total Precipitation	203.2 (8.0)	218.4 (8.6)	365.8 (14.4)	378.5 (14.9)	350.6 (13.8)	358.1 (14.1)
Mean Precipitation	210.8 (8.3)		373.4 (14.7)		354.4 (14.0)	

$(-1)+\left(\dfrac{\textit{phytomass present at earlier sampling}\ (g \cdot m^{-2})}{\textit{phytomass present at later sampling}\ (g \cdot m^{-2})}\right) = \%\,\textit{increase or decrease}$. The values for these calculations are found in Tables 2, 3, and 4.

For the purposes of this study, "live" phytomass is defined as any apparently living herbaceous plant material, CAG of ARTRWY, and any green but woody material associated with ARTRWY or low sagebrush (*Artemisia arbuscula*) CAG. To calculate the percent live fraction of the total phytomass, I divided the mean total phytomass into the sums of the means for each category comprising live plant material. To calculate the percent fraction of the contributing categories to live phytomass, I divided the total mean for each category by the total mean of live phytomass. When phytomass amounts were $\leq 0.01\ \mathrm{g} \cdot \mathrm{m}^{-2}$, the term "trace" (indicated by "t" in the following tables) was used to denote the fact that there was a presence, although very small.

Figure 3 shows a layout of our study area. The plots that are "X'd out" are plots that were used for data collection during the 2001 study (Staggs 2006). The parts of the plots shaded by diagonal lines were also used in the 2001 study but will not be discussed

Table 2 - Total Phytomass estimates among treatments at the first sampling (pre-graze). Standard error values are in parentheses. Units are in $g \cdot m^{-2}$.

	Plot / Treatment	1B Grazed	2B Grazed	3A Grazed	Mean	1C Ungrazed	2A Ungrazed	3B Ungrazed	Mean
	Total Phytomass	1312.6 (67.05)	1062.9 (55.16)	1042.8 (55.66)	1139.4	1144.1 (61.58)	1214.6 (63.68)	1135.4 (40.85)	1164.7
Live plant material	*Artemisia tridentata* CAG	74.5 (6.54)	63.6 (3.78)	68.7 (5.35)	68.9	63.4 (3.79)	94.6 (7.80)	90.4 (6.41)	82.8
Live plant material	*Artemisia tridentata* Woody	464.6 (87.47)	271.1 (17.94)	265.1 (24.53)	333.6	411.4 (70.72)	403.5 (39.70)	351.3 (25.54)	388.7
Live plant material	Other Shrubs' CAG	14.9 (2.07)	7.2 (1.48)	6.2 (0.75)	9.4	10.0 (1.14)	4.5 (0.72)	5.7 (0.90)	6.7
Live plant material	Other Shrubs' Woody	0.0 (0.00)	0.3 (0.29)	0.0 (0.00)	0.1	0.0 (0.00)	0.0 (0.00)	0.3 (0.34)	0.1
Live plant material	Grasses	4.7 (0.58)	8.4 (1.04)	6.3 (0.72)	6.5	3.1 (0.47)	3.9 (0.47)	3.8 (0.55)	3.6
Live plant material	Forbs	8.1 (1.17)	5.1 (1.68)	9.2 (1.74)	7.5	17.3 (3.04)	8.2 (1.42)	14.5 (3.53)	13.3
Dead plant material	Woody Standing Dead	455.0 (63.21)	485.3 (35.10)	468.7 (35.96)	469.7	408.7 (50.83)	488.7 (43.88)	463.6 (43.20)	453.7
Dead plant material	Herbaceous Standing Dead	0.7 (0.10)	0.7 (0.11)	1.0 (0.15)	0.8	1.2 (0.14)	1.0 (0.17)	1.3 (0.20)	1.2
Dead plant material	Woody Litter	288.4 (36.40)	219.6 (24.08)	216.5 (23.44)	241.5	227.6 (25.41)	208.5 (23.23)	202.7 (26.02)	212.9
Dead plant material	Herbaceous Litter	1.7 (0.22)	1.5 (0.16)	1.1 (0.15)	1.5	1.3 (0.17)	1.8 (0.19)	1.7 (0.16)	1.6

Table 3 - Total Phytomass estimates among treatments at the second sampling (post-graze). Standard error values are in parentheses. Units are in $g \cdot m^{-2}$.

	Plot	1B	2B	3A		1C	2A	3B	
	Treatment	Grazed	Grazed	Grazed	Mean	Ungrazed	Ungrazed	Ungrazed	Mean
	Total Phytomass	778.2 (38.6)	871.7 (64.5)	911.4 (40.1)	853.7 (28.9)	1039.5 (53.8)	1231.3 (48.1)	1297.5 (61.2)	1189.4 (34.7)
Live plant material	*Artemisia tridentata* CAG	0.4 (0.1)	2.5 (1.0)	0.8 (0.2)	1.2 (0.4)	55.7 (4.3)	80.2 (5.3)	86.1 (5.6)	74.0 (3.4)
	Artemisia tridentata Woody	232.0 (20.5)	260.1 (17.2)	184.4 (10.8)	225.5 (10.5)	350.4 (23.2)	424.0 (22.9)	451.2 (23.1)	408.5 (14.4)
	Other Shrubs' CAG	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	4.3 (0.8)	1.4 (0.3)	2.9 (0.5)	2.9 (0.4)
	Other Shrubs' Woody	0.0 (0.0)	1.1 (0.8)	0.0 (0.0)	0.4 (0.3)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.1 (0.1)
	Grasses	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.2 (0.2)	1.6 (0.2)	1.3 (0.2)	1.4 (0.1)
	Forbs	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	7.7 (1.0)	2.9 (0.7)	4.6 (1.0)	5.1 (0.6)
Dead plant material	Woody Standing Dead	426.1 (29.2)	501.1 (44.8)	616.8 (31.4)	514.7 (23.2)	526.3 (33.0)	624.9 (38.0)	654.7 (43.3)	602.0 (23.8)
	Herbaceous Standing Dead	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.1 (0.01)	0.7 (0.1)	0.5 (0.1)	0.8 (0.1)	0.7 (0.1)
	Woody Litter	119.0 (11.5)	105.9 (9.4)	108.3 (9.7)	111.1 (5.8)	91.7 (18.5)	94.0 (13.5)	93.7 (10.9)	93.1 (8.3)
	Herbaceous Litter	0.7 (0.1)	0.9 (0.1)	0.9 (0.1)	0.8 (0.6)	1.4 (0.1)	1.7 (0.2)	1.9 (0.2)	1.7 (0.1)

Table 4 - Total Phytomass estimates among treatments at the third sampling (1 year following grazing). Standard error values are in parentheses. Units are in $g \cdot m^{-2}$.

	Plot	1B	2B	3A		1C	2A	3B	
	Treatment	Grazed	Grazed	Grazed	Mean	Ungrazed	Ungrazed	Ungrazed	Mean
	Total Phytomass	564.8 (29.6)	626.3 (30.9)	588.7 (32.1)	593.3 (17.9)	884.1 (23.4)	1003.7 (27.7)	978.3 (35.4)	955.3 (18.1)
Live plant material	*Artemisia tridentata* CAG	17.3 (2.1)	32.8 (2.6)	19.2 (2.5)	23.1 (1.7)	43.5 (2.6)	70.4 (4.0)	67.4 (2.1)	60.4 (2.4)
	Artemisia tridentata Woody	80.8 (13.8)	112.5 (9.0)	58.7 (8.9)	84.0 (6.9)	428.9 (22.2)	508.9 (29.8)	486.9 (24.7)	474.9 (15.4)
	Other Shrubs' CAG	15.2 (1.8)	8.0 (1.4)	9.1 (1.2)	10.7 (1.0)	8.9 (0.8)	3.3 (0.6)	5.8 (1.1)	6.0 (0.6)
	Other Shrubs' Woody	0.0 (0.0)	1.3 (0.7)	0.0 (0.0)	0.4 (0.2)	0.0 (0.0)	0.0 (0.0)	0.8 (0.8)	0.3 (0.3)
	Grasses	9.4 (1.3)	8.8 (0.7)	9.5 (1.4)	9.2 (0.7)	6.9 (0.6)	6.0 (0.9)	4.0 (0.5)	5.6 (0.4)
	Forbs	8.7 (1.3)	12.2 (1.5)	15.0 (2.4)	12.0 (1.1)	20.5 (3.3)	10.2 (1.4)	18.8 (3.2)	16.5 (1.7)
Dead plant material	Woody Standing Dead	321.6 (21.2)	356.9 (23.6)	374.4 (21.9)	351.0 (13.0)	291.9 (14.9)	312.8 (13.9)	306.0 (21.5)	303.6 (9.7)
	Herbaceous Standing Dead	0.2 (0.1)	0.0 (0.0)	0.0 (0.0)	0.1 (0.0)	1.4 (0.1)	1.3 (0.1)	1.3 (0.1)	1.4 (0.1)
	Woody Litter	110.5 (8.5)	92.7 (5.0)	102.1 (6.7)	101.8 (4.0)	79.4 (4.3)	87.6 (7.1)	84.2 (5.0)	83.7 (3.2)
	Herbaceous Litter	1.0 (0.2)	1.0 (0.1)	0.8 (0.1)	0.9 (0.1)	2.6 (0.2)	3.2 (0.3)	3.0 (0.3)	2.9 (0.2)

here. The parts of the plots that are bordered by a heavy black line are the plots where my grazing treatments were applied and where my samples were taken. These are the areas from which data were derived for the present study.

For the first sampling period, the two treatments were compared (grazed vs. ungrazed) against each other because, ideally, their vegetation should be similar prior to the application of the grazing treatments. For the second sampling period, the data were analyzed two ways. First, like treatments were compared between the first and second sample periods (i.e. pre-graze, grazed plots vs. post-graze, grazed plots and pre-graze, controls vs. post-graze controls), comparing pre and post-graze data, to determine the level of use of herbs and shrubs and any change in the other phytomass categories. Secondly, the data were analyzed by treatment (grazed vs. controls), comparing only post-graze data, to examine treatment effects immediately after grazing.

For the third sample period, the data were analyzed three ways. Firstly, like treatments were compared between the first and third sample periods (i.e. pre-graze, grazed plots vs. grazed plots 1 year following the grazing [1YF] and pre-graze, controls vs. controls 1YF) comparing only pre-graze and 1YF data, to determine the initial level of recovery of herbs and shrubs and any changes in other phytomass categories. Secondly, like treatments were compared between the second and third sample periods (i.e. post-grazed, grazed plots vs. grazed plots 1YF and post-graze controls vs. controls 1YF) to determine any changes in phytomass between the 2 periods. Lastly, the data were analyzed by treatment (grazed vs. control), comparing only 1YF data, to examine any differences between treatments 1 year following the grazing.

The strong interactions found and the logical lack of independence between sampling times for plants, particularly dominant perennials, directed me to use repeated measures of ANOVA incorporating the elements of time, blocks, and sub-sampling to analyze the data. The model I used included replications as fixed effect factors. Data were log-transformed as needed to better meet the assumptions of ANOVA. All analyses were performed using the SAS 9.1™ software package.

For this study, visually apparent dead phytomass is defined as any herbaceous plant material remaining from previous growing seasons or any woody material not associated with CAG of ARTRWY or low sagebrush. In order to calculate the percent dead fraction of the total phytomass, I divided the mean total phytomass into the sums of the means for each category comprising dead plant material. To calculate the percent fraction of the contributing categories to dead phytomass, I divided the total mean for each category by the total mean of dead phytomass.

Age Class Structure. Because of difficulty in consistently identifying individuals, I deemed it more appropriate to report the relative contributions of each age class to the total CAG of ARTRWY rather than the numbers of individuals per unit area found in each age class. The mean total CAG was calculated by finding the average of the total CAG for each of the three replicates. This was followed by calculation of the mean for each age class. The relative contributions of each age class were calculated by dividing their mean values by the mean total CAG. Data were then analyzed similarly to the model described for phytomass in the preceding paragraphs.

Biodiversity. I considered two facets of biodiversity, species richness and relative abundance of each species. For species richness, total numbers of species encountered after comparable sampling effort were compared before and after grazing. For the first and third sampling periods, data are reported by treatment to determine if the treatments changed species richness. I used the following equation to calculate changes in species richness on a percent basis:

$$(-1) + \left(\frac{number\ of\ species\ measured\ 1\ year\ following\ grazing}{number\ of\ species\ measured\ immediately\ before\ grazing} \right) = \%\ change\ in\ numbers$$

of species encountered.

As the first (pre-graze) and second (post-graze) periods are separated by less than 60 days during the non-growing season, I assumed that there was no detectable change in species richness. When reporting relative abundance, species were ranked in descending order, 1-n, based upon the amount of phytomass produced. Differences between the first and third sampling periods were of primary concern.

RESULTS

Pre-grazing

Precipitation. The study area received approximately 373 mm (Table 1) of precipitation during the water year preceding my grazing treatments. Of this, approximately 85% was received during the winter and spring months while the remaining 15% came during the summer and fall months.

Phytomass. End of growing season mean total phytomass averaged $1152\,g \cdot m^{-2}$ (Table 5) for the three replications shortly before our treatments were applied. The following fractions of the phytomass, unless specifically mentioned, had no statistically significant ($P < 0.05$) differences between treatments at the first sampling for those categories (Table 6). Determining initial similarity was important as it confirms our assumption that both treatments were alike prior to applying the grazing treatment. At the first sampling, pre-grazing, the percent live fraction of the total end of growing season phytomass averaged 40% of the total phytomass over the three replicates, ranging from 38 to 44%. Of this
live fraction, ARTRWY was 94% -- 16% CAG and 78% wood. CAG of other shrubs comprised 2% of the total live fraction while the woody portion of the other shrubs was only a trace of the total live fraction. Grasses comprised 1% of the total live fraction while forbs comprised 2% of the total live fraction.

The percent dead fraction (standing dead plus litter) of the total end of growing season phytomass at the first sampling averaged 60% of the total phytomass over the three replicates, ranging from 56 to 62%. Of the “dead” fraction, woody standing dead

Table 5 - Total Phytomass estimates among replicates at the first sampling (pre-graze). Standard error values are in parentheses. Units are in g · m^{-2}

	Replication	1	2	3	Mean
	Total Phytomass	1228.3 (47.3)	1138.7 (43.6)	1089.1 (35.0)	1152.0 (24.9)
Live plant material	*Artemisia tridentata* CAG	69.0 (3.8)	79.1 (5.1)	79.5 (4.5)	75.9 (2.6)
Live plant material	*Artemisia tridentata* Woody	438.0 (55.5)	337.3 (24.5)	308.2 (19.1)	361.2 (21.7)
Live plant material	Other Shrubs' CAG	12.5 (1.2)	5.9 (0.8)	5.9 (0.6)	8.1 (0.6)
Live plant material	Other Shrubs' Woody	0.0 (0.0)	0.1 (0.1)	0.2 (0.2)	0.1 (0.1)
Live plant material	Grasses	3.9 (0.4)	6.1 (0.7)	5.1 (0.5)	5.0 (0.3)
Live plant material	Forbs	12.7 (1.8)	6.7 (1.1)	11.8 (2.0)	10.4 (1.0)
Dead plant material	Woody Standing Dead	431.9 (40.1)	487.0 (27.6)	466.2 (27.6)	461.7 (18.6)
Dead plant material	Herbaceous Standing Dead	1.0 (0.1)	0.9 (0.1)	1.2 (0.1)	1.0 (0.1)
Dead plant material	Woody Litter	258.0 (22.5)	214.0 (0.1)	209.6 (17.3)	227.2 (11.1)
Dead plant material	Herbaceous Litter	1.5 (0.1)	1.6 (0.1)	1.4 (0.1)	1.5 (0.1)

Table 6 - Comparison of absolute phytomass estimates between treatments across the 3 sample periods. Units are in g · m^{-2}.

		First Sampling (Pre-graze)			Second Sampling (Post-graze)			Third Sampling (1 year following grazing)		
		Control Plots	Grazed Plots	P	Control Plots	Grazed Plots	P	Control Plots	Grazed Plots	P
Live plant material	Total Phytomass	1164.7	1139.4	0.9993	1189.4	853.7	0.0214	955.3	593.3	0.0140
	Artemisia tridentata CAG	82.8	68.9	0.9302	74.0	1.2	< 0.0001	60.4	23.1	0.0042
	Artemisia tridentata Woody	388.7	333.6	0.8313	408.5	225.5	0.0514	474.9	84.0	< 0.0001
	Other Shrubs' CAG	6.7	9.4	0.7798	2.9	0.0	0.0002	6.0	10.7	0.1999
	Other Shrubs' Woody	0.1	0.1	1.0000	0.1	0.4	0.9933	0.3	0.4	0.9716
	Grasses	3.6	6.5	0.0509	1.4	0.0	0.0003	5.6	9.2	0.1716
	Forbs	13.3	7.5	0.6366	5.1	0.0	0.0006	16.5	12.0	0.9216
Dead plant material	Woody Standing Dead	453.7	469.7	0.9963	602.0	514.7	0.0394	303.6	351.0	0.7402
	Herbaceous Standing Dead	1.2	0.8	0.0342	0.7	0.1	0.0020	1.4	0.1	< 0.0001
	Woody Litter	212.9	241.5	0.4163	93.1	111.1	0.7991	83.7	101.8	0.7964
	Herbaceous Litter	1.6	1.5	0.9632	1.7	0.8	0.0199	2.9	0.9	< 0.0001

comprised 67%. Herbaceous standing dead comprised a trace of the total dead fraction. The estimated value for this component was slightly higher in the control plots than in the plots to be grazed (P = 0.0342). Woody litter comprised 33% of the total dead fraction. Herbaceous litter comprised a trace of the total dead fraction.

Age Class Structure. Total mean end of growing season CAG of ARTRWY averaged $83\,g \cdot m^{-2}$ among the control plots (Table 7) shortly before our treatments were applied. Of the total end of growing season CAG, age classes 1 and 2 comprised only a trace of the total while 3 comprised 2%, 4 comprised 39%, 5 comprised 35%, 6 comprised 15%, 7 comprised 7%, and 8 comprised 1% of total CAG.

Total mean end of growing season CAG of ARTRWY averaged $69\,g \cdot m^{-2}$ among the grazed plots (Table 7) shortly before our treatments were applied. Of the total end of growing season CAG, age classes 1 and 2 comprised only a trace of the total while 3 comprised 2%, 4 comprised 37%, 5 comprised 39%, 6 comprised 12%, 7 comprised 9%, and 8 comprised 2% of total CAG.

Biodiversity

Prior to applying the grazing treatments, the ungrazed control plots had 20 plant species, while the plots that were soon to be grazed had 26 species (Fig. 7). The dominant plant species in the control plots was ARTRWY (Table 8). The relative abundance of the other species, listed in descending rank, were Carpet Phlox (*Phlox hoodii* [PHHO]), Low rabbitbrush (CHVI), Low pussytoes (*Antennaria dimorpha*) [ANDI]), Sandberg bluegrass (POSE), Bluebunch wheatgrass (PSSP), Horsebrush (TECA), Needle-and-thread grass (STCO), Longleaf phlox (PHLO), Low sagebrush (ARAR), Thickspike wheatgrass (*Elymus lanceolatus* [ELLA]), Winterfat (KRLA), and

Table 7 - CAG production of Wyoming big sagebrush among age-classes at the first sampling (pre-graze). Units are in g · m^{-2}.

	Plot	1B	2B	3A		1C	2A	3B	
	Treatment	Grazed	Grazed	Grazed	Mean	Ungrazed	Ungrazed	Ungrazed	Mean
	Total CAG	74.5	63.6	68.7	68.9	63.4	94.6	90.4	82.8
Age Classes	1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	2	0.2	0.1	0.1	0.1	0.6	0.1	0.3	0.4
	3	1.4	0.6	1.2	1.1	1.3	1.7	2.0	1.7
	4	21.8	24.3	29.9	25.3	16.8	40.6	39.4	32.3
	5	28.9	25.9	25.6	26.8	21.7	37.1	28.4	29.1
	6	10.2	6.6	7.0	7.9	15.0	7.1	14.5	12.2
	7	10.1	4.8	3.5	6.1	7.2	6.5	4.2	6.0
	8	1.9	1.3	1.3	1.5	0.9	1.4	1.4	1.2

Bottlebrush squirreltail *Elymus elymoides* (ELEL). These were followed, in lesser amounts, by the remainder of the species listed in Table 8. Note that wherever there is a "t" listed, there were only trace amounts present.

The dominant plant species in the plots soon to be grazed was ARTRWY (Table 8). The companion species, listed in descending rank, were Low rabbitbrush (CHVI), Low pussytoes (ANDI), Hoods phlox/carpet phlox (PHHO), Bluebunch wheatgrass (PSSP), Thickspike wheatgrass (ELLA), Sandberg's wheatgrass (POSE), Needle-and-thread grass (STCO), Bottlebrush squirreltail (ELEL), Longleaf phlox (PHLO), Horsebrush (TECA), Low sagebrush (ARAR), and Indian ricegrass (STHY). These were followed, in lesser amounts, by the remainder of the species listed in Table 8.

Post-grazing

Precipitation. From August 29, 2003 to October 21, 2003 -- the time between the beginning of the first and the end of the second samplings -- there were approximately

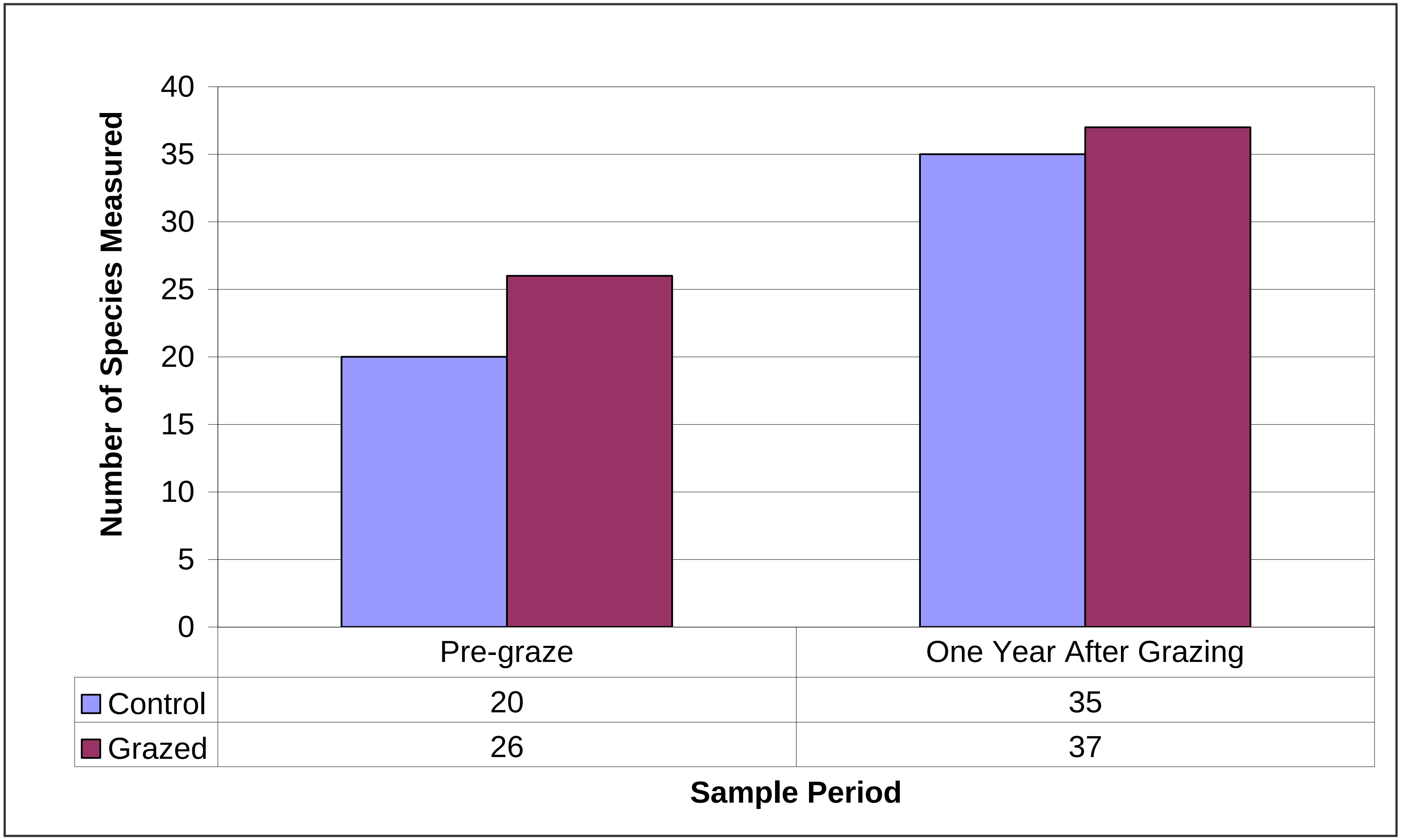


Figure 7 - Species richness between treatments before grazing and 1 year after grazing.

Table 8 - Dominance/diversity of plants encountered during the first sampling.

Control Plots: Pre-graze			
Species Rank	Species Code	mean $g \cdot m^{-2}$	% of total
1	ARTRWY	82.8	78%
2	PHHO	8.0	7%
3	CHVI	6.1	6%
4	ANDI	5.1	5%
5	POSE	1.6	1%
6	PSSP	1.5	1%
7	TECA	0.4	t
8	STCO	0.3	t
9	PHLO	0.2	t
10	ARAR	0.1	t
11	ELLA	0.1	t
12	KRLA	0.1	t
13	ELEL	0.1	t
14	STHY	t	t
15	ERCO	t	t
16	ARHO	t	t
17	ALDE	t	t
18	CRMO	t	t
19	AGCR	t	t
20	TRGY	t	t
	TOTAL	106.5	100%

Plots grazed in 01 & 03: Pre-graze			
Species Rank	Species Code	mean $g \cdot m^{-2}$	% of total
1	ARTRWY	68.9	75%
2	CHVI	9.2	10%
3	ANDI	4.8	5%
4	PHHO	2.4	3%
5	PSSP	2.1	2%
6	ELLA	1.9	2%
7	POSE	1.9	2%
8	STCO	0.4	t
9	ELEL	0.2	t
10	PHLO	0.2	t
11	TECA	0.1	t
12	ARAR	0.1	t
13	STHY	0.1	t
14	ERCO	t	t
15	ALDE	t	t
16	ARHO	t	t
17	SEIN	t	t
18	KRLA	t	t
19	AGCR	t	t
20	DEPI	t	t
21	BRTE	t	t
22	OPUNTIA	t	t
23	PENSTEMON SPP.	t	t
	TOTAL	92.3	100%

mm of precipitation at a weather station 32 km from the study area (Weather Underground 2005). Sampling of precipitation on site was too coarse to detect so little precipitation over such a short time. As the first and second sampling periods were separated by less than 60 days, I assumed this amount of precipitation was insignificant as temperatures were too cool (Weather Underground 2005) for significant plant growth.

Phytomass. Among the control plots, end of growing season mean total phytomass averaged $1189\,g \cdot m^{-2}$ (Table 3), an apparent 2% relative increase from pre-graze levels. In the following fractions of the phytomass, unless specifically mentioned, there were no statistically significant ($P < 0.05$) differences between the pre- and post-grazing samplings in the control plots (Table 9).

For the control plots, the percent live fraction of the total end of growing season phytomass at the second sampling averaged 41% of the total phytomass, ranging from 41 to 42%, an apparent 1% increase from pre-graze levels. Of this live fraction, CAG of ARTRWY was 15%, an apparent 11% decrease from pre-graze levels. The woody portion of ARTRWY was 83%, an apparent 5% increase from pre-graze levels. The CAG of other shrubs comprised 1%, showing a 57% decrease from pre-graze levels ($P = 0.0107$). The woody portion of other shrubs comprised only a trace, showing an apparent 9% decrease from pre-graze levels. Grasses comprised only a trace of the total live fraction, with a 62% decrease from pre-graze levels ($P = 0.0058$). Forbs comprised 1%, showing an apparent 62% decrease from pre-graze levels.

For the control plots, the percent dead fraction (standing dead plus litter) of the total end of growing season phytomass averaged 59% of the total phytomass, ranging from 58 to 59%, an apparent 1% decrease from pre-graze levels. Of the dead fraction,

Table 9 - Comparison of absolute phytomass estimates in the control plots across the 3 sample periods. Units are in $g \cdot m^{-2}$.

		Pre-Graze	Post-Graze	P	Post-Graze	1 year following grazing	P	Pre-Graze	1 year following grazing	P
Live plant material	Total Phytomass	1164.7	1189.4	0.9992	1189.4	955.3	0.0953	1164.7	955.3	0.1486
	Artemisia tridentata CAG	82.8	74.0	0.9835	74.0	60.4	0.8819	82.8	60.4	0.5598
	Artemisia tridentata Woody	388.7	408.5	0.9658	408.5	474.9	0.8722	388.7	474.9	0.4840
	Other Shrubs' CAG	6.7	2.9	0.0107	2.9	6.0	0.0211	6.7	6.0	0.9924
	Other Shrubs' Woody	0.1	0.1	1.0000	0.1	0.3	0.9994	0.1	0.3	0.9996
	Grasses	3.6	1.4	0.0058	1.4	5.6	0.0003	3.6	5.6	0.1182
	Forbs	13.3	5.1	0.0753	5.1	16.5	0.0070	13.3	16.5	0.4747
Dead plant material	Woody Standing Dead	453.7	602.0	0.0126	602.0	303.6	0.0001	453.7	303.6	0.0118
	Herbaceous Standing Dead	1.2	0.7	0.0054	0.7	1.4	0.0006	1.2	1.4	0.3612
	Woody Litter	212.9	93.1	0.0001	93.1	83.7	0.9698	212.9	83.7	< 0.0001
	Herbaceous Litter	1.6	1.7	0.9991	1.7	2.9	< 0.0001	1.6	2.9	< 0.0001

woody standing dead comprised 86% of the total dead fraction, showing a 33% increase from pre-graze levels ($P = 0.0126$). Herbaceous standing dead comprised only a trace of the total dead fraction, showing an apparent 42% decrease from pre-graze levels ($P = 0.0054$). Woody litter comprised 13% of the total dead fraction, showing an apparent 56% decrease from pre-graze levels ($P = 0.0001$). Herbaceous litter comprised only a trace of the total dead fraction, with an apparent 3% increase from pre-graze levels.

For the grazed plots, end of growing season mean total phytomass averaged $854\,g \cdot m^{-2}$ (Table 3), an apparent 25% decrease from pre-graze levels ($P = 0.0377$). In the following fractions of the phytomass, unless specifically mentioned, there were no statistically significant ($P < 0.05$) differences pre and post-grazing (Table 10).

Utilization Achieved by the Grazing Treatment. By comparing pre- and post-grazing data, sheep used 98% of the total available forage. They used 98% of the CAG of ARTRWY, 100% of the CAG of other shrubs, 100% of the grasses, 100% of the forbs, each statistically significant at $P < 0.0001$. The sheep also used 90% of the herbaceous standing dead ($P = 0.0004$), and 44% of the herbaceous litter ($P = 0.0094$). Further, by comparing pre- and post-grazing across the

three replicates, sheep consumed a total of 665.3kg (1,466.7 lbs) of forage and 1,020kg (2,248.7 lbs) of supplement. Using these values, I calculated that each ewe's intake across the 10-day period was 39% onsite-forage and 61% supplement.

For the grazed plots, the percent live fraction of the total end of growing season phytomass averaged 27% of the total phytomass, ranging from 20 to 30%, an apparent 13% decrease from pre-graze levels. Of this live fraction, CAG of ARTRWY was 1%,

Table 10 - Comparison of absolute phytomass estimates in the grazed plots across the 3 sample periods. Units are in $g \cdot m^{-2}$.

		Pre-Graze	Post-Graze	P	Post-Graze	1 year following grazing	P	Pre-Graze	1 year following grazing	P
Live plant material	Total Phytomass	1139.4	853.7	0.0377	853.7	593.3	0.0592	1139.4	593.3	0.0007
	Artemisia tridentata CAG	68.9	1.2	< 0.0001	1.2	23.1	< 0.0001	68.9	23.1	0.0014
	Artemisia tridentata Woody	333.6	225.5	0.3637	225.5	84.0	0.0005	333.6	84.0	< 0.0001
	Other Shrubs' CAG	9.4	0.0	< 0.0001	0.0	10.7	< 0.0001	9.4	10.7	0.9306
	Other Shrubs' Woody	0.1	0.4	0.8351	0.4	0.4	0.9644	0.1	0.4	0.4372
	Grasses	6.5	0.0	< 0.0001	0.0	9.2	< 0.0001	6.5	9.2	0.4023
	Forbs	7.5	0.0	< 0.0001	0.0	12.0	< 0.0001	7.5	12.0	0.1930
Dead plant material	Woody Standing Dead	469.7	514.7	0.7089	514.7	351.0	0.0070	469.7	351.0	0.0421
	Herbaceous Standing Dead	0.8	0.1	0.0004	0.1	0.1	0.9996	0.8	0.1	0.0003
	Woody Litter	241.5	111.1	< 0.0001	111.1	101.8	0.4562	241.5	101.8	< 0.0001
	Herbaceous Litter	1.5	0.8	0.0094	0.8	0.9	0.9586	1.5	0.9	0.0256

an apparent 98% decrease from pre-graze levels (P < 0.0001). The woody portion of ARTRWY comprised 99% of the total live fraction, or an apparent 32% decrease from pre-graze levels. CAG of other shrubs comprised 0%, an apparent 100% decrease from pre-graze levels (P < 0.0001). The woody portion of other shrubs comprised a trace of the total live fraction, showing an apparent 282% relative increase from pre-graze levels. Grasses comprised 0% of the total live fraction, or an apparent 100% relative decrease from pre-graze levels (P < 0.0001). Forbs comprised 0% of the total live fraction, showing an apparent 100% relative decrease from pre-graze levels (P < 0.0001).

For the grazed plots, the percent dead fraction (standing dead plus litter) of the total end of growing season phytomass averaged 73% of the total phytomass, ranging from 70 to 80%, an apparent 13% increase from pre-graze levels. Of the dead fraction, woody standing dead comprised 82% of the total dead fraction, an apparent 10% increase from pre-graze levels. Herbaceous standing dead comprised only a trace of the total dead fraction, or an apparent 90% decrease from pre-graze levels (P = 0.0004). Woody litter comprised 18% of the total dead fraction, showing an apparent 54% relative decrease from pre-graze levels (P < 0.0001). Herbaceous litter comprised only a trace of the total dead fraction, an apparent 44% relative decrease from pre-graze levels (P < = 0.0094).

When comparing treatments, using only post-graze data, there were significant differences (P < 0.05) for the following categories: total phytomass (P = 0.0214), CAG of ARTRWY (P < 0.0001), CAG of other shrubs (P = 0.0002), grasses (P = 0.0003), forbs (P = 0.0006), herbaceous standing dead (P = 0.0020), and herbaceous litter (P < 0.0199). No statistically significant differences were found between treatments for the following categories: the woody portion of ARTRWY, the woody portion of other shrubs, woody standing dead, and woody litter.

Age Class Structure. For the control plots, total mean end of growing season CAG of ARTRWY averaged 74 $g \cdot m^{-2}$ (Table 11) at the second sampling. Of the total end of growing season CAG, age class 1 comprised 0% of the total while 2 comprised only a trace, 3 comprised 1%, 4 comprised 14%, 5 comprised 25%, 6 comprised 32%, 7 comprised 24%, and 8 comprised 3% of total CAG.

For the grazed plots, total mean end of growing season CAG of ARTRWY averaged 1.2 $g \cdot m^{-2}$ (Table 11) at the second sampling. Of the total end of growing season CAG, age classes 1 and 2 comprised 0% of the total while 3 comprised 5%, 4 comprised 16%, 5 comprised 42%, 6 comprised 7%, 7 comprised 30%, and 8 comprised 0% of total CAG. Any differences in age class percentage values between the first and second sampling periods are largely due to sampling error.

Biodiversity. As the first and second samplings were separated by less than 60 days, during the non-growing season, I assumed there would be no detectable changes in species richness or dominance between treatments and data were thus not analyzed for this period.

One Year after Grazing

Precipitation. The study area received approximately 354 mm of precipitation during the water year following our grazing treatments (Table 1). Of this, approximately 90% was received during the winter and spring months while the remaining 10% came during the spring and summer months. This precipitation was 39% above the estimated long-term mean for this area (NRCS 2004).

Table 11 - CAG production of Wyoming big sagebrush among age-classes at the second sampling (post-graze). Units are in $g \cdot m^{-2}$.

	Plot	1B	2B	3A		1C	2A	3B	
	Treatment	Grazed	Grazed	Grazed	Mean	Ungrazed	Ungrazed	Ungrazed	Mean
	Total CAG	0.4	2.5	0.8	1.2	55.7	80.2	86.1	74.0
Age Classes	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.4	0.3	0.2	0.3
	3	0.0	0.0	0.1	0.1	0.5	0.9	1.4	0.9
	4	0.1	0.3	0.2	0.2	5.2	16.6	9.3	10.3
	5	0.2	1.0	0.4	0.5	11.7	21.7	22.0	18.5
	6	0.0	0.1	0.1	0.1	15.6	24.0	32.3	24.0
	7	0.0	1.0	0.1	0.4	20.2	13.6	19.2	17.7
	8	0.0	0.0	0.0	0.0	2.2	3.1	1.7	2.3

Phytomass. For the control plots, end of growing season mean total phytomass averaged 955 $g \cdot m^{-2}$ (Table 4), an apparent 20% decrease from post-graze levels and an apparent overall decrease of 18% from pre-graze levels. In the following fractions, unless specifically mentioned, there were no significant ($P < 0.05$) differences.

For the control plots, the percent live fraction of the total end of growing season phytomass averaged 59% of the total phytomass, ranging from 58 to 60%, for an apparent 18% increase from post-graze levels and an apparent 19% increase from pre-graze levels. Of this fraction, CAG of ARTRWY comprised 11%, showing an apparent 18% decrease from post-graze levels and an apparent overall decrease of 27% from pre-graze levels (Table 12). The woody portion of ARTRWY comprised 84% of the live fraction, showing an apparent 16% increase from post-graze levels and an apparent overall increase of 22% from pre-graze levels. CAG of other shrubs comprised 1% of the live fraction, showing an apparent 109% increase from post-graze levels ($P = 0.0211$), and an apparent overall decrease of 11% from pre-graze levels. The woody portion of other shrubs comprised only a trace of the total live fraction, showing an apparent 173% increase from post-graze levels and an apparent increase of 148% from pre-graze levels. Grasses comprised 1% of the live fraction, showing an apparent 313% increase from post-graze levels ($P = 0.0003$), an apparent increase of 56% from pre-graze levels. Forbs comprised 3% of the live fraction, showing an apparent 226% increase from post-graze levels ($P = 0.0070$), an apparent overall increase of 24% from pre-graze levels.

For the control plots, the percent dead fraction (standing dead plus litter) of the total end of growing season phytomass averaged 41% of the total phytomass, ranging from 40 to 42%, or an apparent 18% decrease from post-graze levels and an apparent

Table 12 - Comparison of relative changes in the phytomass estimates in the control plots across the 3 sample periods. Units are in $g \cdot m^{-2}$.

		Pre-Graze	Post-Graze	% Change	Post-Graze	1 year following grazing	% Change	Pre-Graze	1 year following grazing	% Change
Live plant material	Total Phytomass	1164.7	1189.4	2%	1189.4	955.3	-20%	1164.7	955.3	-18%
	Artemisia tridentata CAG	82.8	74.0	-11%	74.0	60.4	-18%	82.8	60.4	-27%
	Artemisia tridentata Woody	388.7	408.5	5%	408.5	474.9	16%	388.7	474.9	22%
	Other Shrubs' CAG	6.7	2.9	-57%	2.9	6.0	107%	6.7	6.0	-10%
	Other Shrubs' Woody	0.1	0.1	0%	0.1	0.3	200%	0.1	0.3	200%
	Grasses	3.6	1.4	-61%	1.4	5.6	300%	3.6	5.6	56%
	Forbs	13.3	5.1	-62%	5.1	16.5	224%	13.3	16.5	24%
Dead plant material	Woody Standing Dead	453.7	602.0	33%	602.5	303.6	-50%	453.7	303.6	-33%
	Herbaceous Standing Dead	1.2	0.7	-42%	0.7	1.4	100%	1.2	1.4	17%
	Woody Litter	212.9	93.1	-56%	93.1	83.7	-10%	212.9	83.7	-61%
	Herbaceous Litter	1.6	1.7	6%	1.7	2.9	71%	1.6	2.9	81%

19% decrease from pre-graze levels. Of the dead fraction, woody standing dead comprised 78% of the total dead fraction, showing an apparent 50% decrease from post-graze levels (P = 0.0001) and an apparent decrease of 33% from pre-graze levels (P = 0.0118). Herbaceous standing dead comprised only a trace of the total dead fraction, showing an apparent 100% increase from post-graze levels (P = 0.0006) and an apparent increase of 16% from pre-graze levels. Woody litter comprised 21% of the total dead fraction, showing an apparent 10% decrease from post-graze levels and an apparent overall decrease of 61% from pre-graze levels (P < 0.0001). Herbaceous litter comprised 1% of the total dead fraction, showing an apparent increase of 77% from post-graze levels (P < 0.0001) and an apparent increase of 82% from pre-graze levels (P < 0.0001).

For the grazed plots, end of growing season total phytomass averaged 593 $g \cdot m^{-2}$ (Table 4), or an apparent 31% decrease from post-graze levels and an apparent overall decrease of 48% from pre-graze levels (P = 0.0007). In the following fractions of the phytomass, unless specifically mentioned, it was determined that there were no significant (P < 0.05) differences.

For the grazed plots, the percent live fraction of the total end of growing season phytomass averaged 24% of the total phytomass, ranging from 19 to 28%, for an apparent 3% increase from post-graze levels and an apparent decrease of 16% from pre-graze levels. Of the live fraction, CAG of ARTRWY comprised 17%, showing an apparent 1,825% increase from post-graze levels (P < 0.0001) (Table 13) and an apparent decrease of 66% from pre-graze levels (P = 0.0014). The woody portion of ARTRWY comprised 60% of the live fraction, showing an apparent decrease of 63% from post-graze levels (P = 0.0005) and an apparent decrease of 75% from pre-graze levels (P < 0.0001). CAG of other shrubs comprised 8% of the live fraction, showing an apparent 796,534% increase from post-graze levels (P < 0.0001), and an apparent increase of 14% from pre-graze levels. The woody portion of other shrubs comprised only a trace of the total live fraction, showing an apparent 18% increase from post-graze levels and an apparent increase of 351% from pre-graze levels. Grasses comprised 7% of the live fraction, showing an apparent 176,021% increase from post-graze levels (P < 0.0001) and an apparent increase of 43% from pre-graze levels. Forbs comprised 9% of the live fraction, showing an apparent 74,387% increase from post-graze levels (P < 0.0001) and an apparent increase of 60% from pre-graze levels.

For the grazed plots, the percent dead fraction (standing dead plus litter) of the total end of growing season phytomass averaged 76% of the total phytomass, ranging from 72 to 81% for an apparent 3% increase from post-graze levels and an apparent increase of 16% from pre-graze levels. Of the dead fraction, woody standing dead comprised 77% of the total dead fraction, showing an apparent 32% decrease from post-graze levels (P = 0.0070) and an apparent decrease of 25% from pre-graze levels (P = 0.0421). Herbaceous standing dead comprised only a trace of the total dead fraction, showing an apparent 34% decrease from post-graze levels and an apparent decrease of 94% from pre-graze levels (P = 0.0003). Woody litter comprised 22% of the total dead fraction, showing an apparent 8% decrease from post-graze levels and an apparent decrease of 58% from pre-graze levels (P < 0.0001). Herbaceous litter comprised only a trace of the total dead fraction, an apparent 12% increase from post-graze levels and an apparent decrease of 37% from pre-graze levels (P = 0.0256).

When comparing treatments, using only data from one year following treatment,

Table 13 - Comparison of relative changes in the phytomass estimates in the grazed plots across the 3 sample periods. Units are in $g \cdot m^{-2}$.

		Pre-Graze	Post-Graze	% Change	Post-Graze	1 year following grazing	% Change	Pre-Graze	1 year following grazing	% Change
Live plant material	Total Phytomass	1139.4	853.7	-25%	853.7	593.3	-31%	1139.4	593.3	-48%
	Artemisia tridentata CAG	68.9	1.2	-98%	1.2	23.1	1825%	68.9	23.1	-66%
	Artemisia tridentata Woody	333.6	225.5	-32%	225.5	84.0	-63%	333.6	84.0	-75%
	Other Shrubs' CAG	9.4	0.0	-100%	0.0	10.7	*	9.4	10.7	14%
	Other Shrubs' Woody	0.1	0.4	300%	0.4	0.4	0%	0.1	0.4	300%
	Grasses	6.5	0.0	-100%	0.0	9.2	*	6.5	9.2	42%
	Forbs	7.5	0.0	-100%	0.0	12.0	*	7.5	12.0	60%
Dead plant material	Woody Standing Dead	469.7	514.7	10%	514.7	351.0	-32%	469.7	351.0	-25%
	Herbaceous Standing Dead	0.8	0.1	-88%	0.1	0.1	0%	0.8	0.1	-88%
	Woody Litter	241.5	111.1	-54%	111.1	101.8	-8%	241.5	101.8	-58%
	Herbaceous Litter	1.5	0.8	-47%	0.8	0.9	13%	1.5	0.9	-40%

* Because the denominator for this equation is 0, this value is incalculable.

there were significant differences ($P < 0.05$) for the following categories(Table 14): total phytomass ($P = 0.0140$), CAG of ARTRWY ($P = 0.0042$), the woody portion of ARTRWY ($P < 0.0001$), herbaceous standing dead ($P < 0.0001$), and herbaceous litter ($P < 0.0001$). No statistically significant differences were found between treatments at the third sampling for the following categories: CAG of other shrubs, the woody portion of other shrubs, grasses, forbs, woody standing dead, and woody litter.

Though I assume these results were due to the grazing treatment, we must appreciate other possible biological influences on vegetation dynamics. Insects such as the Aroga moth defoliate sagebrush, which impacts sagebrush and associated vegetation. During my study, a fungal attack of snowmold significantly influenced sagebrush in the control plots. Though this will be discussed later, I mention it now as a reminder that natural disturbances, over which we have no control, also impact the systems we manage.

Age Class Structure. For the control plots, total mean end of growing season CAG of ARTRWY averaged 60 $g \cdot m^{-2}$ (Table 15) one year after the grazing treatments were applied. Of the total end of growing season CAG, age class 1 comprised 0% of the total while 2 comprised only a trace, 3 comprised 2%, 4 comprised 6%, 5 comprised 33%, 6 comprised 37%, 7 comprised 18%, and 8 comprised 3% of total CAG.

For the grazed plots, total mean end of growing season CAG of ARTRWY averaged 23 $g \cdot m^{-2}$ (Table 15) one year after the grazing treatments were applied. Of the total end of growing season CAG, age class 1 comprised 0% of the total while 2 comprised 1%, 3 comprised 3%, 4 comprised 11%, 5 comprised 19%, 6 comprised 22%, 7 comprised 30%, and 8 comprised 14% of total CAG.

Biodiversity. One year after the treatments were applied, the ungrazed controls

Table 14 - Comparison of relative changes in phytomass estimates between treatments across the 3 sample periods. Units are in $g \cdot m^{-2}$.

		First Sampling (Pre-graze)			Second Sampling (Post-graze)			Third Sampling (1 year following grazing)		
		Control Plots	Grazed Plots	% Difference	Control Plots	Grazed Plots	% Difference	Control Plots	Grazed Plots	% Difference
Live plant material	Total Phytomass	1164.7	1139.4	-2%	1189.4	853.7	-28%	955.3	593.3	-38%
	Artemisia tridentata CAG	82.8	68.9	-17%	74.0	1.2	-98%	60.4	23.1	-62%
	Artemisia tridentata Woody	388.7	333.6	-14%	408.5	225.5	-45%	474.9	84.0	-82%
	Other Shrubs' CAG	6.7	9.4	40%	2.9	0.0	-100%	6.0	10.7	78%
	Other Shrubs' Woody	0.1	0.1	0%	0.1	0.4	300%	0.3	0.4	33%
	Grasses	3.6	6.5	81%	1.4	0.0	-100%	5.6	9.2	64%
	Forbs	13.3	7.5	-44%	5.1	0.0	-100%	16.5	12.0	-27%
Dead plant material	Woody Standing Dead	453.7	469.7	4%	602.0	514.7	-15%	303.6	351.0	16%
	Herbaceous Standing Dead	1.2	0.8	-33%	0.7	0.1	-86%	1.4	0.1	-93%
	Woody Litter	212.9	241.5	13%	93.1	111.1	19%	83.7	101.8	22%
	Herbaceous Litter	1.6	1.5	-6%	1.7	0.8	-53%	2.9	0.9	-69%

had 35 vascular plant species (Fig. 7), a 75% increase from the first sampling. The grazed plots had 37 vascular plant species, a 61% increase from the first sampling.
In the control plots, the dominant plant species continued to be ARTRWY (Table 16), however, its relative importance had declined by 10% from the first sampling. The relative abundance of companion species, listed in descending rank, were Carpet phlox (PHHO), Low pussytoes (ANDI), Low rabbitbrush (CHVI), Bluebunch wheatgrass (PSSP), Starveling milkvetch (*Astragalus jejunus* [ASJE]), Prickly phlox (*Leptodactylon pungens* [LEPU]), Sandberg bluegrass (POSE), Bushy bird's beak (*Cordylanthus ramosus* [CORA]), Horsebrush (TECA), Muttongrass (*Poa fendleriana* [POFE]), Bottlebrush squirreltail (ELEL), Longleaf phlox (PHLO), Hollyleaf clover (*Trifolium gymnocarpon* [TRGY]), Western wheatgrass (PASM), Thickspike wheatgrass (ELLA), Needle-and-thread grass (STCO), Cushion daisy (*Erigeron compactus* [ERCO]), Browse milkvetch (*Astragalus cibarius* [ASCI]), Low sagebrush (ARAR), Indian ricegrass (STHY), Winterfat (KRLA), Lesser rushy milkvetch (*Astragalus convallarius* [ASCO]), and Desert madwort (*Alyssum desertorum* [ALDE]).

Among these species there were some notable changes in rankings from the first to the third samplings. Low pussytoes increased from 5% to 6% of the total current year's growth. Bluebunch wheatgrass increased from 1% to 2% of the total current year's growth. Horsebrush, Bottlebrush squirreltail, Longleaf phlox, Hollyleaf clover, and Thickspike wheatgrass each increased from trace amounts at the first sampling to 1% each of the total current year's growth. Several species that were not even encountered at the first sampling appeared and each contributed 1% of the total current year's growth at the third sampling; those species were: Starveling milkvetch, Prickly phlox, Bushy bird's

Table 15 - CAG production of Wyoming big sagebrush among age-classes at the third sampling (1 year after grazing). Units are in g · m^{-2}.

	Plot	1B	2B	3A		1C	2A	3B	
	Treatment	Grazed	Grazed	Grazed	Mean	Ungrazed	Ungrazed	Ungrazed	Mean
	Total CAG	17.2	32.8	19.2	23.1	43.5	70.4	67.4	60.4
Age Classes	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.3	0.3	0.2	0.2	0.1	0.4	0.2
	3	0.3	1.3	0.7	0.8	1.1	1.0	1.0	1.0
	4	1.1	4.3	1.9	2.4	2.4	7.2	2.2	3.9
	5	2.2	9.5	1.3	4.3	9.3	29.1	20.8	19.7
	6	6.5	6.0	3.0	5.2	17.4	21.1	29.5	22.7
	7	4.8	8.3	7.9	7.0	11.3	9.6	12.0	11.0
	8	2.2	3.1	4.1	3.1	1.9	2.2	1.6	1.9

beak, Muttongrass, and Western wheatgrass. These were followed, in lesser amounts, by the remainder of the species listed in Table 16.

In the grazed plots, the dominant plant species was still ARTRWY (Table 16), however, its relative importance had declined 33% from the first sampling. The companion species, listed in descending rank, were Low rabbitbrush (CHVI), Low pussytoes (ANDI), Bluebunch wheatgrass (PSSP), Starveling milkvetch (ASJE), Western wheatgrass (PASM), Bushy bird's beak (CORA), Thickspike wheatgrass (ELLA), Bottlebrush squirreltail (ELEL), Browse milkvetch (ASCI), Needle-and-thread grass (STCO), Hollyleaf clover (TRGY), Bastard toadflax (*Comandra umbellata* [COUM]), Sandberg bluegrass (POSE), Cushion daisy (ERCO), Indian ricegrass (STHY), Longleaf phlox (PHLO), Carpet phlox (PHHO), Low sagebrush (ARAR), Muttongrass (POFE), Horsebrush (TECA), Lesser rushy milkvetch (ASCO), Prickly phlox (LEPU), Desert madwort (ALDE), Tapertip onion (*Allium acuminatum* [ALAC]), and Lambquarters

Table 16 - Dominance/diversity of plants encountered during the third sampling.

Control Plots - 1 year after grazing			
Species Rank	Species Code	mean $g \cdot m^{-2}$	% of total
1	ARTRWY	60.4	68%
2	PHHO	5.9	7%
3	ANDI	5.3	6%
4	CHVI	5.2	6%
5	PSSP	2.0	2%
6	ASJE	1.4	2%
7	LEPU	1.1	1%
8	POSE	0.9	1%
9	CORA	0.7	1%
10	TECA	0.6	1%
11	POFE	0.6	1%
12	ELEL	0.6	1%
13	PHLO	0.5	1%
14	TRGY	0.5	1%
15	PASM	0.5	1%
16	ELLA	0.5	1%
17	STCO	0.4	t
18	ERCO	0.3	t
19	ASCI	0.3	t
20	ARAR	0.1	t
21	STHY	0.1	t
22	KRLA	0.1	t
23	ASCO	0.1	t
24	ALDE	0.1	t
25	ASPU	t	t
26	ALAC	t	t
27	AGCR	t	t
28	CACH	t	t
29	ARHO	t	t
30	COUM	t	t
31	CHAL	t	t
32	BRTE	t	t
33	LOAM	t	t
34	LOMA	t	t
35	GIIN	t	t
	TOTAL	88.6	100%

Plots grazed in 01 & 03: 1 year after grazing			
Species Rank	Species Code	mean $g \cdot m^{-2}$	% of total
1	ARTRWY	23.1	42%
2	CHVI	10.3	19%
3	ANDI	4.5	8%
4	PSSP	3.5	6%
5	ASJE	2.3	4%
6	PASM	2.2	4%
7	CORA	1.9	3%
8	ELLA	1.0	2%
9	ELEL	1.0	2%
10	ASCI	0.6	1%
11	STCO	0.6	1%
12	TRGY	0.5	1%
13	COUM	0.4	1%
14	POSE	0.4	1%
15	ERCO	0.4	1%
16	STHY	0.3	1%
17	PHLO	0.3	1%
18	PHHO	0.3	t
19	ARAR	0.3	t
20	POFE	0.2	t
21	TECA	0.2	t
22	ASCO	0.2	t
23	LEPU	0.1	t
24	ALDE	0.1	t
25	ALAC	0.1	t
26	CHAL	0.1	t
27	ARHO	t	t
28	HAPA	t	t
29	LOAM	t	t
30	LOMA	t	t
31	BRTE	t	t
32	KRLA	t	t
33	ASPU	t	t
34	GIIN	t	t
35	CACH	t	t
36	ZIPA	t	t
37	OPUNTIA	t	t
	TOTAL	55.1	100%

* note: a value of "t" indicates a trace amount

(*Chenopodium album* [CHAL]).

Among these species there were also some notable changes in rankings from the first to the third samplings. Low rabbitbrush increased from 6% to 19% of the total current year's growth. Low pussytoes increased from 6% to 8% of the total current year's growth. Bluebunch wheatgrass increased from 2% to 6% of the total current year's growth. Bottlebrush squirreltail increased from 1% to 2% of the total current year's growth. There were several species that were encountered only in trace amounts at the first sampling and increased to 1% of the total current year's growth at the third sampling, these were: Needle-and-thread grass, Cushion daisy, and Indian ricegrass. There were also several species that I did not even encounter at the first sampling that each contributed varying amounts to the total current year's growth at the third sampling, these were: Starveling milkvetch (4%), Western wheatgrass (4%), Bushy bird's beak (3%), Browse milkvetch (1%), Hollyleaf clover (1%), and Bastard toadflax (1%). It is interesting to note that in the above cases, as ARTRWY decreased the other species increased in ranking, however, in the case of Carpet phlox, this is not true. Carpet phlox decreased from 7% at the first sampling to only trace amounts of the total current year's growth at the third sampling. These were followed, in lesser amounts, by the remainder of the species listed in Table 16.

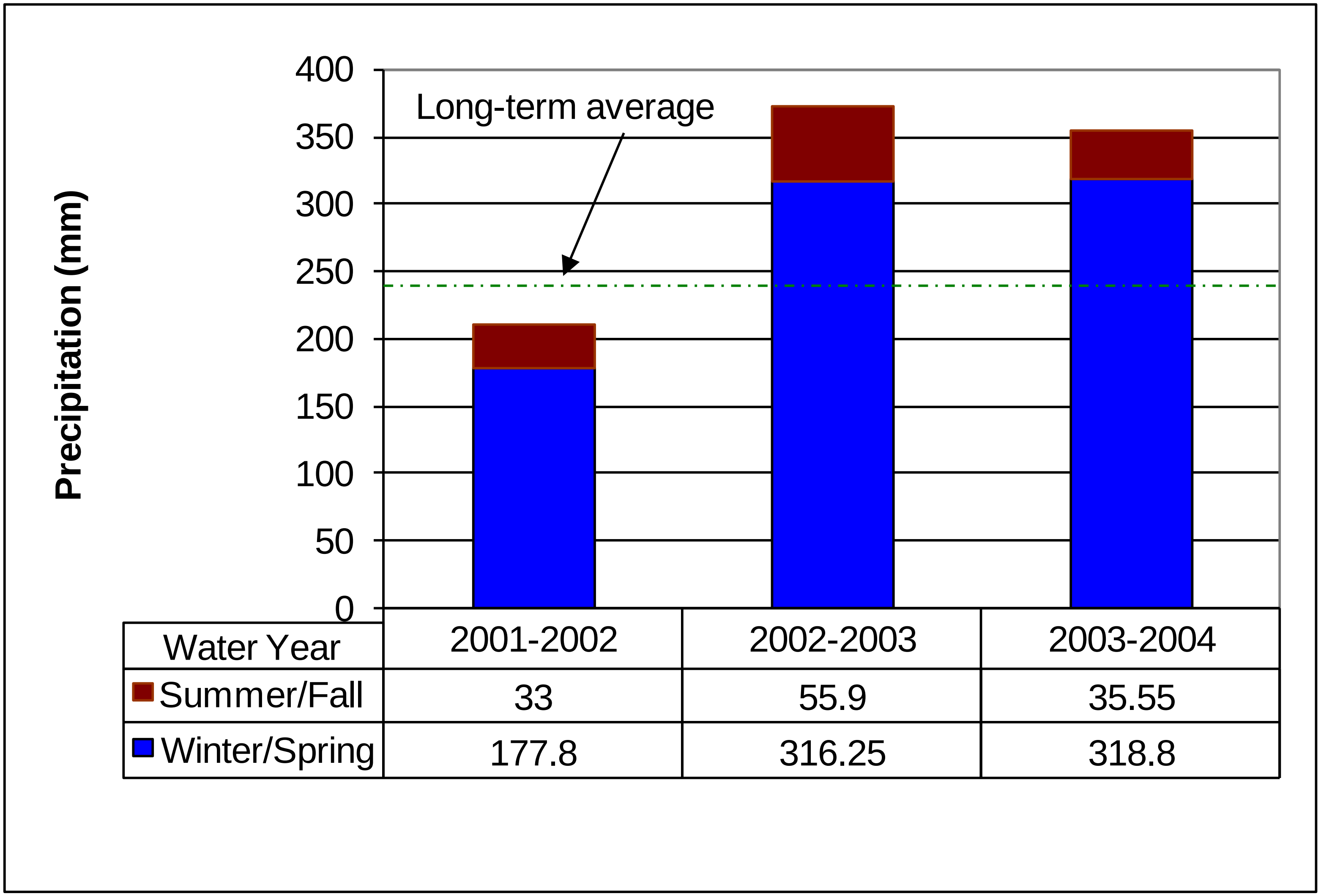
DISCUSSION

Pre-grazing

Precipitation. Precipitation is probably the single most important influence on vegetation in the sagebrush-steppe (Welch 2005). The cumulative growing-year precipitation prior to the first sample period (pre-graze) was 77% higher than that received during the 2001 study (Staggs 2006) and 47% higher (Fig. 8) than the long-term mean for this area (NRCS 2004). The previous growing-year (2001-2002) precipitation levels were 17% lower (Fig. 8) than the estimated long-term mean for this site. After recovering from a droughty period the previous years, the precipitation in 2002-2003 probably helped recharge soil moisture and drive production of vegetation during my study.

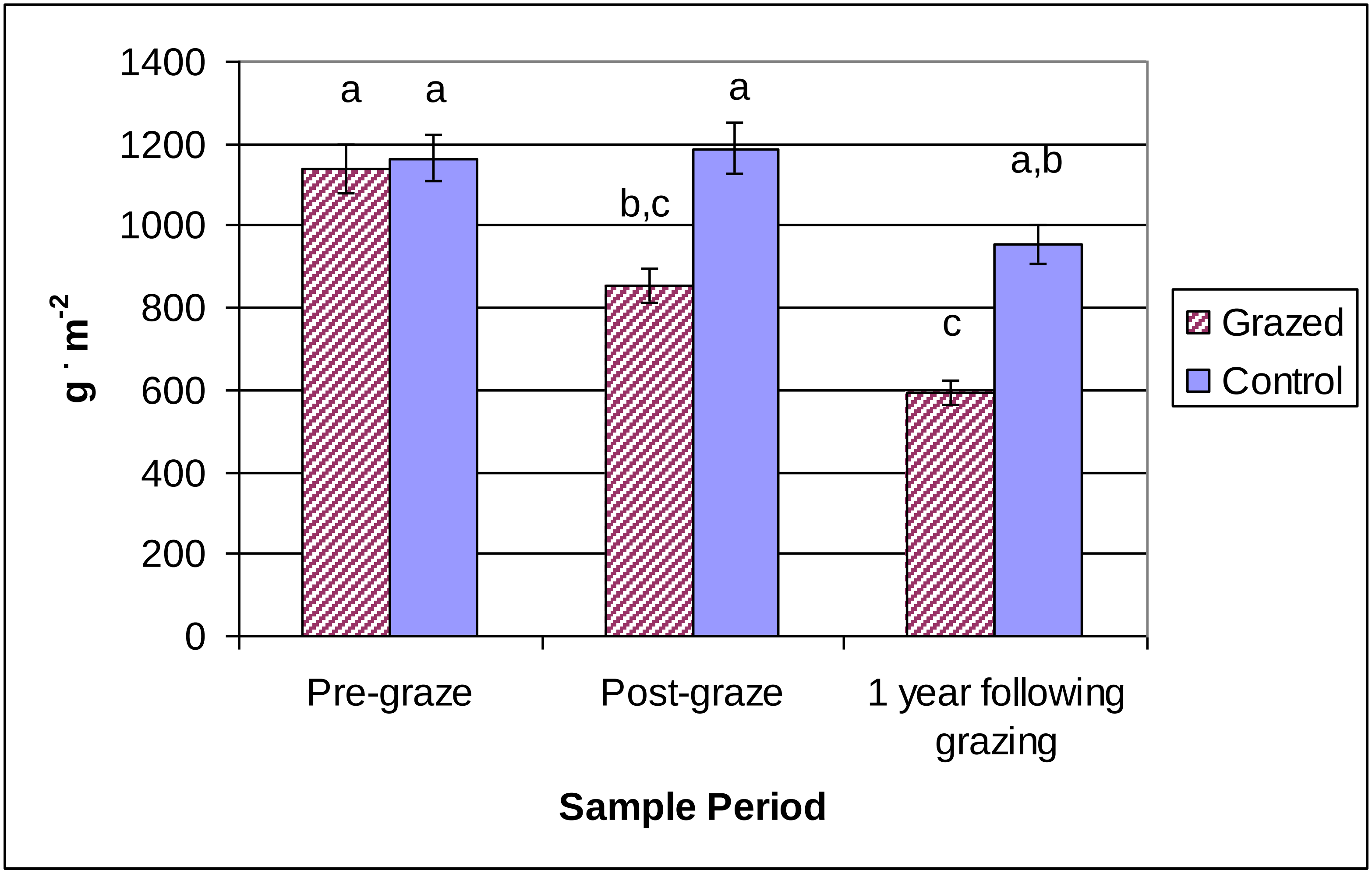
Phytomass. As no statistically significant difference was found between the two treatments at the first sampling, when considering total phytomass (Fig. 9), both the control plots and the plots to be grazed were at an even starting point, thus making it potentially easier to discern any treatment effects. The majority of the phytomass was, however, comprised of dead material (herbaceous and woody). This was expected, as one looks at these communities, it is obvious that the woody and herbaceous litter and standing dead far outweigh their living counterparts, a situation we considered undesirable for wild and domestic animals.

The subcategories with no significant differences between treatments at the first sampling were CAG of ARTRWY, woody portion of ARTRWY, CAG of other shrubs, woody portion of other shrubs, grasses, forbs, woody standing dead, herbaceous standing dead, woody litter, and herbaceous litter (Figs. 10, 11, 12, 13, 14, 15, 16, 17, 18, and 19).



Water Year	2001-2002	2002-2003	2003-2004
Summer/Fall	33	55.9	35.55
Winter/Spring	177.8	316.25	318.8

Figure 8 - Amount and timing of mean annual precipitation received at the study area for 3 consecutive years.



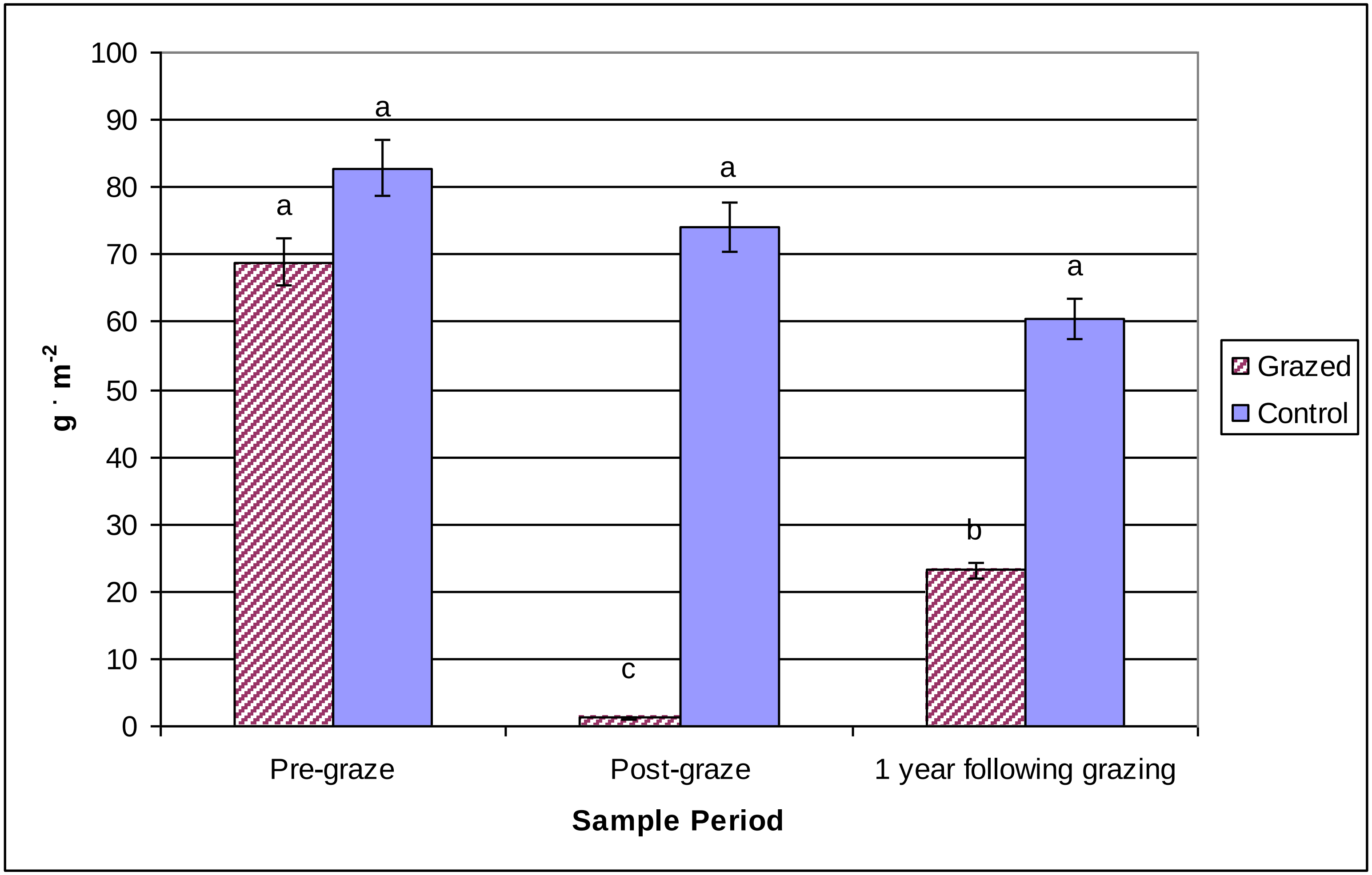
Columns with a different letter are significantly different ($p < 0.05$).

Figure 9 - Comparison of total phytomass between treatments across the 3 sample periods.

The only category where a significant difference was detected between treatments at the first sampling was herbaceous standing dead (Fig. 17). There was more herbaceous standing dead in the ungrazed control plots than in the plots to be grazed. This difference may be due either to sampling error, or the plots we were going to graze were heavily grazed during the fall of 2001 (Staggs 2006), and may not have re-grown an amount of herbaceous material comparable to that in the ungrazed controls, thus having less herbaceous standing dead material 2 years later. At any rate, as this category represents a relatively small portion of the total biomass, this difference is not of great concern.

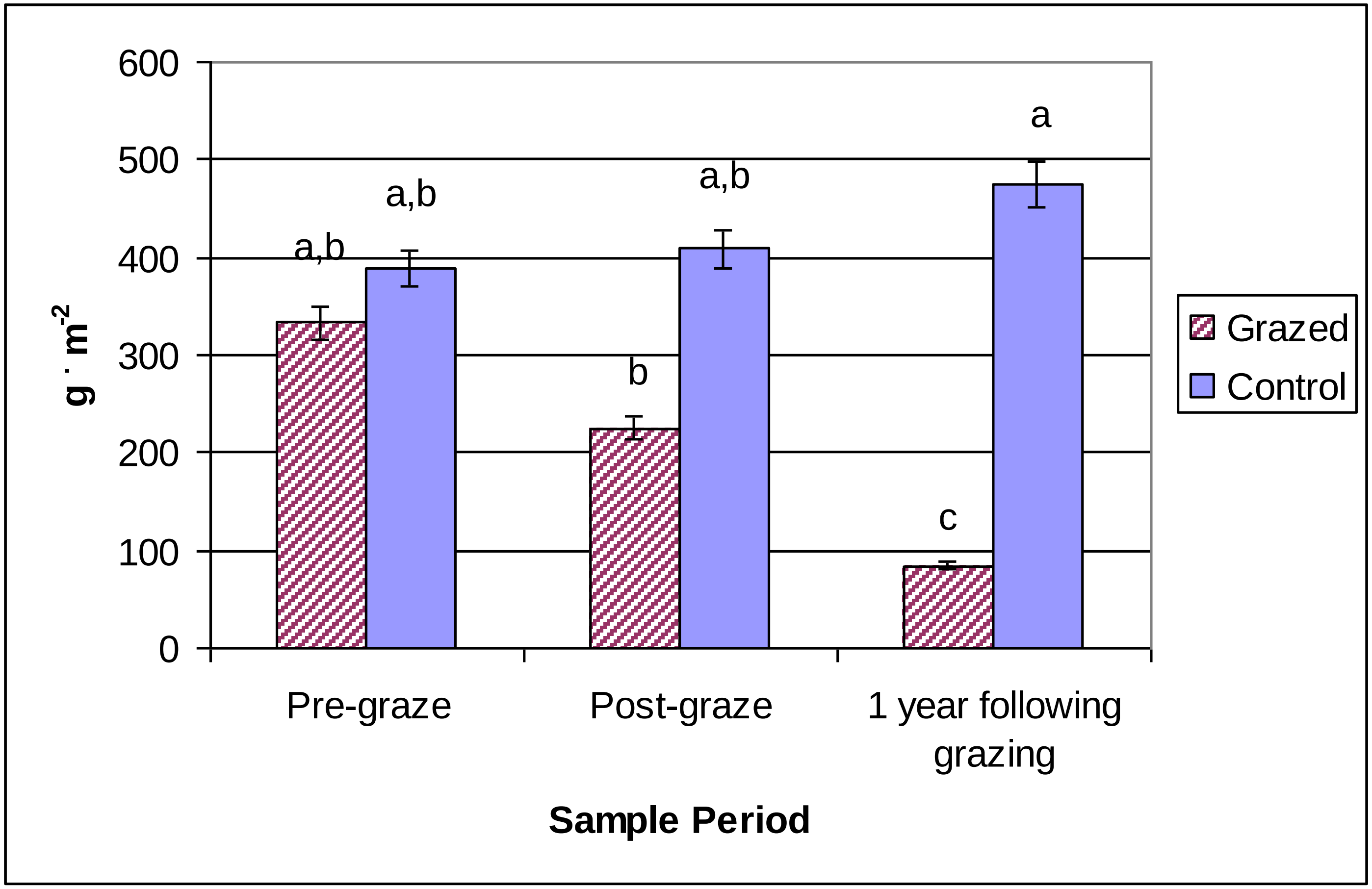
Age Class Structure. When considering the age class distribution of ARTRWY, I wanted to see how close the actual distribution was to the ideal. Theoretically, an ideal distribution in the fall/winter would have the majority of ARTRWY in age classes 5, 6, 7, and 8, with a lesser amount in age classes 2, 3, and 4, and very little in age class 1 (Fig. 20). In the spring, I would expect much more coming from the younger age classes, as most of those die through the course of the usual drought of summer (Welch 2005). However, as I measured the relative contribution of each age class to the total CAG of ARTRWY, rather than $\text{numbers of plants} \cdot \text{m}^{-2}$, these differences were undetectable. I consider an inordinate amount coming from any one group or groups of age classes undesirable. For instance, I would be concerned that most of the available resources are tied up in the older, aging and senile plants with little to no recruitment taking place if I saw 25% of age class 8, 30% of age class 7, 26% of age class 6, 8% of age class 5, 5% of age class 4, 3% of age class 3, 2% of age class 2 and, $\leq$1% of age class 1.

When comparing the two treatments at the first sampling, the age class distribution of ARTWY was nearly the same in all three replicates (Fig. 21). I did not



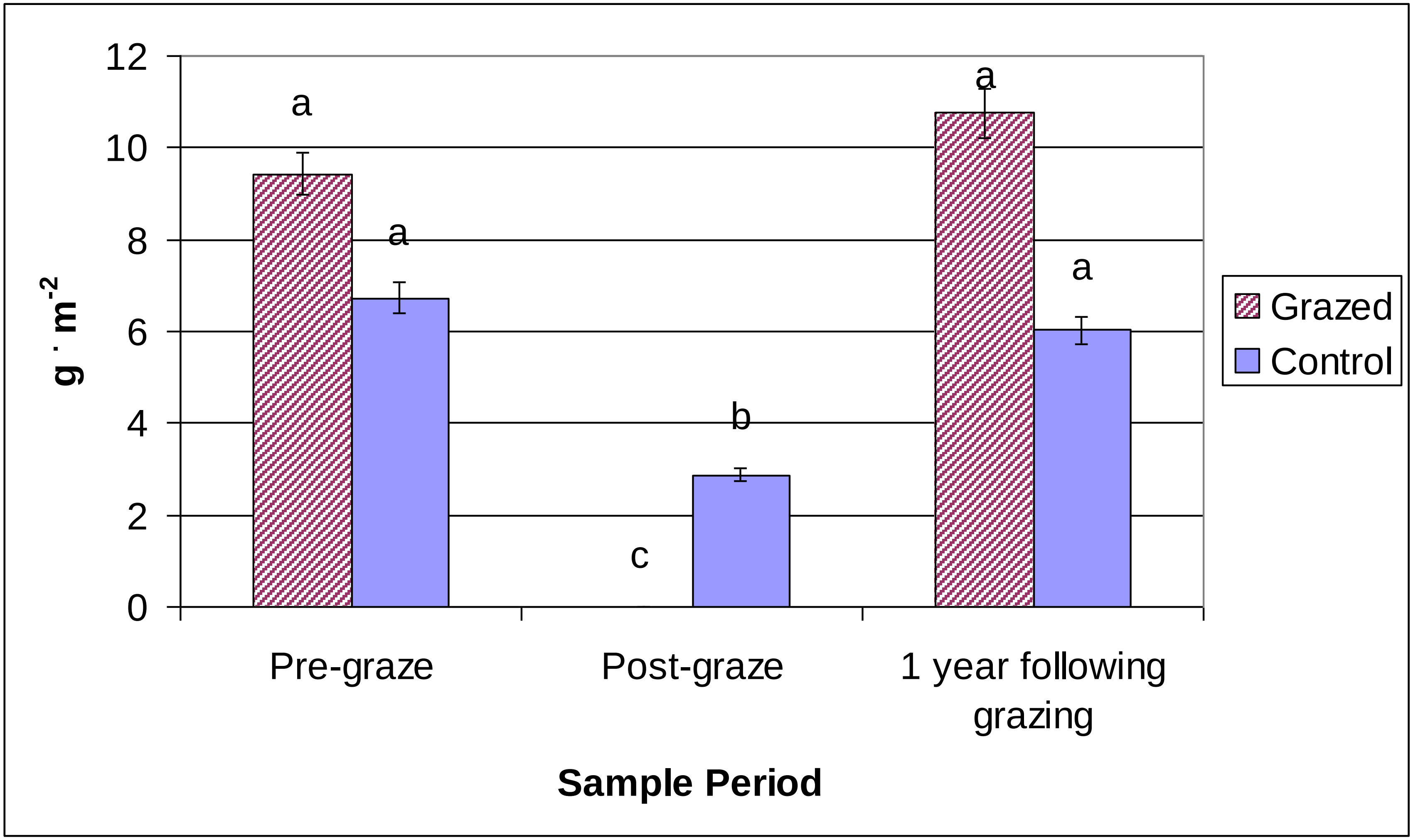
Columns with a different letter are significantly different ($p < 0.05$).

Figure 10 - Comparison of Wyoming big sagebrush CAG between treatments, across the three sample periods.



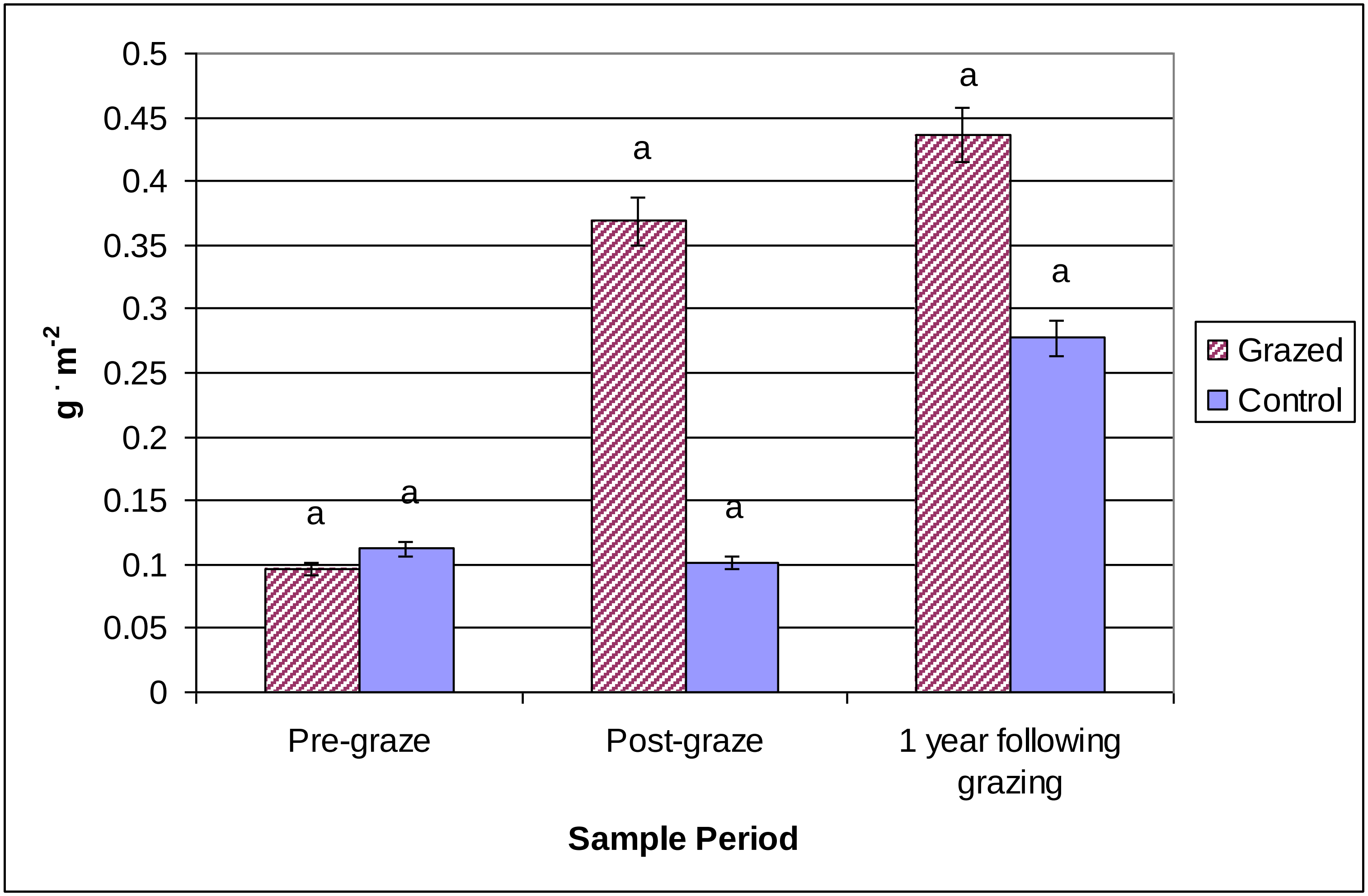
Columns with a different letter are significantly different ($p < 0.05$).

Figure 11 - Comparison of the woody portion of Wyoming big sagebrush between treatments, across the three sample periods.



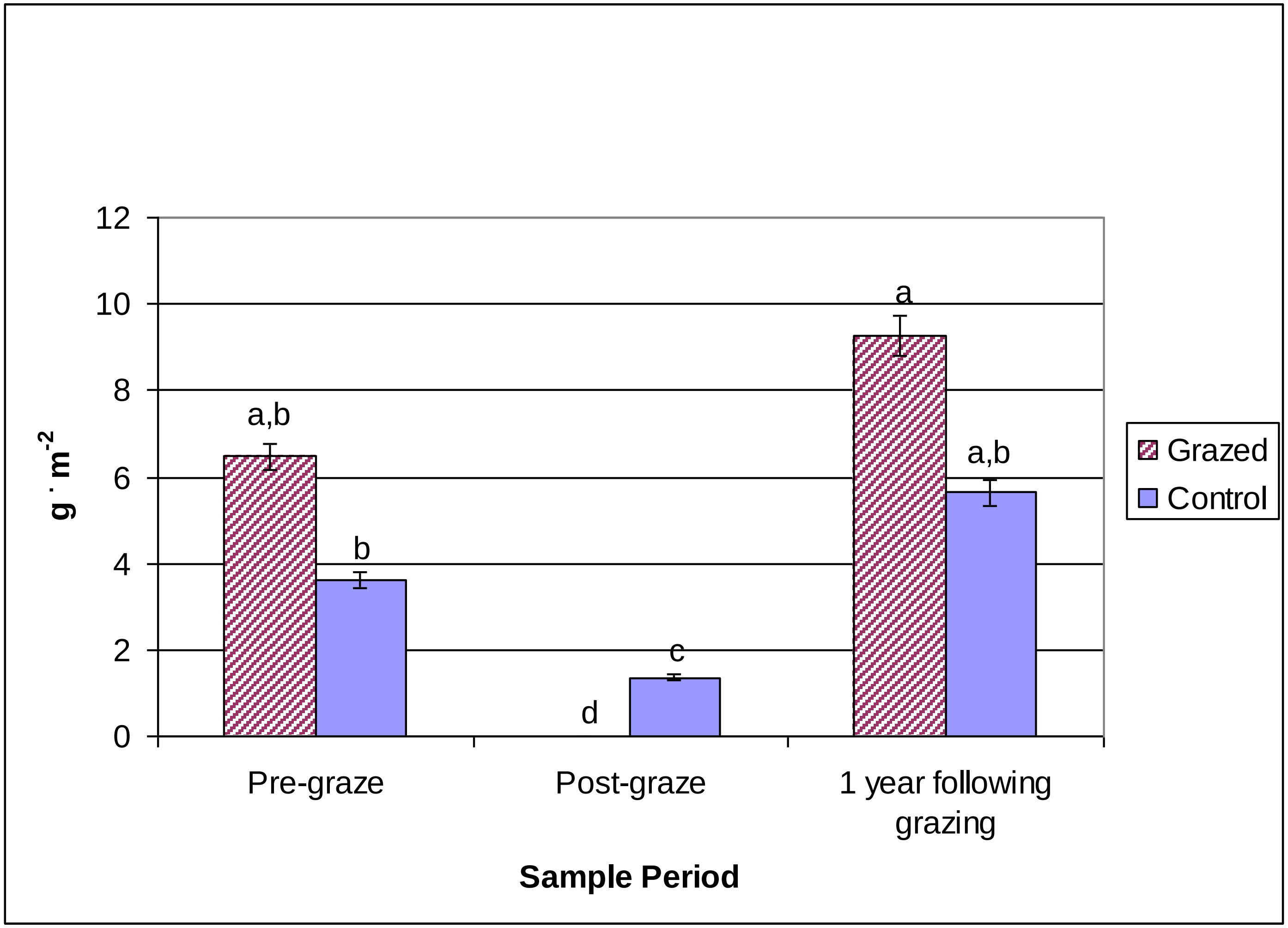
Columns with a different letter are significantly different ($p < 0.05$).

Figure 12 - Comparison of the CAG of other shrubs between treatments, across the three sample periods.



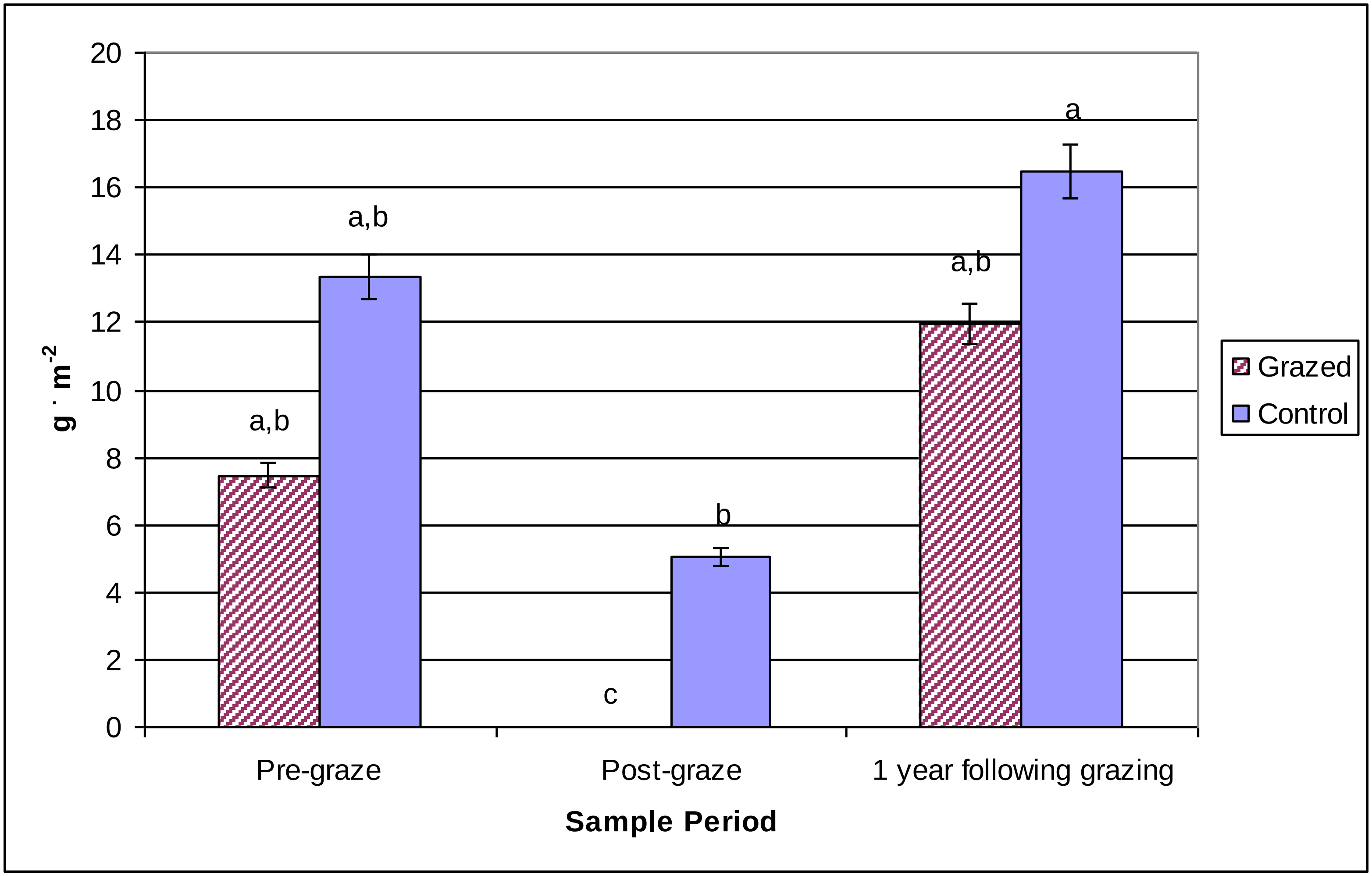
Columns with a different letter are significantly different ($p < 0.05$).

Figure 13 - Comparison of the woody portion of other shrubs between treatments, across the three sample periods.



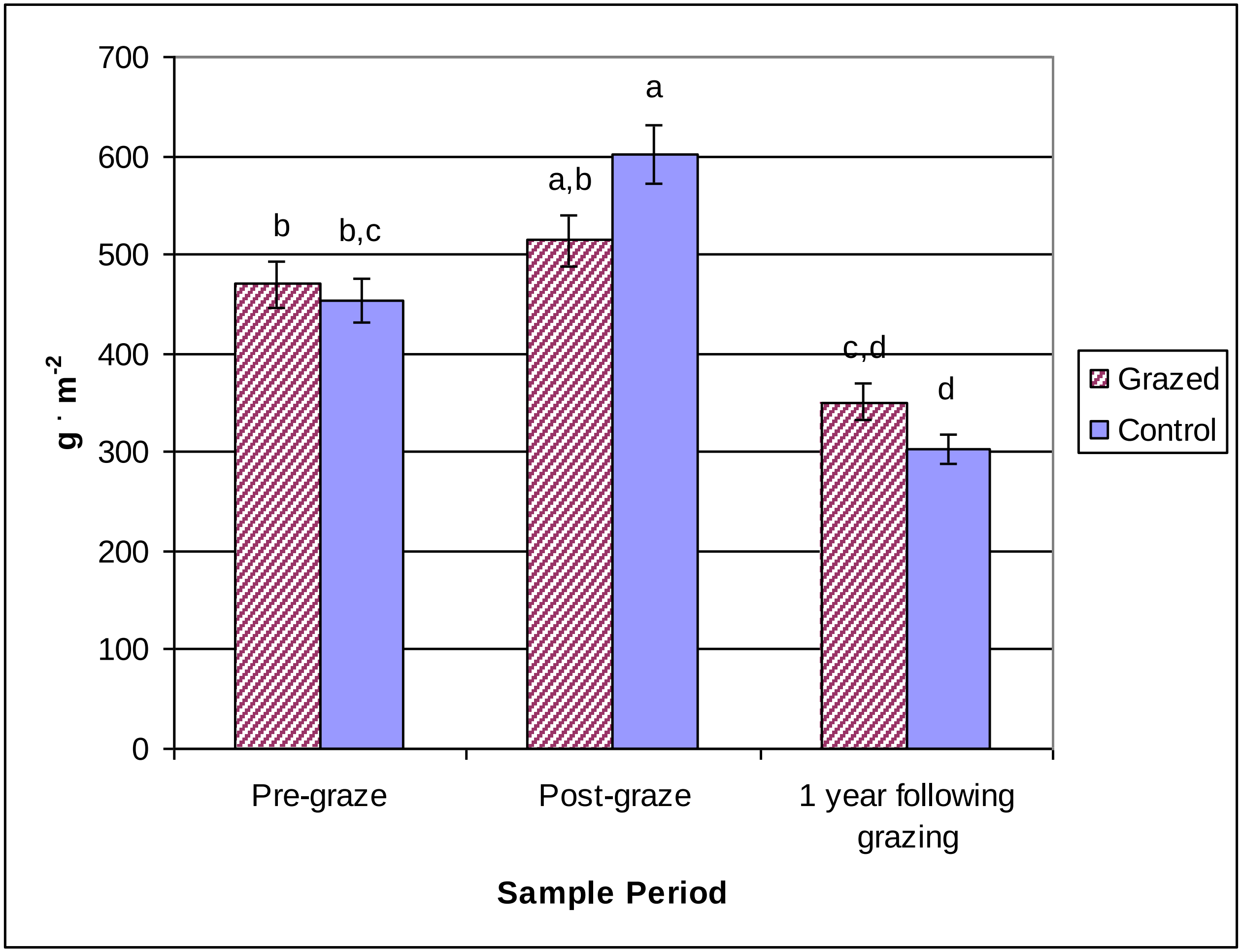
Columns with a different letter are significantly different ($p < 0.05$).

Figure 14 - Comparison of grasses between treatments, across the three sample periods.



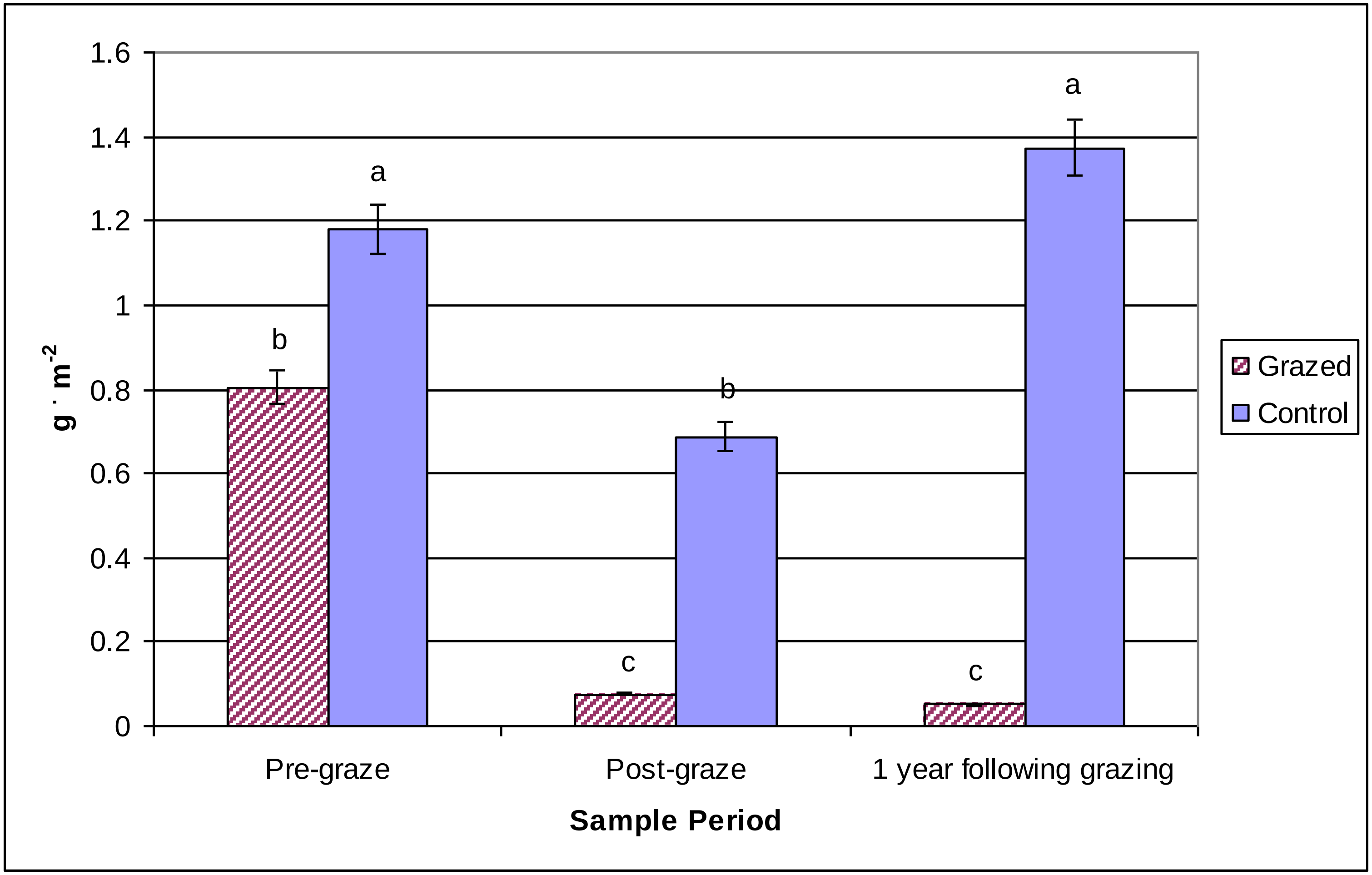
Columns with a different letter are significantly different ($p < 0.05$).

Figure 15 - Comparison of forbs between treatments, across the three sample periods.



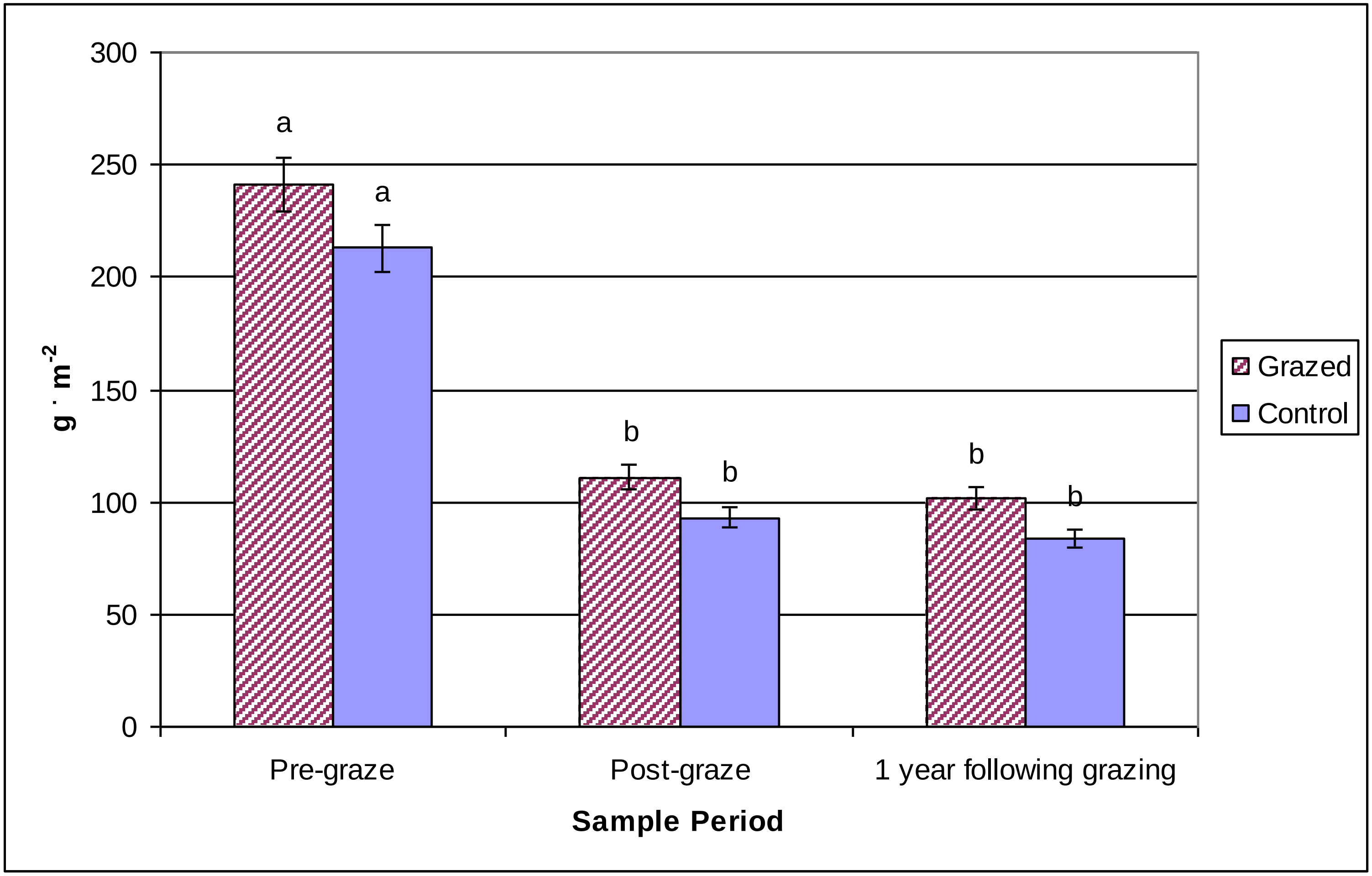
Columns with a different letter are significantly different ($p < 0.05$).

Figure 16 - Comparison of woody standing dead material between treatments, across the three sample periods.



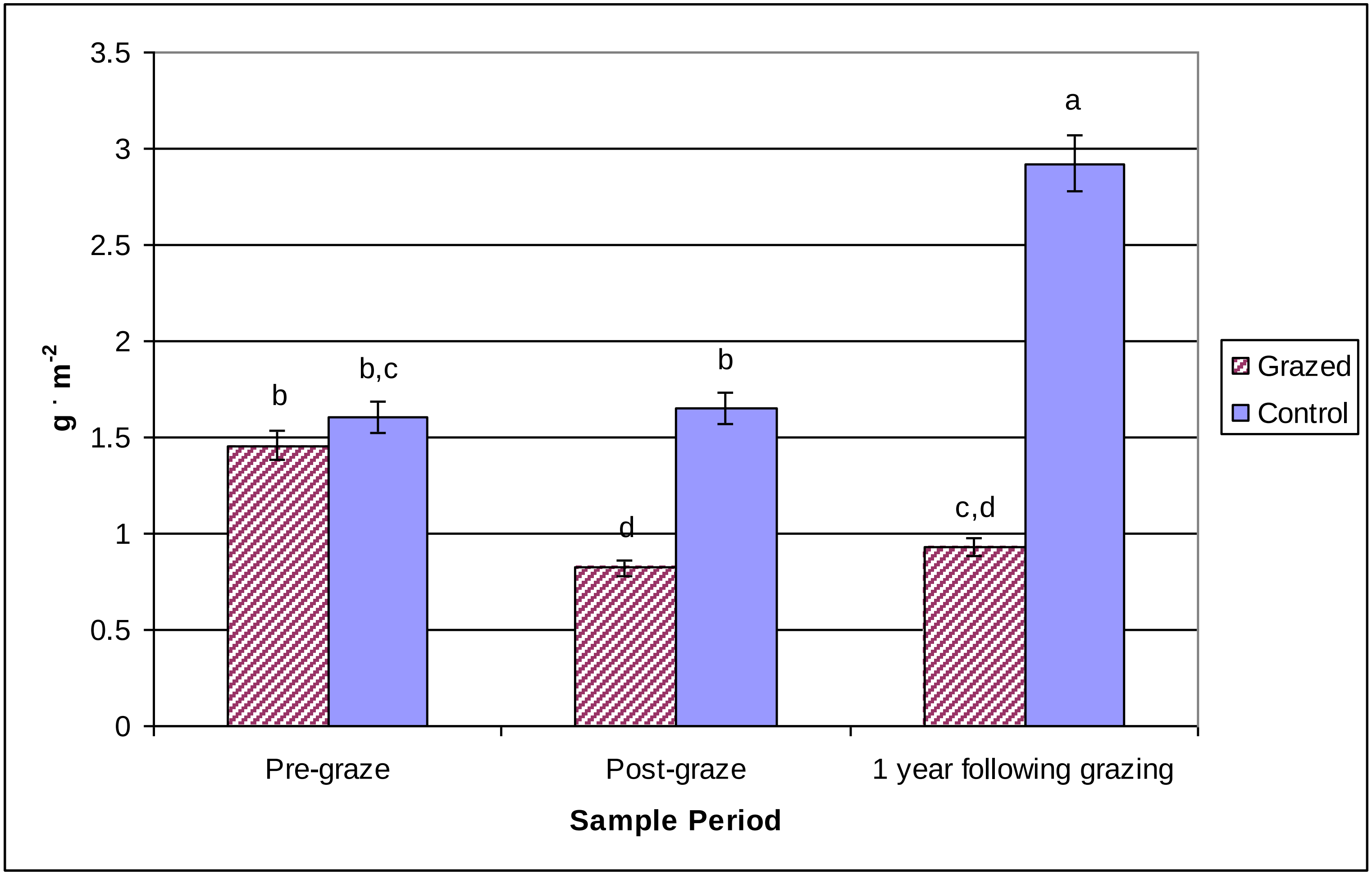
Columns with a different letter are significantly different ($p < 0.05$).

Figure 17 - Comparison of herbaceous standing dead material between treatments, across the three sample periods.



Columns with a different letter are significantly different ($p < 0.05$).

Figure 18 - Comparison of woody litter between treatments, across the three sample periods.



Columns with a different letter are significantly different ($p < 0.05$).

Figure 19 - Comparison of herbaceous litter between treatments across, the three sample periods.

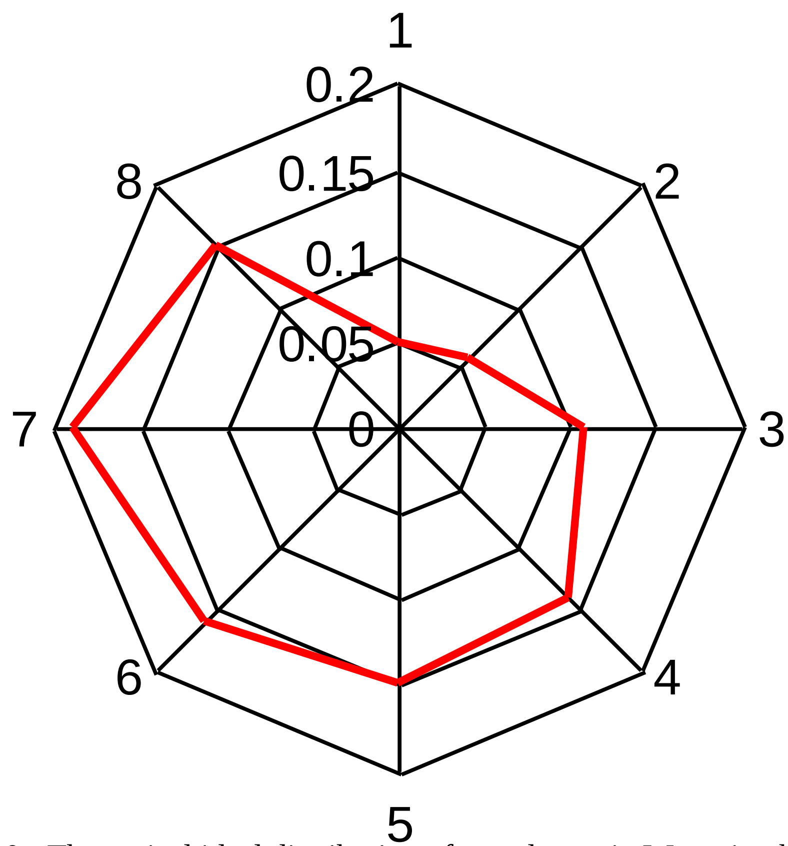


Figure 20 - Theoretical ideal distribution of age classes in Wyoming big sagebrush.

expect to find much, if any, difference in proportions of the various age classes at this point in time. The majority of CAG production of ARTRWY came from age classes 4 and 5, with small amounts from the other classes. Age class 4 is still considered juvenile/pre-reproductive (Gatsuk et al. 1980). Age class 5 is obviously older because of the development of a few reproductive stalks (Fig. 6). Thus, during the first sampling period, the majority of the sagebrush was young-middle aged according to my classification system. Why did we see such a huge percentage occur in these two classes? One possible explanation is that when this area was grazed heavily by sheep from about 1880 to 1969 -- approximately 65,000 head at the peak (Washington-Allen 2003) -- sagebrush was kept at a lower density. With the switch from sheep to cattle grazing in the early 1970's, sagebrush had a competitive advantage, due to the emphasis on spring and summer grazing of herbs by cattle, that likely caused a surge in its population growth. We could now be seeing the results of that recruitment with a dominance of the adolescent/middle-aged plants in age classes 4 and 5. I hypothesized that through the grazing treatment, I could make this distribution more even throughout the other age classes.

Biodiversity. When discussing species richness, the control plots started with 6 fewer species than did the grazed plots at the first sampling (Fig. 7). I expected them to be more similar than they were. I do not know why the initial difference existed, but it is possible that when the three replicates were selected, they were not as uniform as we had originally expected. Alternatively, the difference could be due to grazing by sheep in an experiment conducted in 2001 (Staggs 2006).

Regardless of the previous treatment, when considering species

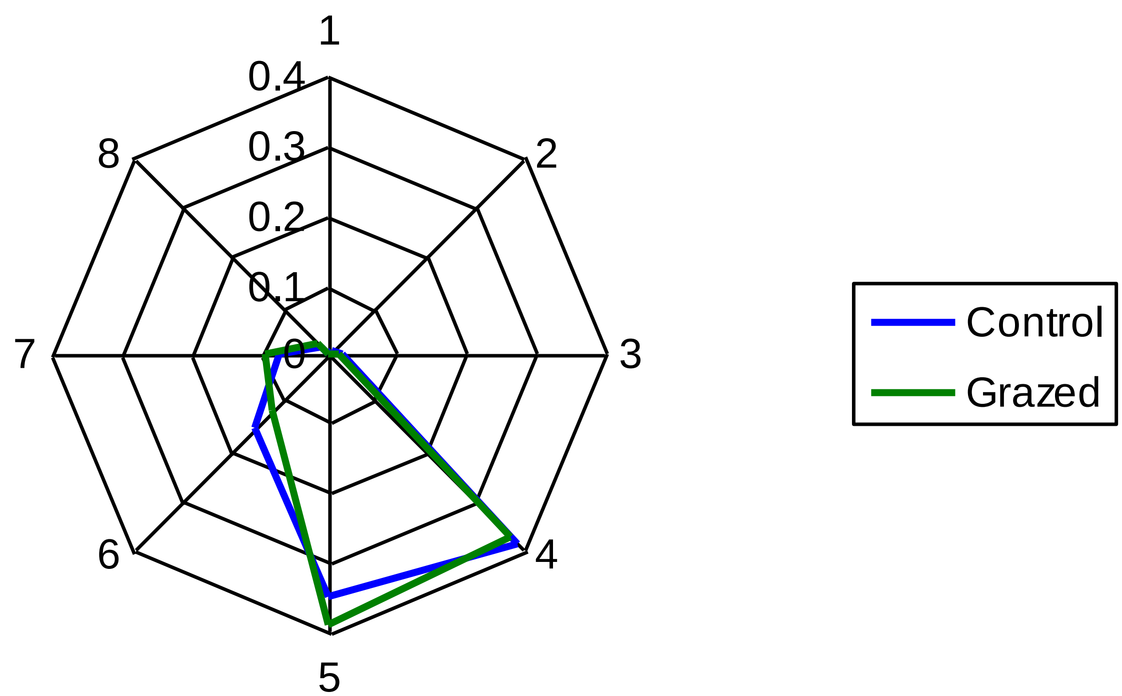


Figure 21 - Relative contributions (%) of each age class to the total mean CAG ($g \cdot m^{-2}$) of Wyoming big sagebrush, between treatments, at the first sampling.

dominance/diversity, there were several "major players" common in all the grazed and control plots. The initially common dominant plant was ARTRWY (Tables 8 & 17). Another shrub common between treatments was Low rabbitbrush. Of the perennial grasses, Bluebunch wheatgrass and Sandberg bluegrass were the major contributors to total phytomass. The dominant perennial forbs were Carpet phlox and Low pussytoes.

In the control plots, there were 5 species of shrubs, 7 species of grasses, and 8 species of forbs. Of the grasses, all of the species encountered were perennials. Of the forbs, seven species were perennials and one was an annual. Using the values in Table 8 and the following equation, forbs were estimated to be 79% of the herbaceous phytomass, while grasses were 21% of the total herbaceous phytomass:

$$proportion\ of\ grasses / forbs = \frac{\sum forb/grass\ phytomass\,(g \cdot m^{-2})\ values\ in\ column\ 3}{\sum all\ herbaceous\ phytomass\,(g \cdot m^{-2})\ values\ in\ column\ 3}$$

Thus, forbs were an important component of these systems.

In the grazed plots, there were 5 species of shrubs, 8 species of grasses (7 perennial, 1 annual), and 10 species of forbs (8 perennial, 2 annual). Using the aforementioned equation, I calculated that, of the herbaceous species, forbs were 53% and grasses were 47%. Although forbs did not make up as large of a proportion of the herbaceous component in this instance, they were still an important component of the vegetation. This difference may be explained by variations in previous disturbances, in potential production between sites, or due to recent sheep grazing in 2001 (Staggs 2006) following several previous decades by cattle (Washington-Allen 2003).

Overall, the data generally showed: dominance by sagebrush, with forbs and grasses playing a lesser role. I hypothesized the grazing treatments would reduce the

Table 17 - Comprehensive list of plant species encountered during the study, across the three sample periods. Abbreviations used, Latin and common names (from *PLANTS* website), and desirability to managers of Deseret Land and Livestock.

Species Code	Latin Name	Common Name	Desirability
AGCR	*Agropyron cristatum*	Crested Wheatgrass	Desirable
ALAC	*Allium acuminatum*	Tapertip Onion	Desirable
ALDE	*Alyssum desertorum*	Desert Madwort	Undesirable
ANDI	*Antennaria dimorpha*	Low Pussytoes	Desirable
ARHO	*Arabis holboellii*	Holboell's Rockcress	Undesirable
ARAR	*Artemisia arbuscula*	Little Sagebrush	Desirable
ARTRWY	*Artemisia tridentata* ssp. *Wyomingensis*	Wyoming Big Sagebrush	Desirable
ASCI	*Astragalus cibarius*	Browse Milkvetch	Desirable
ASCO	*Astragalus convallarius*	Lesser Rushy Milkvetch	Desirable
ASJE	*Astragalus jejunus*	Starveling Milkvetch	Desirable
ASPU	*Astragalus purshii*	Woolypod Milkvetch	Desirable
BRTE	*Bromus tectorum*	Cheatgrasss	Undesirable
CACH	*Castellja chromosa*	Indian Paintbrush	Desirable
CHAL	*Chenopodium album*	Lambsquarters	Undesirable
CHDO	*Chaenactis douglasii*	Douglas' Dustymaiden	Desirable
CHVI	*Chrysothamnus viscidiflorus*	Yellow Rabbitbrush	Undesirable
COUM	*Comandra umbellata*	Bastard Toadflax	Undesirable
CORA	*Cordylanthus ramosus*	Bushy Bird's Beak	Undesirable
CRMO	*Crepis modocensis*	Modoc Hawksbeard	Desirable
DEPI	*Descurainia pinnata*	Western Tansymustard	Undesirable
ELEL	*Elymus elemoides*	Squirreltail	Desirable
ELLA	*Elymus lanceolatus*	Thickspike Wheatgrass	Desirable
ERCO	*Erigeron compactus*	Cushion Daisy	Desirable
GIIN	*Gilia inconspicua*	Shy Gilia	Desirable
HAPA	*Hackelia patens*	Stickseed	Undesirable
KRLA	*Kraschennikovia lanata*	Winterfat	Desirable
LEPU	*Leptodactylon pungens*	Prickly Phlox	Undesirable
LOAM	*Lomatium ambiguum*	Wyeth Biscuitroot	Desirable
LOMA	*Lomatium macrocarpum*	Bigseed Biscuitroot	Desirable
OPUNTIA	*Opuntia polycantha*	Plains Pricklypear	Undesirable
PASM	*Pascopyrum smithii*	Western Wheatgrass	Desirable
PENSTEMON SPP.	*Penstemon* sp.	Penstemon	Desirable
PHHO	*Phlox hoodii*	Carpet Phlox	Desirable
PHLO	*Phlox longifolia*	Longleaf Phlox	Desirable
POFE	*Poa fendleriana*	Muttongrass	Desirable
POSE	*Poa secunda*	Sandberg Bluegrass	Desirable
PSSP	*Pseudoroegneria spicata*	Bluebunch Wheatgrass	Desirable
SEIN	*Senecio integerrimus*	Columbia ragwort	Desirable
STCO	*Stipa comata*	Needle-and-thread	Desirable
STHY	*Stipa hymenoides*	Indian Ricegrass	Desirable
TECA	*Tetradymia canescens*	Spineless Horsebrush	Undesirable
TRGY	*Trifolium gymnocarpon*	Hollyleaf Clover	Desirable
ZIPA	*Zigadenus paniculatus*	Deathcamus	Undesirable

dominance by sagebrush and increase the herbaceous understory, but not necessarily in the manner of a zero sum game (Welch 2005), as both components could increase as well, as they did under the wetter than average conditions encountered following an extended drought (Washington-Allen 2003).

Post-grazing

Precipitation. The small amount of precipitation received between the first and second samplings (1.7 mm), in addition to its timing during a cool period, probably had little effect on the vegetation shortly after the sheep left on October 16 and 17, 2003.

Phytomass. I compared the first and second samplings. The lack of any significant difference from the first to the second periods in total phytomass for the control plots was expected (Fig. 9). As the time separating the two sample periods was so short, it is unlikely much additional growth occurred during the cool temperatures after our first sampling. When referring to Figures 10, 12, 14, and 15, the categories that could have regrown enough to increase total phytomass (CAG of shrubs or herbaceous species) actually decreased. Also referring to Figures 11 and 16, the woody components most likely responsible for the increase in total phytomass could not have actually increased that much in so short a time. The other explanation is that there was a significant amount of fall “green-up” that took place. However, this is unlikely as the amount of precipitation received was very small (1.7 mm) and by this time the cool season grasses had begun to senesce and even some of the persistent leaves of ARTRWY had started to drop. Miller and Shultz (1987) found that sagebrush plants only maintain 1/3 of their leaves over winter. Both of these influences would actually decrease total phytomass.

Of the total phytomass in the control plots, the live portion decreased slightly. Because leaf senescence and abscission are normal in October (Miller and Shultz 1987), this was not surprising. Of the live fraction, the amount of ARTRWY CAG in the control plots tended to decrease from the first to the second sampling, as expected (Miller and Shultz 1987), though the change was not statistically significant. As shown in Tables 9 and 16, plots 2A and 3B had more ARTRWY CAG ($g \cdot m^{-2}$) than plot 1C in the pre-graze period, and this trend continued to the second sample period with all three showing a roughly equal decrease. This trend is important as it suggests the differences do not come from sampling error, but rather inherent differences between replicates in either their capabilities for production or subtle differences in previous disturbance histories.

The woody portion of ARTRWY did not increase in the control plots over time (Fig. 11). The CAG of other shrubs in the control plots also decreased from the first sample period (Fig. 12), as expected due to normal leaf senescence and abscission in late summer/fall (Miller and Shultz 1987). This leaf shedding was also visually noticeable for other shrub species such as Low rabbitbrush, Horsebrush, and Winterfat. The decrease in the woody portion of other shrubs (Fig. 13) is of little concern, however, as it is a relatively small contribution to the total phytomass. This decrease is likely due to sampling error, or as mentioned with ARTRWY, to increased visibility of the woody portion of the plants after leaf senescence, especially for Low sagebrush. Thus my estimates of this component were probably more accurate during the second sampling than the first.

The significant decrease of grasses in the control plots was somewhat unexpected (Fig. 14). Even when considering leaf senescence, I did not expect the grasses to decrease to this degree between the first and second sample periods. Though sampling error is one explanation, data collection at the second sample period was interrupted by an early snowstorm, rendering our study site inaccessible until early the following spring. It is possible grasses alive and standing in the fall were pushed over, decomposed, or counted as herbaceous litter when sampling resumed in the spring, thus misrepresenting this category. Another explanation is that leaf senescence and abscission played more of a role between the two samplings than I originally reckoned. The forbs in the control plots more closely followed what I expected to see. Although there was a decrease between the first and second sample periods (Fig. 15), it was within expected bounds and can likely be attributed to leaf senescence.

Of the total phytomass in the control plots, the dead portion decreased slightly. As this decrease was quite small (1%), it is not of concern. Any differences between the first and second samplings are most likely due to sampling error. Of the dead fraction in the control plots, the increase in woody standing dead (Fig. 16; $P < 0.0126$) and the decrease of woody litter (Fig. 18; $P = 0.0001$) should largely be attributed to sampling error as the likelihood is very small that a significant amount of dead woody material was either created or lost from the first to the second sampling.

Herbaceous standing dead material decreased from the first to the second sampling in the control plots (Fig. 17; $P = 0.0054$). This was expected as some herbaceous standing dead normally breaks off or falls over at the end of the growing season, which would cause an increase in herbaceous litter. Herbaceous litter tended to increase in the control plots from the first to the second sampling, though not significantly (Fig. 19). This increase is not surprising; however, if herbaceous standing dead decreased, I would expect herbaceous litter to increase, even considering the short time period involved. With this in mind I must attribute these changes, at least in part, to sampling error.

Total phytomass in the grazed plots decreased from the first to the second sampling, as expected (Fig. 9; P = 0.0377). I knew that with the degree of use I hoped to achieve with the sheep grazing there would be a stark difference in total phytomass between the two sampling periods. The live fraction of total phytomass in the grazed plots showed a noticeable decrease (13%), which, again, was expected. The sheep ate almost all the green foliage, both from the shrubs and herbaceous plants. At the density they were grazed, the sheep did not have much choice.

Of the live fraction in the grazed plots, CAG of ARTRWY, CAG of other shrubs, grasses, and forbs all decreased drastically from the first sampling (Figures 10, 12, 14, and 15). Again, at the density that the sheep were grazing ($60\,m^2 \cdot ewe^{-1}$), I expected them to eat almost all green foliage. I knew sheep would eat sagebrush, under various conditions (Dziba et al. 2007, Burritt et al. 2000, Snowder et al. 2001, Welch et al. 1987, Frischknecht and Harris 1973), but I was not sure how much they would eat under the conditions of this experiment. As the grazing began, the sheep initially concentrated on the forbs and grasses, but by day 3 the herbaceous understory was almost completely used; from this point on the sheep were mostly restricted to the use of CAG of ARTRWY for the bulk of their diets, as well as any herbaceous litter and herbaceous standing dead under the shrub crowns that became available as the shrubs were stripped of their foliage. The result was that they ate 98% of the CAG of ARTRTWY, 100% of the CAG of other shrubs, 100% of live grass, 100% of the forbs, 90% of herbaceous standing dead material, and 44% of the herbaceous litter. These levels of consumption may be due to the lack of alternatives, but we must also seriously consider the interplay of stocking rates, stock density and animal behavior, as well as the effect of the supplement on the sheep's physiological ability to offset the effects of the secondary metabolites in ARTRWY.

Although the sheep grazed these plots for a total of 10 days, the desired level of utilization probably occurred around day 6 (F. Provenza, pers. observation). The difference between those 4 days could potentially be very important. Using 10 days as the grazing period, the sheep-days are calculated as follows:

$$60m \times 40m = 2400m^2 \Rightarrow \frac{2,400m^2}{10,000m^2\ ha^{-1}} = 0.24\,ha \Rightarrow \frac{40hd}{0.24ha} = \frac{166.6hd}{ha} \times 10\,days = 1,666\ sheep - days\ \cdot ha^{-1}.$$

However, when sheep-days are based on a 6-day grazing period the result is as follows:

$$60m \times 40m = 2400m^2 \Rightarrow \frac{2,400m^2}{10,000m^2\ ha^{-1}} = 0.24\,ha \Rightarrow \frac{40hd}{0.24ha} = \frac{166.6hd}{ha} \times 6\,days = 999.6\,\text{sheep - days} \cdot \text{ha}^{-1}.$$

The difference of 666.4 sheep-days $\cdot\ \text{ha}^{-1}$ means it may be possible to reach a desired level of use in this and similar vegetation over a shorter time. This result has potentially important economical, physiological, and ecological implications. Shortening the grazing period could save money while reducing the risk of crossing possibly harmful thresholds for both animal and vegetational responses. Remember, our goals were not to kill all of the sagebrush. They were to reestablish co-dominance with perennial herbaceous plants and restructuring the shrub size-age-vigor classes, without losing significant body condition of the sheep.

The other components of the live fraction of total phytomass, the woody portions of ARTRWY and other shrubs, also changed from the first to the second sampling. The decrease in the woody portion of ARTRWY (Fig. 11) could be explained by sampling error. There is also a possibility that the sheep ate some of the woody tissue, but the estimated 32% is unlikely. It is also possible that, as noted for the control plots, the second sampling was more accurate as more of the woody material was visible due to the removal of foliage by the sheep. The woody portion of other shrubs also showed a dramatic, yet statistically insignificant, increase (Fig. 13). This is, again, likely due to sampling error, or the fact that more of the shrubs, especially Low sagebrush, became visible, which enabled me to make more accurate estimates.

The dead fraction of total phytomass in the grazed plots increased slightly (13%), as expected. We anticipated the sheep would, through movements associated with grazing and extreme defoliation of older plants, create more dead woody material. Of the dead fraction, woody standing dead increased (Fig. 16) due to sheep grazing. At the first sampling, if a sagebrush plant had CAG attached to it, then at least part of it was recorded as live. If the sheep grazed a sagebrush plant particularly hard, or pushed one "teetering" on the verge of death over the edge, it shifted from live to dead. As expected, the herbaceous standing dead material decreased (Fig. 17) due to grazing by sheep.

I do not know why woody litter in the grazed plots decreased from the first to the second sampling (Fig. 18). If the woody standing dead decreased, then the woody litter should have increased. However, the woody standing dead increased, and the woody litter decreased. Where did that woody litter go? It is unlikely that it was consumed by the sheep, so we have to attribute this change to either sampling error or disappearance under the soil surface disturbed by the sheep's hooves. The decrease in the herbaceous litter from the first to the second sampling (Fig. 19) was expected. The sheep first ate the available live forbs and grasses, and then they ate the herbaceous standing dead and herbaceous litter before consuming significant amounts of ARTRWY CAG.

Age Class Structure. Referring to Tables 7 and 11 and Figure 22, the age class distribution in the control plots shifted from the first to the second sampling periods, something I did not expect. I attribute this shift largely to sampling error, as it is unlikely such a marked shift occurred in so short a time. It may also be due to leaf senescence. A plant may have appeared older during the second sampling than at the first because the physical characters used to assign an age class -- amount of reproductive stalks and vegetative growth (Gatsuk et al. 1980) -- were reduced or less apparent, hence the apparent shift.

Referring to Tables 7 and 11 and Figure 23, a shift in age class distribution is evident in the grazed plots as well. Figure 23 shows that while the amount of CAG in age class 5 showed little change, there was a dramatic decrease in age class 4 and a dramatic increase in age class 7. Again, as the time between the two sampling periods was so short, I attribute this difference to a change in how the shrubs were assigned to classes. Considering sheep removed most of the physical characters used to assign age classes, it is not surprising some plants were assigned incorrectly to age classes.

Referring to Figure 24, there is a clear difference in age class distribution between the two treatments. Because the two treatments started out with nearly the same age class distribution (Fig. 21), they should not be too much different less than 60 days later; hence I attribute this difference to sampling error, as well as incorrect assignments to age class.

Biodiversity. As the first and second samplings were separated by less than 30 days, I assumed that no detectable changes in either species richness or dominance/diversity

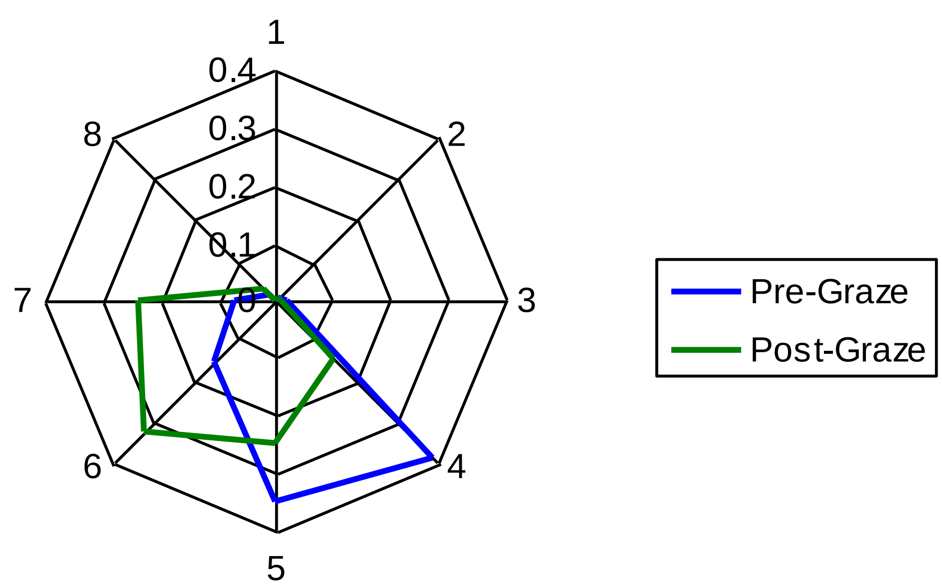


Figure 22 - Relative contributions (%) of each age class to the total mean CAG ($g \cdot m^{-2}$) of Wyoming big sagebrush, in the control plots, between the first and second samplings.

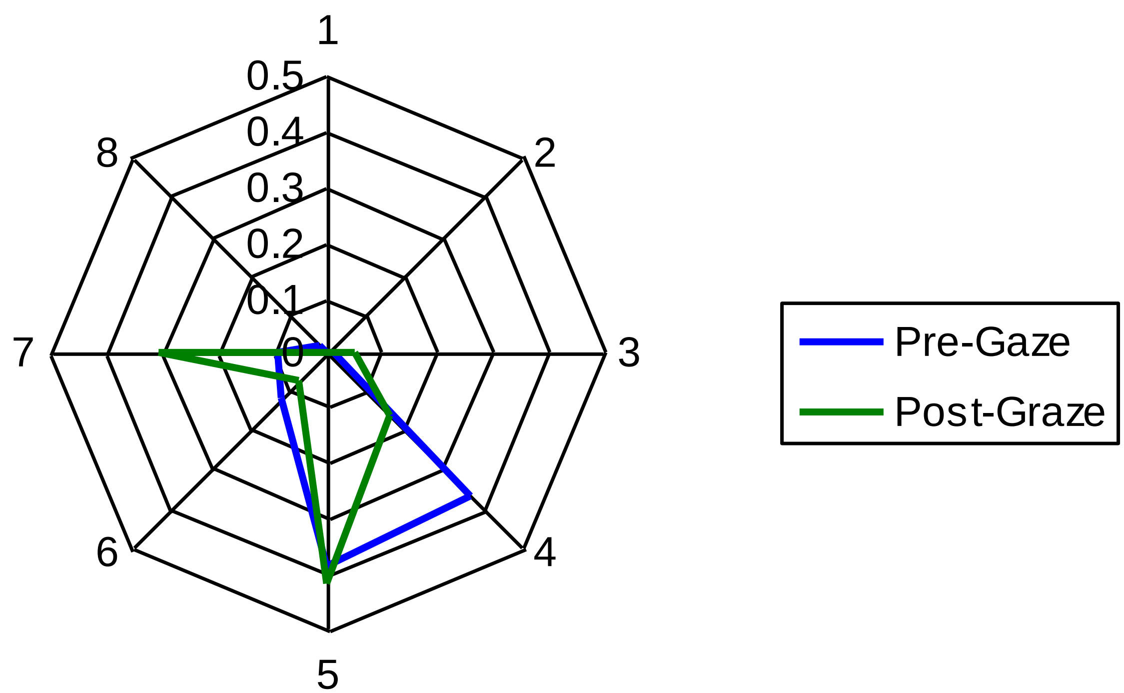


Figure 23 - Relative contributions (%) of each age class to the total mean CAG ($g \cdot m^{-2}$) of Wyoming big sagebrush, in the grazed plots, between the first and second samplings.

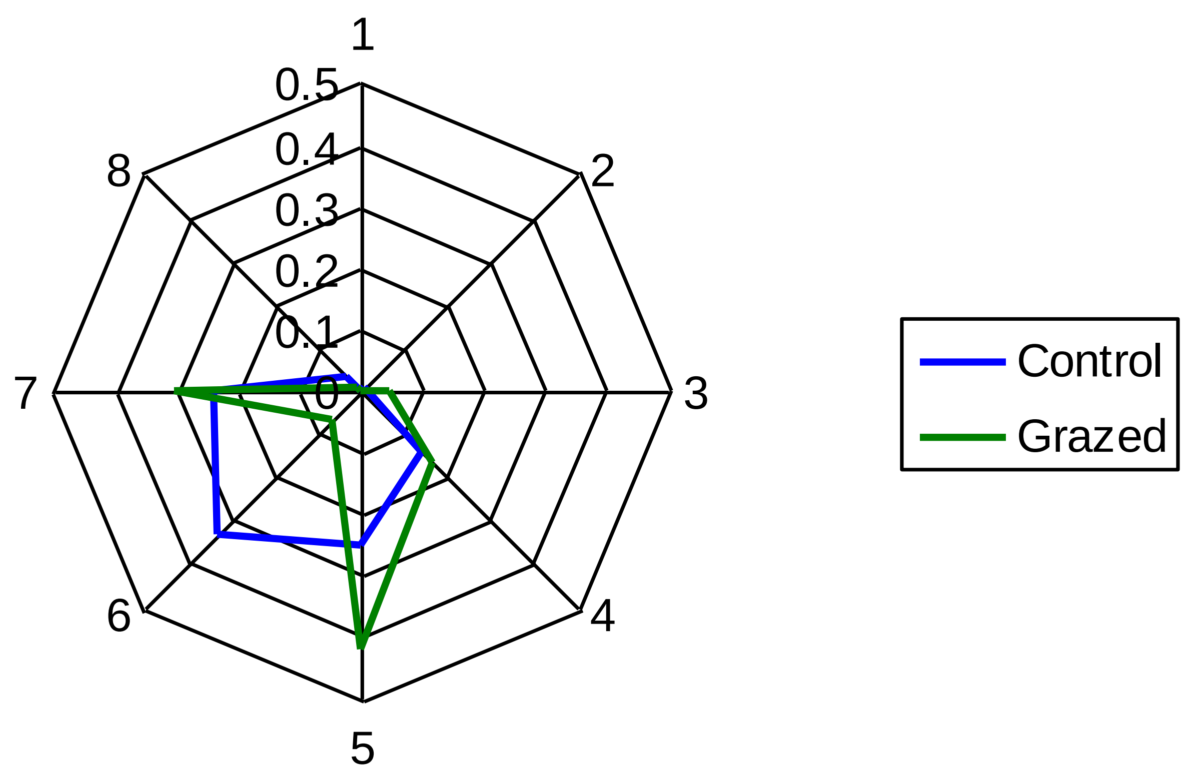


Figure 24 -Relative contributions (%) of each age class to the total mean CAG ($g \cdot m^{-2}$) of Wyoming big sagebrush, between treatments, at the second sampling.

were evident within treatments, between times, or between treatments at the second sampling. Hence, data were collected, but not analyzed, for this period.

One Year After Grazing

Precipitation. Precipitation during the 2003-2004 crop year (CYP) was 5% lower than that received during the previous crop year. However, CYP in 2003-2004 was 68% higher than that received during the 2001 study and 40% higher than the estimated long-term average for this ecological site. The amount of precipitation received in the winter/spring was slightly higher than the previous crop year (Table 1 and Fig. 8). These 2 consecutive years of above-average precipitation set the stage for a favorable response from the vegetation in our study, regardless of its previous disturbance history. If there was any effect to be seen from our grazing treatment, the soil moisture was there to support it.

Phytomass. The end of growing season mean total phytomass in the control plots decreased from the first to the third sampling and from the second to the third sampling (Fig. 9). There are two possible explanations for this decrease. The first is, of course, sampling error. The second stems from a fungal attack (snowmold) on sagebrush in the spring of 2004. By comparing data, I calculated that the CAG of ARTRWY in the control plots decreased 27% from the first to the third sampling, with an 18% decrease from the second to the third sampling. While neither decrease was statistically significant, the potential biological significance warrants some discussion. I attribute the reduction at the third sampling almost totally to the snowmold. What I saw agrees with Welch's (2005) review and with Allen et al. (1987), in that I too noticed reduced reproductive stalks and CAG. The growth on the plants had a wilted appearance that persisted throughout the summer. While I am unsure of the species of fungi, they had a noticeable impact on the shrubs in the control plots.

The snowmold may have been a blessing in disguise. While it made it difficult to cleanly discern any treatment effect from sheep grazing, it provides an opportunity for the effects of snowmold on sagebrush productivity to be quantified, something lacking in the literature (Allen et al. 1987, Welch 2005). The difficulty in studying fungal attacks, outside the laboratory, is that it is impossible to know when and where conditions will be favorable for an attack, hence making it difficult to obtain “pre-attack” data. The fungi themselves are always present (F. Baker, pers. comm.), they just need the right conditions to manifest themselves on a noticeable scale. However, we are fortunate in this case to have data from before and after the fungi attacked, providing an excellent opportunity for the first quantification of the effects of these organisms on sagebrush productivity.

The live fraction of the total phytomass in the control plots increased from the first to the third samplings due to increased production of herbaceous species. With favorable climatic conditions, and a reduction in sagebrush competition from the snowmold, the herbaceous species increased, hence increasing the live fraction of the total phytomass. As mentioned earlier, the CAG of ARTRWY decreased dramatically from the first to the second to the third sampling. Again, this dramatic reduction in the CAG of ARTRWY in the control plots can be attributed to a combination of both snowmold and sampling error. Once again, for this component in the controls, there was a noticeable difference between replicate 1 and the other 2 replicates (Table 4), likely due to differences in site potential or disturbance history between replicates.

The decrease in the CAG of other shrubs in the control plots from the first to the third sampling (Fig. 12) was not statistically significant. This was not surprising as we did not expect any significant change to take place with these minor species in the control plots when measured at the same point in the growing season 1 year apart. However, I noticed that the rabbitbrush did not look as healthy and robust during the third sampling as it did in the previous year during the first sampling. This suggests the snowmold may have impacted that species as well. Referring to Tables 8 and 16, rabbitbrush is the only "other shrub" that underwent an obvious decrease, while horsebrush increased, and winterfat and low sagebrush stayed nearly the same. The increase in the CAG of other shrubs from the second to the third sampling, significant at $P = 0.0211$, was expected and can be explained as reasonable recovery from normal leaf senescence the previous fall. Noticeable differences occurred among replicates for this component, in the controls, at the third sampling (Table 4). This same general pattern also existed at the first and second samplings, suggesting differences in site potential or disturbance histories rather than sampling error, though that cannot be ruled out.

The woody portion of other shrubs in the control plots did not change significantly from the first to the third and from the second to the third samplings. The only shrub for which I measured the woody portion, besides ARTRWY, was Low sagebrush. Since this component was only a small part of the total net primary production this lack of change was of little overall concern.

Although the grasses in the control plots comprised only a small part of the live fraction, I saw dramatic changes in this component. While the increase from the second to the third sampling ($P = 0.0003$) is not surprising and can most likely be explained as normal recovery from leaf senescence the previous fall, the increase from the first to the third sampling was not expected. While this increase was not statistically significant, the 56% increase from the first sampling was more than I expected. Aside from sampling error, it is also possible that the snowmold which attacked the shrubs may have enabled an increase in grasses as resources previously used by the shrubs became available to the grass species.

Contrary to the NRCS (1994) ecological site guide, forbs comprised more of the live fraction than did the grasses. As with the grasses, forbs increased from the second to the third sampling (P = 0.0070), likely due to normal recovery from leaf senescence the previous fall. However, the apparent increase from the first to the third sampling was not expected. While not statistically significant, it represents a 24% increase from pre-graze levels. However, if CAG of ARTRWY was reduced (possibly by the snowmold), both forbs and grasses had an opportunity to increase, though not necessarily in a 1:1 fashion (Welch 2005). Crested wheatgrass (*Agropyron cristatum*) production is inversely correlated with ARTRWY crown cover and each 1% increase in ARTRWY crown cover is associated with a 3.3-5.2% decline in potential production of Crested wheatgrass (Rittenhouse and Sneva 1976). Similar inferences may apply to other herbaceous species. Therefore, considering the combined possible effects of the snowmold and favorable climatic conditions, the increase of forbs and grasses in the control plots, while unexpected, is not surprising.

The dead fraction (standing dead plus litter) in the control plots decreased from the first and second to the third sample period. This is likely due to the increased amount of herb production noted earlier. As the relative amount of live phytomass increased, the relative amount of dead phytomass decreased. Of the dead fraction, woody standing dead decreased from the first ($P = 0.0118$) and second ($P = 0.0001$) samplings to the third sampling (Fig. 16). This was not expected. In the grazed plots, some decrease in woody standing dead was expected due to sheep breaking branches as they moved through the stands. However, there was no such influence in the control plots. The increases in herbaceous standing dead in the control plots from the first and second sampling periods to the third sampling (Fig. 17) was not entirely surprising. The increase from the first to the third sampling period was not significant and is of little interest. Additionally, as these plots were not grazed, by ungulates, the current year's live growth would add to the next year's standing dead material. The increase from the second to the third sampling period, however, was significant ($P = 0.0006$), but likely due to sampling error because, if anything, the amount of herbaceous standing dead should have decreased as the previous year's growth wilted, shattered and became litter. It is also possible that, as mentioned earlier, due to the data collection being interrupted during the second sampling, by the time I resumed data collection in the spring the material that would previously have been measured as standing dead was either decomposed or considered litter and hence this category may have been underestimated. However, as herbaceous standing dead comprised only a trace of the total dead fraction, and even less of the total phytomass, it is of little concern.

Woody litter in the control plots also decreased from both the first and second samplings to the third sample period (Fig. 18). The decrease from the first to the third sampling was significant ($P < 0.0001$). So, "Where did the woody litter go?" The difference in this case is most likely due to sampling error as it is illogical to see a decrease in this component, especially where the hoof action from the sheep was not an influence. The decrease from the second to the third sampling was not significant. The herbaceous litter in the control plots also increased from the first to the second to the third period (Fig. 19; $P < 0.0001$). One explanation is that as the previous season's standing dead forbs/grasses fell over, they contributed to the increase in herbaceous litter. However, this is unlikely because, as noted earlier, the herbaceous standing dead actually increased, rather than decreased. Another explanation is that the ephemeral leaves of ARTRWY that fell the previous autumn added to this increase, and as it was a better year climatically, there could have been more ephemeral leaves than in drier years past (Miller and Shultz 1987). Coupled with the effects of snowmold, much of the herbaceous litter likely came from both ephemeral and persistent ARTRWY leaves killed by the snowmold. However, as the components of the herbaceous litter were not individually analyzed, this is speculation.

The end of growing season total phytomass in the grazed plots decreased from the first to the third sampling (Fig. 9), statistically significant at $P = 0.0007$. Sheep removed a significant amount of the vegetation through grazing, mostly herbaceous, but also some woody. Sheep consumed some of the smaller, softer woody material associated with the CAG of ARTRWY that contributed significantly to total phytomass. Total phytomass also decreased from the second to the third sampling, though not significantly.

The live fraction of the total phytomass in the grazed plots decreased (16%) from the first to the third samplings, but increased (3%) from the second to the third samplings. The decrease from the first to the third samplings is not surprising as the majority of the live phytomass is the woody portion of ARTRWY. Some of these plants died from sheep grazing. Although there was an increase in other categories, it was not as significant as the decrease in the woody portion of ARTRWY, hence the overall decrease in total phytomass. An alternate explanation for the decrease could also be sampling error. The increase in the live fraction from the second to the third sampling, although not large; should be addressed. One possible explanation for this increase is that after the sheep grazed these plots, there was little live material left. In fact, during data collection it was difficult to tell whether some of the ARTRWY plants were alive or dead. One year following grazing, there was more live material and hence it comprised a larger percentage of the total phytomass than at the second sampling.

Of the live fraction in the grazed plots, the decrease in the CAG of ARTRWY from the first to the third sampling (Fig. 10; $P = 0.0014$) was expected as sheep grazing in this manner is likely to kill some sagebrush plants, but not others. There was a 66% reduction 1 year after treatment. An equally important story will have to do with the years to come, as the lifespan of the effect must be considered as with any treatment of sagebrush (Blaisdell et al. 1982, Workman and Tanaka 1991). One must consider the possible benefits (e.g. reduced shrub abundance, increased forage for livestock and wildlife) weighed against the potential costs (e.g. monetary costs, the possibility that undesirable species will invade). However, if grazing is viewed as an ongoing part of management, to be used annually to influence vegetation across a landscape, rather than as a treatment to be imposed occasionally, this changes the nature of the analysis.

As previously mentioned, the control plots were subjected to fungal attack by snowmold, something the grazed plots did not experience due to the fact that, following the grazing treatment, there was no foliage for the fungus to attack. The foliage on

ARTRWY did not begin to recover until the following spring. The increase ($P < 0.0001$) from the second to the third sampling was also expected. As noted earlier, sheep used 98% of the CAG of ARTRWY as a forage source; hence any increase in CAG of ARTRWY represented recovery. Basically, the CAG of the surviving ARTRWY plants in the grazed plots had nowhere to go but up after the sheep were removed.

The woody portion of ARTRWY in the grazed plots decreased from the first to the second ($P < 0.0001$) to the third ($P = 0.0005$) sampling (Fig. 11). I expected this component would decrease slightly from the first to the third sampling, but not to the degree I saw. I expected that as the sheep moved throughout the plots, they would break branches and even consume a small amount of the woody tissue, which they did. However, a decrease from the second to the third sampling was not expected. Rather, from the second to the third sampling, this component should have stayed the same or increased through regrowth. Thus, this difference may be due to sampling error.

For the CAG of other shrubs, the differences among the grazed plots at the third sampling (Table 4) should be addressed. The estimations for this category were significantly higher in plot 1B than in plots 2B and 3A. This pattern existed at the first sampling as well, even in the paired control plot, suggesting that this difference may stem from inherent differences in site potential or disturbance history, rather than sampling error. When comparing this category in the grazed plots across sampling periods, the increase from the first to the third sampling was not significant (Fig. 12). I was unsure how the shrub species other than ARTRWY would respond to the sheep grazing. Ideally, a decrease in rabbitbrush and horsebrush and an increase in winterfat and low sagebrush would have been desirable. While other shrubs increased overall, rabbitbrush increased

12%, horsebrush increased 100%, low sagebrush increased 200%, and winterfat stayed more or less the same (Tables 8 and 16). While it would have been managerially desirable to decrease rabbitbrush and horsebrush, it is encouraging that low sagebrush actually increased. While the total amount of low sagebrush is quite small on this site, this shrub species can be quite important to sage grouse during different times of the year (Crawford et al. 2004), and so the possibility that it could potentially increase is encouraging.

The increase in the CAG of other shrubs in the grazed plots, from the second to the third sampling, was significant ($P < 0.0001$). As the sheep grazed these plots, the herbaceous plants were the first to be eaten followed by shrubs such as green rabbitbrush, horsebrush, winterfat, and finally sagebrush. Shrub species, other than sagebrush, were heavily utilized, creating essentially a new starting point near zero at the second sampling period. Their recovery was therefore inevitably substantial. As mentioned earlier, it appeared the snowmold impacted rabbitbrush in the control plots as they had a wilted appearance throughout the summer. This was not evident in the grazed plots. In fact, rabbitbrush in the grazed plots appeared more robust at the third sampling than during the first sampling. This is possibly a response from the browsing. There is also the possibility that it is due to the reduced competition of ARTRWY and the increased moisture received that year.

The woody portion of other shrubs increased in the grazed plots from the first and second samplings to the third sampling (Fig. 13). However, neither of these increases was significant. As the woody portion of other shrubs comprised only a trace of the total phytomass, it was of little concern.

Grasses increased in the grazed plots from the first to the third sampling (Fig. 14). We did expect to see an increase in this category, and while this increase was not statistically significant, its potential biological significance warrants some discussion. The increase from the first to the third sampling may be due to the reduction of ARTRWY through grazing. As mentioned earlier, as sagebrush canopy increases, grass production decreases and visa versa (Rittenhouse and Sneva 1976). However, Welch (2005) cautions this relationship may not be as simple as it appears, and overzealous sagebrush reductions may result in short-lived increases in grass production, creating an opportunity for invasion by noxious weeds or reduction in fertility of the site. During the study, precipitation was above average and grasses increased in the control plots as well. However, as the fungal attack influenced the production of ARTRWY, it is difficult to say whether the increase in grasses, in both the grazed and ungrazed plots, is more a function of the reduced competition from ARTRWY or the increased precipitation or the interplay of both conditions, which is most likely.

While this increase was not statistically significant, it may still have valuable implications for management. From a livestock grazing point of view, the decrease in sagebrush and increase in palatable forage is a positive thing. From a wildlife perspective it could also be positive. Although different species have varying food and cover needs, the increase in both grasses and forbs offers more food while the remaining structure of the sagebrush plant has value for cover for both large and small mammals and birds. However, we must remember that some species preferring more dense brush for cover and, in hard winters, rely heavily on sagebrush for winter forage. Thus, the best approach is to create a mosaic of grazing-induced sagebrush-forb abundances across the landscape to better meet the needs of a variety of creatures. The increase from the second to the third sampling ($P < 0.0001$) was also expected. As mentioned earlier, the sheep used 100% of the grass, so after they left, there was nowhere to go but up.

The initial responses of forbs in the grazed plots were similar to the grasses. While they increased from the first to the third sampling (Fig. 15), it was not statistically significant. The increase between the two samplings can be explained in much the same way as the grasses and, again, while not statistically significant, this increase may also be of potential importance in management. The same cautions Welch (2005) suggests for the relationship between grasses and sagebrush also apply to forbs. The increase from the second to the third samplings ($P < 0.0001$) can, again, be explained in much the same way as the grasses. After the sheep left, the forbs had nowhere to go but up. The increase in forbs was encouraging as a strong forb component in the plant community is important not only as livestock forage, but also extremely valuable to wildlife such as sage grouse (Klebenow and Gray 1968, Barnett and Crawford 1994, Drut et al. 1994a, b, Wirth and Pyke 2003, Crawford et al. 2004,).

It is encouraging to note the initial resilience of the herbs in the grazed plots. This study was carried out in the fall to avoid high levels of herbivory during the growing period of these plants, hence avoiding potentially irreversible harm. After witnessing the level to which the sheep removed the vegetation and seeing the initial plant response 1 year later, I was content with the approach taken. However, these plant responses were only short-term, and monitoring on these sites should continue in order to determine the long-term effects of this kind of grazing treatment.

The dead fraction of the total phytomass in the grazed plots increased from both the first and second samplings to the third sampling. The increase from the first to the third sampling was expected due to mortality caused as sheep intensely browsed the ARTRWY plants. The increase from the second to the third sampling was not expected, but not necessarily surprising, as during the second sampling some of the ARTRWY plants appeared live, but by the following summer had suffered mortality, and were thus recorded as dead. The increase was only 3% and so was not an alarming number. Woody standing dead material in the grazed plots decreased from both the first ($P = 0.0118$) and the second ($P = 0.0001$) samplings to the third sampling (Fig. 16). The decrease from the first to the third sampling was expected. I hypothesized that as the sheep moved through these plots they would break off many of the older, dead branches of ARTRWY thus decreasing the amount of woody standing dead in the grazed plots. However, the decrease I saw from the second to the third sampling was not expected. After the sheep left, there was little that would cause the dead branches to break off or fall over. There is the possibility that snow between the two sampling could have done this to a small degree, but it is doubtful that this took place at a significant level. As the canopy is reduced, so is the likelihood of damage from snow, hail, or wind. Considering this, the apparent decrease could likely be due to sampling error.

Herbaceous standing dead material in the grazed plots decreased from the first to the third sampling (Fig. 17; $P < 0.0001$). After the sheep consumed all of the preferred live grasses and forbs, they consumed 94% of the previous years' growth. I did not expect the sheep to leave any of the herbaceous standing dead, thus almost all herbaceous material encountered the following year was live growth. Considering this, I did not expect this component to change significantly between the second and third samplings.

Woody litter decreased in the grazed plots from the first to the third sampling ($P < 0.0001$), but not from the second to the third sampling (Fig. 18). I expected woody standing dead to decrease, which would logically increase the amount of woody litter. It is possible sheep consumed some of the litter, or broke it down and covered it in the soil disturbed through hoof action. However, the likelihood sheep ate, covered, or carried off a significant amount of woody litter, especially considering woody standing dead also decreased, is small. Hence, this decrease is most likely due to sampling error. There was a consistent pattern for woody litter between the treatments across time (Figure 18). Using the mean values in Table 2, I calculated the control plots had 88% of what the grazed plots had at the first sampling, a difference of 29 $g \cdot m^{-2}$. Using the mean values for woody litter in Table 3, I calculated the control plots had 84% of what the grazed plots had at the second sampling, a difference of 18 $g \cdot m^{-2}$. Using the mean values in Table 4, I calculated the control plots had 82% of what the grazed plots had at the third sampling, a difference of 18 $g \cdot m^{-2}$. There are similar patterns in some of the other categories, but none as clear or consistent as within woody litter.

Herbaceous litter decreased in the grazed plots from the first to the second sampling ($P = 0.0256$), but did not change from the second to the third sampling (Fig. 19). As with herbaceous standing dead, I expected the sheep to consume a large portion of herbaceous litter. They ate 44% of the herbaceous litter in the plots, which was surprising as I thought this number would be higher. It may have been easier for the sheep to use ARTRWY than to search for the herbaceous litter, which was likely made up of the CAG of ARTRWY anyway.

Age Class Structure. The age class distribution of ARTRWY in the control plots at the third sampling is comprised mostly of CAG from plants in age classes 5 and 6 (Fig. 25), with lesser amounts from age classes 4, 7, and 8, and minimal contributions from age classes 2 and 3. The majority of ARTRWY CAG comes from the middle age classes, with little to no recruitment from the younger age classes. There was a noticeable shift in distribution (Fig. 26), from the first to the third sampling, to slightly older plants. The estimations at the third sampling were problematic. Just as the sheep had removed the physical characters needed to accurately assign age classes in the grazed plots, the snowmold similarly affected the ARTRWY in the control plots at the third sampling. The snowmold-infected plants in the controls had little reproductive tissue and the CAG had a wilted appearance. Considering these influences, some plants may have actually appeared older and were mistakenly assigned to an older age class. This suggests that these differences may actually be due to sampling error. However, if the snowmold has a long lasting effect, it may actually alter the age structure in these plots. This warrants further monitoring.

The differences between the second and the third sampling were more subtle. The trend was still toward older plants, but more evenly distributed than the third sampling. Again, sampling error and confoundment by the snowmold must be considered as driving what I observed. As the controls were not subjected to ungulate grazing, their age class structure should have remained relatively constant, thus the observed results were not expected. However, we cannot rule out the possible effects of the snowmold and

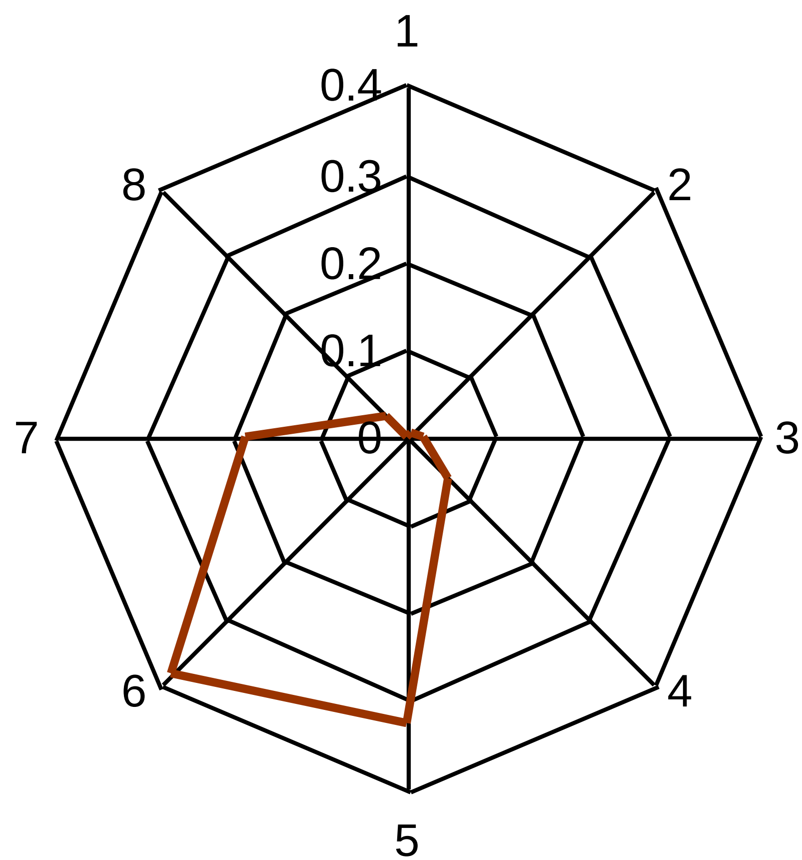


Figure 25 - Relative contributions (%) of each age class to the total mean CAG (g · m^{-2}) of Wyoming big sagebrush, in the control plots, at the third sampling.

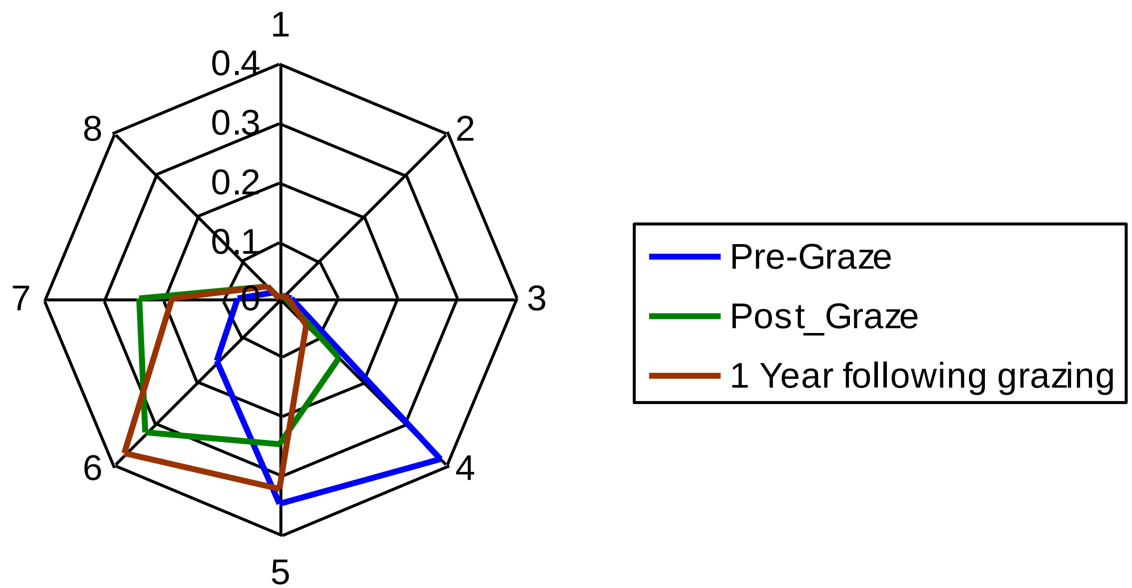


Figure 26 - Relative contributions (%) of each age class to the total mean CAG ($g \cdot m^{-2}$) of Wyoming big sagebrush, in the control plots, across the three sample periods.

invertebrates on these plants.

The age class distribution in the grazed plots at the third sampling is primarily CAG from age classes 5, 6, 7, and 8 (Fig. 27), with a lesser amount from the 2, 3, and 4 age classes. Again, the trend is towards the older age classes, with little recruitment from the younger classes, but there is a more even distribution among the age classes than existed at either the first or second samplings (Fig. 28). While this time period is too short to tell the lasting effects of my sheep grazing on the age classes, it appears that there was an increase in age class 6, the most reproductively important (Fig. 6). It also appears that some of the older plants that were nearing senility and low production in age class 7 were shifted into age class 8. The problems with the measurements at the second sampling have been addressed previously, and some of these biases could have affected the third sampling. Plants may have appeared older than they actually were due to grazing and snowmold. Some plants may have appeared younger than they actually were due to allocating an unusually large portion of resources to reproduction rather than vegetative growth following grazing.

The time between the first and third samplings is relatively short in relation to these landscapes, and long-term monitoring will be required to see if we actually had a prolonged effect on the age class distributions or not.

When we consider the fact that the grazed and control plots started out very similar (Fig. 21) in their age class distributions, we can see there is a difference at the third sampling between the two treatments (Fig. 29). Both treatments are still dominated by the older plants, but the grazed plots have a more even distribution among age classes, rather than a domination by 2 or 3 classes. This even distribution could be due to grazing creating opportunities for younger plants, and creating a mosaic among the middle aged and older plants. The bottom line is there was a difference between treatments, whether from the grazing, the snowmold, or sampling error. The real difference, if any exists, will only become apparent over time especially if we see a significant recruitment in the younger age classes (i.e. 1, 2, and 3). To monitor this, a more appropriate approach may be to quantify age classes by density ($\text{plants} \cdot \text{m}^{-2}$) rather than a biomass-weighted method ($\text{g} \cdot \text{m}^{-2}$) as was done in this study.

There may also be an unexpected outcome of altering the age classes of the ARTRWY. A visual observation of the site indicates some of the older, less productive plants may have been killed in the grazed plots, but their "skeleton" remained. This is a different out come than is typically seen in other treatments such as burning or disking/plowing where those individuals would have been completely burned up or knocked down. This is important because there may be some species of birds that rely on the insects living in, or on, the bark of these old, dead plants. This potentially adds to the value of this treatment in relation to the positive effect it could have on biodiversity.

Biodiversity: Species Richness. As mentioned previously, species richness and dominance/diversity did not change between the first and second samplings, so I will focus on the differences between the first and third samplings in this discussion. At the third sampling, the control plots had 35 plants species (Table 16), which is a 75% increase from the first sampling. This number represents a collective increase among all the control plots, not a 75% increase in each replicate. As the quantification of species richness was very straight forward, it is unlikely this increase is due to sampling error. It is possible that the snowmold reduced sagebrush competition enough that there was an

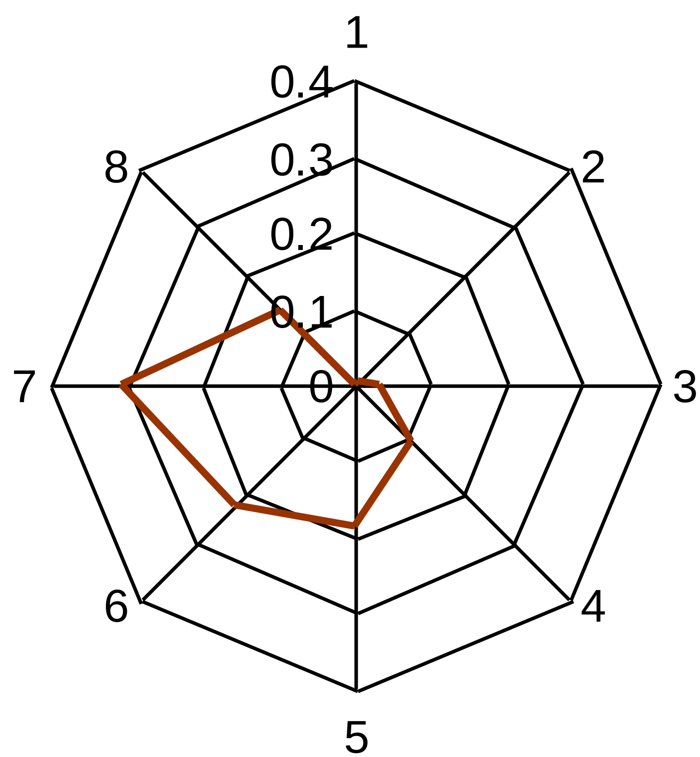


Figure 27 -Relative contributions (%) of each age class to the total mean CAG ($g \cdot m^{-2}$) of Wyoming big sagebrush, in the grazed plots, at the third sampling.

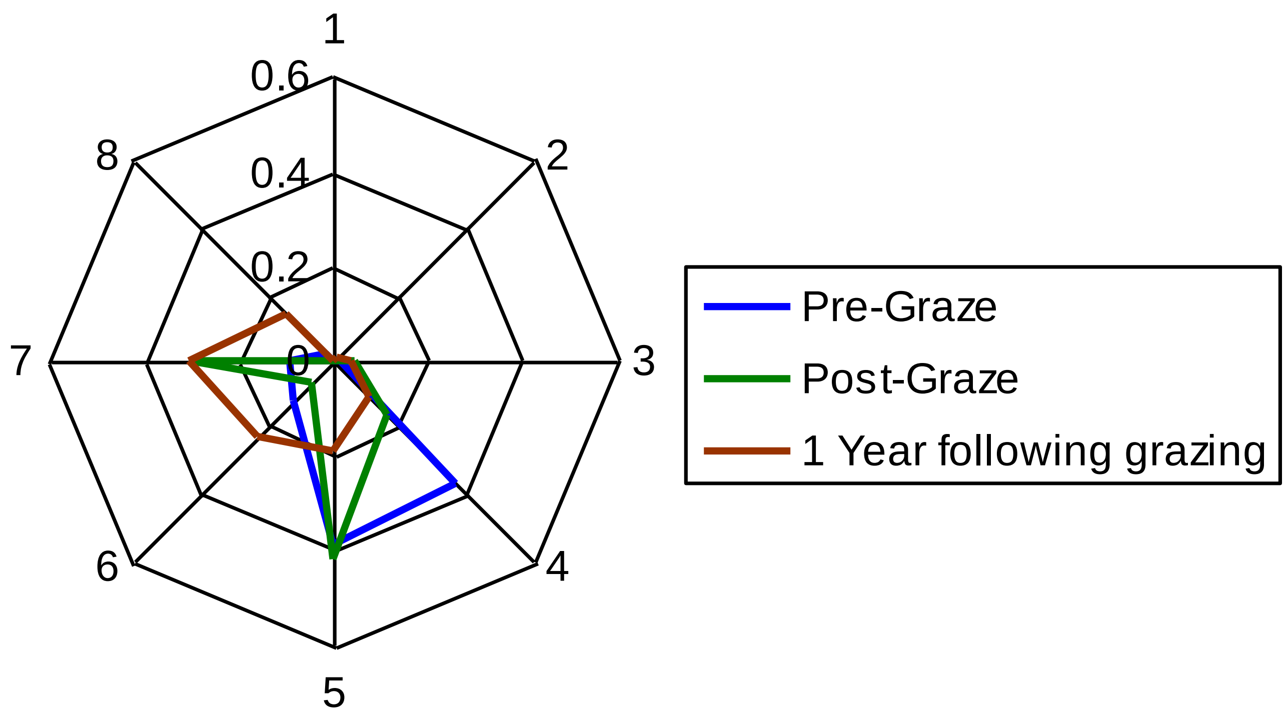


Figure 28 - Relative contributions (%) of each age class to the total mean CAG ($g \cdot m^{-2}$) of Wyoming big sagebrush, in the grazed plots, across the three sample periods.

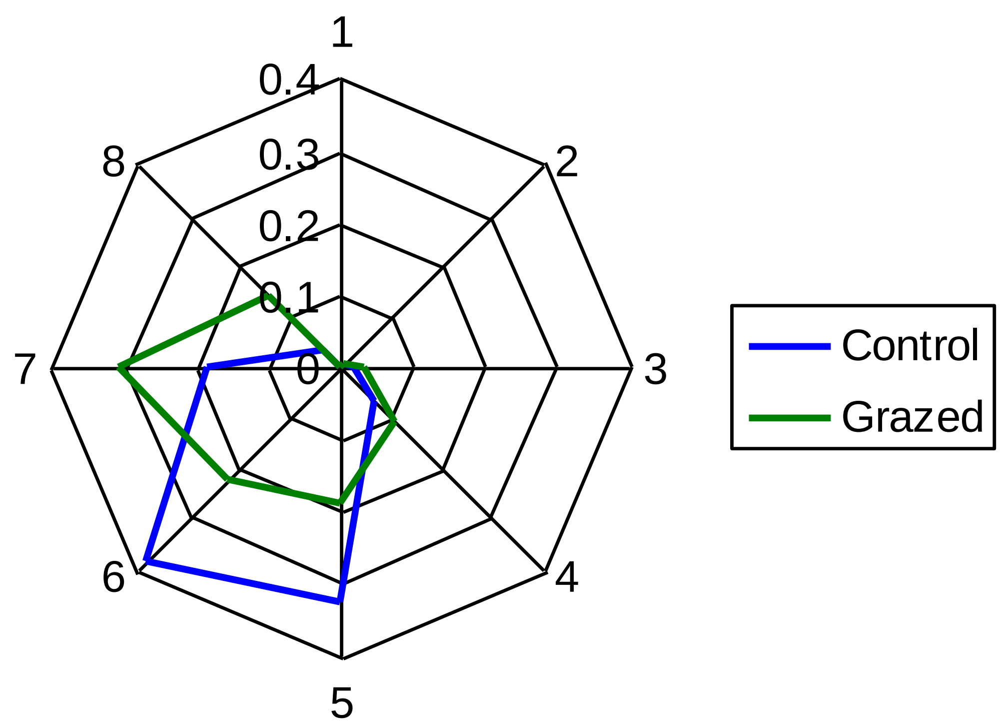


Figure 29 - Relative contributions (%) of each age class to the total mean CAG ($g \cdot m^{-2}$) of Wyoming big sagebrush, between treatments, at the third sampling.

opportunity for more plants to grow. In addition, precipitation was above average and thus supplied the resources needed for these plants to grow. Many of the “new” plants in the control plots are ephemeral forbs such as the *Lomatium* spp., *Trifolium sp*., and the *Astragalus* spp (Table 16). Plants such as these likely have always been present, but waiting until conditions were favorable to grow. Thus, this response likely is due to both biotic and environmental influences.

At the third sampling, the grazed plots had 37 different plant species (Table 16), which represents a 61% increase from the first sampling. Again, this number is a collective increase among all the grazed plots and not a 61% increase in each replicate. While we anticipated an increase in richness as a result of the grazing treatments, we must remember that the relationship between shrubs and herbs is not a 1:1 tradeoff and that it is probably not accurate to attribute all of the results exclusively to the grazing treatment. Similarly for the control plots, it is important that we do not dismiss the fact that the years this study was carried out saw above-average precipitation at our site.

At the third sampling, the grazed plots had two more species than were encountered in the control plots, for a 5% difference. While both treatments increased in species richness, we must be impressed that the control plots increased much more relative to the first sampling. However, we must be equally impressed that the grazed plots had more total species overall. As with the control plots, many of the “new” species in the grazed plots were short-lived forbs (i.e. *Trifolium* sp., *Lomatium* spp., and *Zigadenus* sp.) and were likely present, just waiting in soil seed reserves for favorable conditions before growing. While species richness for the shrubs remained constant, as was expected, from the first to the third sampling in both the control and grazed plots, the above species, in addition to the “trace” species, represents a 43% increase in the number of grass species encountered in the control plots and a 13% increase in the number of grass species encountered in the grazed plots. In addition, these species also represent a 150% increase in the number of forb species encountered in the control plots and a 130% increase in the number of forb species encountered in the grazed plots.

When discussing these increases, a valid concern arises of the possibility of the invasion of undesirable plants such as thistles, mustards, and cheatgrass when the land is exposed to a disturbance as severe as the one this experiment imposed. When one talks about desirable vs. undesirable plants, we run into the dilemma that a plant species considered desirable may differ depending upon management objectives. For the purpose of this discussion, the desirability of plant species will be considered from the management objectives of Deseret Land & Livestock (livestock/wildlife forage & wildlife habitat). In general terms, at the first sampling, in the control plots, there were 16 (75%) desirable species (Tables 8 and 17) and 4 (25%) undesirable species while in the plots to be grazed there were 16 (56%) desirable species and 7 (44%) undesirable species. One year following the grazing treatments, in the control plots, I found 26 (65%) desirable species (Tables 16 and 17) and 9 (35%) undesirable species while in the grazed plots, I encountered 25 (56%) desirable species and 11 (44% undesirable species). One can see that in the control plots, the relative amount of desirable species actually decreased from the first to the third sampling while in the grazed plots the relative amounts remained more or less constant. This suggests that, in the context of this experiment, while the relative amount of desirable plants neither increased or decreased, it may allow us to impose similar treatments without risking an invasion of undesirable plants.

***Biodiversity: Dominance/Diversity*.** The major species contributing to dominance/diversity or equitability are those with a numeric value (anything other than a "t") in Table 16. In the control plots, at the third sampling the dominant plant was ARTRWY, just as it was at the first sampling, but it dropped from 79% of the total herbaceous growth at the first sampling to 68% at the third sampling. Of the "other shrubs," Low rabbitbrush, Horsebrush, Winterfat, and Low sagebrush were also major players. At the first sampling, the other shrubs' CAG constituted 6% of the total herbaceous growth in the control plots but increased to 7% at the third sampling.

Of the perennial grasses, Bluebunch wheatgrass, Sandberg bluegrass, Muttongrass, Bottlebrush squirreltail, Western wheatgrass, Thickspike wheatgrass, Needle-and-thread grass, and Indian ricegrass were the major contributors to total phytomass. At the first sampling, the grasses were 3% of the total herbaceous growth in the control plots but increased to 6% at the third sampling.

The forbs most dominant in the control plots at the third sampling were Carpet phlox, Low pussytoes, Starveling milkvetch, Prickly phlox, Bushy birds beak, Longleaf phlox, Hollyleaf clover, Cushion daisy, Browse milkvetch, Lesser rushy milkvetch, and Desert madwort. At the first sampling, forbs constituted 12% of the total herbaceous growth in the control plots but increased to 19% by the third sampling.

When I combine the mean values for the grasses and forbs in the control plots, they totaled 16.9 $g \cdot m^{-2}$ (16% of the total live herbaceous growth) at the first sampling, and they increased to 22.1 $g \cdot m^{-2}$ (25% of the total live herbaceous growth) at the third sampling. This is something I did not expect to see in the ungrazed control plots.

In the grazed plots at the third sampling the dominant plant was ARTRWY, just as for the first sampling, but it dropped from 75% of total herbaceous growth at the first sampling to 42% at the third sampling. Of the "other shrubs," Low rabbitbrush, Low sagebrush, and Horsebrush were major players. At the first sampling, the other shrubs' CAG was 10% of the total herbaceous growth in the grazed plots and 19% at the third sampling.

Of the perennial grasses, Bluebunch wheatgrass, Western wheatgrass, Thickspike wheatgrass, Bottlebrush squirreltail, Needle-and-thread grass, Sandberg bluegrass, Indian ricegrass, and Muttongrass, were the major contributors to total phytomass. At the first sampling, these grasses constituted 7% of the total herbaceous growth in the grazed plots and 17% at the third sampling.

The forbs most dominant in the grazed plots at the third sampling were Low pussytoes, Starveling milkvetch, Bushy bird's beak, Browse milkvetch, Hollyleaf clover, Bastard toadflax, Cushion daisy, Longleaf phlox, Carpet phlox, Lesser rushy milkvetch, Prickly phlox, Desert madwort, Tapertip onion, and Lambsquarters. At the first sampling, the forb species constituted 8% of the total herbaceous growth in the grazed plots and 22% at the third sampling.

When I combine the mean values for the grasses and forbs in the grazed plots, they totaled only 13.9 $g \cdot m^{-2}$ (15% of the total live herbaceous growth) at the first sampling and 21.2 $g \cdot m^{-2}$ (38% of the total live herbaceous growth) at the third sampling.

I hypothesized that as the amount of ARTRWY decreased the relative contribution of the grasses and forbs to total live herbaceous growth would increase.

Though unexpected, the abundance of ARTRWY decreased in both the ungrazed and grazed plots, and in both instances, a dramatic increase in the relative amounts of grasses and forbs were observed. Whether these outcomes can be attributed solely to the reduction of ARTRWY is hard to say as many factors influence these responses.

Before I consider herbaceous species, I am going to discuss what took place with the shrub species other than ARTRWY. In the control plots, Low Rabbitbrush was 6% of the total current year's growth at both the first and third samplings while Horsebrush, Winterfat, and Low sagebrush were only in trace amounts at both samplings. It is interesting to note, however, that abundance of Low rabbitbrush was reduced by 15% from the first to the third sampling while the abundance of Horsebrush increased 50% during the same time frame. The other shrub species stayed relatively constant. In the grazed plots, at the first sampling, Low rabbitbrush was 10% of the total current year's growth and increased to 19% at the third sampling. Horsebrush, Winterfat, and Low sagebrush remained relatively constant through both samplings.

Of the grasses in the control plots, at the first sampling, the more desirable perennial species made up 2% of the total current year's growth, as did a less desirable perennial species. At the third sampling, the more desirable perennial species made up 5% of the total current year's growth, while a less desirable perennial species made up 1%. In the control plots at the first sampling, the more desirable perennial grass species made up 56% of the total grass production while a less desirable perennial species made up the remaining 44%. At the third sampling the more desirable perennial species made up 84% of the total grass production while a less desirable perennial species made up the remaining 16%.

Of the grass species in the grazed plots, at the first sampling, the more desirable perennial species made up 5% of the total current year's growth and increased to 16% at the third sampling. The less desirable perennial species made up 2% of the total current year's growth at the first sampling, in the grazed plots, but decreased to 1% at the third sampling. At the first sampling, the more desirable perennial species constituted 71% of the total grass production while a less desirable perennial species made up the remaining 29%. At the third sampling, the more desirable perennial species made up 96% of the total grass production while a less desirable perennial species made up the remaining 4%.

Of the forb species in the control plots at the first sampling, the more desirable perennial species made up 12% of the total current year's growth while there were no detectible amounts of any less desirable annual species. At the third sampling the more desirable perennial species made up 11% of the total current year's growth while a few less desirable annual species made up 1%. In the control plots, at the first sampling, the more desirable perennial forb species made up 100% of the total forb production. At the third sampling the more desirable perennial species decreased to 92% of the total forb production in the control plots while a few less desirable annual species made up the remaining 8%.

Of the forb species in the grazed plots at the first sampling, the more desirable perennial species made up 8% of the total current year's growth while there were no detectible amounts of any less desirable annual species. At the third sampling the more desirable perennial species made up 17% of the total current year's growth while a few less desirable annual species made up 5%. At the first sampling, the more desirable perennial forb species made up 100% of the total forb production. At the third sampling the more desirable perennial species decreased to 79% of the total forb production in the grazed plots while a few less desirable annual species made up the remaining 21%.

When I compare the control plots to grazed plots one year after grazing (third sampling), some similarities existed in the plant species that dominated forage production (anything with a numeric value in the "% of total" column in Table 16). In both cases, ARTRWY remained the dominant plant, along with the shrub Low rabbitbrush, in both the ungrazed and the grazed plots. The dominant grass species in both treatments were the perennials Sandberg bluegrass, Bottlebrush squirreltail, Western wheatgrass, Needle-and-thread grass, Bluebunch wheatgrass, and Thickspike wheatgrass. The dominant forb species were perennials; Low pussytoes, Longleaf phlox, Starveling milkvetch, and Hollyleaf clover, with the only annual forb being Bushy bird's beak, the latter species being a root parasite on sagebrush (Welch 2005).

While the ungrazed and grazed plots had some commonalities, there were also distinct differences. At the third sampling, Horsebrush was a dominant shrub in the control, but not in the grazed plots, whereas the perennial Muttongrass was dominant in the control but not in the grazed plots, and the perennial forbs Carpet phlox and Prickly phlox were dominant in the control, but not in the grazed plots. At the third sampling, there were no dominant shrub species unique to the grazed plots, but the perennial grass, Indian ricegrass, was a major player in the grazed but not in the control plots. Finally, the perennial forbs Browse milkvetch, Bastard toadflax, and Cushion daisy were dominant in the grazed but not the control plots.

CONCLUSION

In an environment where social, economic, and ecological pressures are growing increasingly restrictive and sensitive, managers need further options to accomplish vegetation improvement objectives. I assessed the effects of fall grazing by sheep supplemented with nutrients as a possible way to influence shrub age class structure and herbaceous species richness and dominance in sagebrush steppe.

As with most ecological research, conducted in the field, this experiment involved circumstances making clear discernment of relationships between treatment and vegetation responses somewhat difficult. However, under the conditions of this experiment, the following changes occurred in the grazed plots: 1) the abundance of Wyoming big sagebrush was reduced (66%) from the first sampling, 2) species richness increased (61%) from the first sampling, 3) the relative abundance of herbaceous species increased (grasses 43%, forbs 60%, total herbaceous growth [grasses + forbs] 51%), and 4) there was, albeit slight, a more even distribution of age classes among the Wyoming big sagebrush one year following the grazing. Monitoring of these sites needs to continue in order to determine the long-term effects of the kind of sheep grazing employed in this experiment.

Two factors make it difficult to clearly discern the degree to which grazing impacted vegetation one year later. Firstly, we received above-average precipitation the winter and spring before our third sampling (85% above average [Utah Climate Summaries 2006]), which influenced vegetation responses on both grazed and ungrazed plots. Secondly, the fungal attack of snowmold further complicates the story. I had hypothesized that as Wyoming big sagebrush was reduced through grazing, herbaceous understory production and species richness and abundance would increase. I expected sagebrush in the control plots to be ungrazed, and as a result remain relatively constant. However, this was not the case due to snowmold. Indeed, control plots responded quite favorably, from the first to the third sampling, in the following respects: reduced ARTRWY CAG (27%), increased forage production (grasses 55%, forbs 24%, total herbaceous growth [grasses + forbs] 31%), and increased species richness (75%). It is likely our hypothesis -- that as the abundance of ARTRWY was reduced, in this case by a fungal attack, understory production increases -- holds true even in the context of the "ungrazed" control plots. As a fungal attack is a natural occurring event associated with specific site and climatic conditions, it is nearly impossible to predict when, where, and to what degree it will occur; thus disqualifying it from being a viable tool for vegetation management.

In carrying out this research, we ran into a couple of situations that added some difficulty in determining treatment effects. Following the grazing period in the fall of 2003, an early snowstorm hampered our efforts to complete collection of all the "post-grazing" data. In an effort to collect reliable data, the remainder of the post-grazing data were collected early the following March before the major flush of new growth began. During the 2003/2004 winter, the sagebrush in the study area was also subjected to fungal attack of snowmold. The snowmold seemed to attack only plants that had ample foliage. This created a situation where our control plots were impacted to some degree (ARTRWY plants apparently having 27% less CAG in the third sampling compared to the first sampling) and the treatment plots were not noticeably impacted by the snowmold, evidently because those sagebrush plants had been almost totally defoliated during the grazing period, hence leaving nothing for the fungi to attack. The reduced sagebrush production in the control plots could have led to increased herbaceous production there as well, making it difficult to cleanly discern treatment effects due to sheep grazing alone. Such surprises encountered while conducting ecological research makes it impossible to carry out a completely controlled experiment unaffected by other environmental factors.

Considering these results, one may think that this approach is ready to be applied to a land management scenario to reduce the abundance of Wyoming big sagebrush while increasing herbaceous species richness and abundance. However, there are a couple of things that the land manager must keep in mind. Firstly, considering we saw similarly favorable outcomes in the control plots, which were subjected to a lower degree of ARTRWY reduction from the fungal attack, it is conceivable that some management objectives may be reached by a lower degree of utilization. This has the potential to lower costs while reducing the risk to both plants and animals. This is one area of the study that warrants further refinement. When the trial began, we were unsure of the appropriate stocking rate. Through this and similar studies (Bork et al. 1998, Staggs 2006), we are that much closer to finding the appropriate combination. Secondly, the land manager must remember the conditions under which these sheep were grazed. There were enclosed by a wire fence. Under extensive conditions, this will not be feasible. Thirdly, there is always the possibility that interactions or relationships exist that we just aren't seeing, which when applied in a different context could result in very different outcomes. Fourthly, we must remember the sites we used had a source of desirable plants and seeds and, fortunately, were not heavily invaded with undesirable plants such as cheatgrass. If this were not the case, a land manager would have to consider the possibility of seeding the ground and the risk this level of utilization may open up the system for an invasion of undesirable plants.

A land manager considering applying treatments similar to ours must also understand the criteria mentioned earlier for a management option to be sustainable: 1) it must be ecologically sound, 2) it must be socially acceptable, and 3) it must be economically viable. This experiment looked primarily at the ecological impacts of the sheep grazing, thus presenting opportunities for future research including the social and economic aspects of this approach to vegetation management, as well as other relationships between plants and animals we did not consider.

Considering some of the difficulties I encountered during this study, there are some suggestions I would offer to future researchers looking at this site or applying similar treatments on other sites. Firstly, train others to assist in data collection. I felt that to collect the best data, I should make all visual estimates myself. This came at the expense of slow data collection. It is possible for more than one individual to collect biomass data using the reference unit method (Carpenter and West 1987) without compromising statistical integrity. This would allow for data to be collected faster, hence possibly capturing a truer picture of production and also avoiding a temporal separation in data collection, as happened in our second sampling. Secondly, I would also advise any subsequent studies to modify the data collection if they were going to look at the age class structure of ARTRWY. I think counting the number of individuals in each age class per m^2 will give a more representative accounting than the way we measured it (relative contributions [$g \cdot m^{-2}$] of each age class to the total CAG production of ARTRWY).

Lastly, I would suggest to subsequent researchers on this topic that the method for estimating the woody portion of ARTRWY, woody standing dead, and woody litter be refined. As one can tell from my results, the data representing these components did not always display a logical outcome, suggesting a large influence from sampling error.

It was my hope to explore the possibility of a surrogate to natural disturbance in the use of a biological agent, sheep. While the results are encouraging, it must be remembered that this occurred at one place in one point in time. There is a need to study the effects of similar treatments at many other locations over longer periods of time in order to strengthen its generality and applicability in a real world setting. Plans are currently underway to apply this treatment on a larger scale in Utah, Wyoming, and Nevada. Bold steps such as these from private operators and land management agencies are an encouraging sign that will build upon the knowledge gained from this experiment.

LITERATURE CITED

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

Andrew, M.H., Noble, I.R. and R.T. Lange. 1979. A non-destructive method for estimating the weight of forage on shrubs. *Australian Rangeland Journal* 1: 225-231.

Andrew, M.H., Noble, I.R., Lange, R.T. and A.W. Johnson. 1987. The measurement of shrub forage weight: three methods compared. *Australian Rangeland Journal* 3: 74-82.

Aoude, A. 2002. The effects of four rangeland manipulations on plant and animal richness and abundance [thesis]. Logan, UT, USA: Utah State University. 49 p.

Barnett, J.K. and J.A. Crawford. 1994. Pre-laying nutrition of sage grouse hens in Oregon. *Journal of Range Management*. 47:114-118.

Blaisdell, J.P. and W.F. Mueggler. 1956. Effect of 2,4-D on forbs and shrubs associated with big sagebrush. *Journal of Range Management*. 9:38-40.

Blaisdell, J.P., Murray, R.B. and E.D. McArthur. 1982. Managing intermountain rangelands-sagebrush-grass ranges. Ogden, UT, USA: US Department of Agriculture, Forest Service, INT-GTR-134. 41 p.

Bonham, C.D. 1989. Biomass. *In*: C.D. Bonham [ED.]. Measurements for terrestrial vegetation. New York, NY, USA: John Wiley & Sons. p. 32-41.

Bork, E.W., West, N.E., and J.W. Walker. 1998. Cover components on long-term seasonal sheep grazing treatments in three-tip sagebrush steppe. *Journal of Range Management*. 51: 293-300.

Britton, C.M. and M.H. Ralphs. 1979. Use of fire as a management tool in sagebrush ecosystems. *In*: The Sagebrush ecosystem: a symposium; April 1978; Logan, UT, USA: Utah State University. p. 101-110.

Bureau of Land Management. 2002. Management considerations for sagebrush (*Artemisia*) in the Western United States: a selective summary of current information about the ecology and biology of woody North American sagebrush taxa. U.S. Department of the Interior, Bureau of Land Management. Washington, DC.

Burkhardt, J.W. 1996. Herbivory in the Intermountain West. Moscow, ID, USA: University of Idaho, Idaho Forest, Wildlife and Range Experiment Station, Station Bulletin 58. 35 p.

Burritt, E.A., Banner R.A., and F.D. Provenza. 2000. Sagebrush ingestion by lambs: effects of experience and macronutrients. *Journal of Range Management*. 53:91-96.

Cabral, D.R. and N.E. West. 1986. Reference unit-based estimates on winterfat browse weights. *Journal of Range Management*. 39:187-189.

Caldwell, M.M. 1979. Physiology of sagebrush. *In*: The Sagebrush ecosystem: a symposium; April 1978; Logan, UT, USA: Utah State University. p. 74-85.

Carpenter, A.T. and N. E. West. 1987. Validating the reference unit method of aboveground phytomass estimation on shrubs and herbs. *Vegetatio*. 72:75-79.

Clapp, E.H. 1936. The major range problems and their solution – a resume. *In*: Committee on Agriculture and Forestry [ED.]. The western range. 74th Congress, 2nd Session. Washington DC, USA: United States Government Printing Office. p. 1-69.

Cook, C.W. 1971. Effects of season and intensity of use on desert vegetation. Logan, UT, USA: Utah State University, Utah Agricultural Experiment Station, Station Bulletin 483. 57 p.

Crawford, J.A., Olson, R.A., West, N.E., Mosley, J. C., Schroeder, M.A., Whitson, T.D., Miller, R.F., Gregg, M.A., and C.S. Boyd. 2004. Ecology and management of sage-grouse and sage-grouse habitat. *Journal of Range Management*. 57:2-19.

Dziba, L.E. 2004. Feeding behavior of sheep in relation to kinetics of sagebrush monoterpenes: implications for landscape biodiversity [dissertation]. Logan, UT, USA: Utah State University. 225 p.

Dziba, L.E., Provenza, F.D, Villalba, J.J., Atwood, S.B. 2007. Supplemental energy and protein increase use of sagebrush by sheep. *Small Ruminant Research*. 69:203-207.

Deseret Land and Livestock. 2004. Ranch History. Available at: http://www.deseretlandandlivestock.com/pages/RanchHistory/index.html. Accessed 1 May 2004.

Drut, M.S., Pyle W.H., and J.A. Crawford. 1994a. Technical Note: Diets and food selection of sage grouse chicks in Oregon. *Journal of Range Management*. 47: 90-93.

Drut M.S., Crawford J.A., and M.A. Gregg. 1994b. Brood habitat use by sage grouse in Oregon. *Great Basin Naturalist*. 54:170-176.

Ensminger, M.E., Oldfield, J.E., and W.W. Heinemann. 1990. Feeds & nutrition. 2nd ed. Clovis, California, USA: The Ensminger Publishing Company. 1552 p.

Evans, R.A., Young, J.A., and R.E. Eckert. 1979. Use of herbicides as a management tool. *In*: The Sagebrush ecosystem: a symposium; April 1978; Logan, UT, USA: Utah State University. p.110-116.

Frischknecht, Neil C. 1979. Biological methods: a tool for sagebrush management. *In*: The Sagebrush ecosystem: a symposium; April 1978; Logan, UT, USA: Utah State University. p. 121-128.

Frischknect, N.C. and L.E. Harris. 1973. Sheep can control sagebrush on seeded range if - - -. *Utah Science*. 34:27-30.

Gatsuk, L.E., Smirnova, O.V., Vorontzova, L.I., Zaugolnova, L.B. and L.A. Zhukova. 1980. Age states of plants of various growth forms: a review. *Journal of Ecology*. 68:675-696.

Holechek, J.L., Pieper, R.D., and C.H. Herbel. 2001. Range Management: Principles and practices. 4th ed. Upper Saddle River, NJ, USA: Prentice Hall. 587 p.

Johnson, K.H., Olson, R.A., and T.D. Whitson. 1996. Composition and diversity of plant and small mammal communities in tebuthiuron-treated big sagebrush (*Artemisia tridentata*). *Weed Technology*. 10:404-416.

Kelsey, R.G., Stephens, J.R. and Shafizadeh, F. 1982. The chemical constituents of sagebrush foliage and their isolation. *Journal of Range Management*. 35:617-622.

Kirmse, R.D. and B.E. Norton. 1985. Comparison of the reference unit method and dimensional analysis for two large shrubby species in Caatinga woodlands. *Journal of Range Management*. 38:425-428.

Klebenow, D.A. and G.M. Gray. 1968. Food habits of Juvenile sage grouse. *Journal of Range Management*. 21:80-83.

Knight, D.H. 1994. Mountains and plains: the ecology of Wyoming landscapes. New Haven, CT, USA: Yale University Press. 338 p.

Laycock, W.A. 1991. Stable states and thresholds of range condition on north American rangelands – a viewpoint. *Journal of Range Management*. 44:427-433.

Laycock, W.A. 1967. How heavy grazing and protection affect sagebrush-grass ranges. *Journal of Range Management*. 20:206-213.

Laycock, W.A. 1961. Improve your range by heavy fall grazing. *National Woolgrower*. 51:16, 30.

McArdle, R.E., Costello, D.F., Birkmaier, E.E., Ewing, C., Hendricks, B.A., Kutzleb, C.A., Simpson, A.A., and A.R. Standing. 1936. The white man's toll. *In*: Committee on Agriculture and Forestry [ED.]. The western range. Washington DC, USA: 74th Congress, 2nd Session. United States Government Printing Office. p. 81-116.

Miller, A.E. 1957. Sagebrush Control. *Soil Conservation*. 23:18-19.

Miller R.F. and L.I. Shultz. 1987. Development and longevity of ephemeral and perennial leaves on *Artemisia tridentata* ssp. *wyomingensis*. *Great Basin Naturalist*. 47:227-30.

Miller, R.F., T.J. Svejcar, and N.E. West. 1994. Implications of livestock grazing in the intermountain sagebrush region: plant composition. *In*: M. Vavra, W.A. Laycock, and R.D. Pieper [EDS.] Ecological implications of livestock herbivory in the west. Denver, CO, USA: Society for Range Management. p. 101-146.

Miller, R.F. and L.L. Eddleman. 2001. Spatial and temporal changes in sage grouse habitat in the sagebrush biome. Corvallis, OR, USA: Oregon State University, Agricultural Experiment Station, Station Bulletin 151. 35 p.

Morris, M.S. 1931. Increasing forage on sagebrush land. Fort Collins, CO, USA: Colorado Agricultural College, Extension Service, Bulletin 308-A. p. 1-7.

Mueggler, W.F. 1950. Effects of spring and fall grazing by sheep on vegetation of the Upper Snake River Plains. *Journal of Range Management*. 3:308-315.

Naeem, S., F.S. Chapin III, R. Costanza, P.R. Ehrlich, F.B. Golley, D.U. Hooper, J.H. Lawton, R.V. OíNeill, H.A. Mooney, O.E. Sala, A.J. Symstad, and D. Tilman. 1999. Biodiversity and Ecosystem Functioning: Maintaining Natural Life Support Processes. *Issues in Ecology*. 4:1-11.

Natural Resource Conservation Service. 1982. Soil Survey of Rich County Utah. Washington DC, USA: US Department of Agriculture, United States Government Printing Office. 340 p.

Natural Resource Conservation Service. 1994. EFOTG. Available at: http://efotg.nrcs.usda.gov/treemenuFS.aspx?Fips=49033&MenuName=menuUT.zip. Accessed 18 October 2004.

Noy-Meir, I. 1973. Desert ecosystems: Environment and producers. *Annual Review of Ecology and Systematics*. 4:25-51.

Olson, R. A. and T.D. Whitson. 2002. Restoring structure in late-successional sagebrush communities by thinning with tebuthiuron. *Restoration Ecology*. 10(1):146-155.

Panter, K.E., Baker, D.C. and P.O. Kechele. 1996. Water hemlock (*Cicuta douglasii*) toxicoses in sheep: pathologic descriptions and prevention of lesions and death. *Journal of Veterinary Diagnostic Investigation.* 8:474-480.

Parker, K.G. 1979. Use of mechanical methods as a management tool. *In*: The Sagebrush ecosystem: a symposium; April 1978; Logan, UT, USA: Utah State University. p. 117-128.

Pickford, G.D. 1932. The influence of continued heavy grazing and of promiscuous burning on spring-fall ranges in Utah. *Ecology*. 13:159-171.

Provenza, F.D. 1995. Postingestive feedback as an elementary determinant of food selection and intake in ruminants. *Journal of Range Management*. 48:2-17.

Provenza, F.D., J.J. Villalba, L.E. Dziba, S.B. Atwood and R.E. Banner. 2003a. Linking herbivore experience, varied diets, and plant biochemical diversity. *Small Ruminant Research*. 49:257-274.

Provenza, F.D., J.J. Villalba, and J.P. Bryant. 2003b. Foraging by herbivores: Linking the biochemical diversity of plants with herbivore culture and landscape diversity. *In*: J.A. Bissonette and I. Storch [EDS.] Landscape ecology and resource management: linking theory with practice. New York, NY, USA: Island Press. p. 387-342.

Provenza, F.D. 2003. Twenty-five years of paradox in plant-herbivore interactions and "sustainable" grazing management. *Rangelands*. 25:4-15.

Pyne, S.J. 1982. Our grandfather fire: fire and the American Indian. *In*: S.J. Pyne [ED.]. Fire in America: a cultural history of wildland and rural fire. Princeton, NJ, USA: Princeton University Press. p. 71-83.

Rittenhouse, L.R. and F.A. Sneva. 1976. Expressing the competitive relationship between Wyoming big sagebrush and crested wheatgrass. *Journal of Range Management*. 29:326-327.

Sharif, C.M. and N.E. West. 1968. Forage moisture variations on mountain summer range. *Journal of Range Management*. 21:228-235.

Shaw, R.J. 1993. Vascular plants of Northern Utah. Logan, UT, USA: Utah State University Press. 412 p.

Sneva, F.A. and C.M. Britton. 1983. Adjusting and forecasting herbage yields in the intermountain big sagebrush region of the steppe province. Corvallis, OR, USA: Oregon State University, Agricultural Experiment Station. Station Bulletin 659. 61 p.

Snowder, G.D., Walker J.W., Launchbaugh, K.L., and L.D. Vleck. 2001. Genetic and phenotypic parameters for dietary selection of mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* [Rybd] Beetle) in Rambouillet sheep. *Journal of Animal Science*. 79:846-492.

Staggs, T. 2006. Early vegetational responses to supplemented and unsupplemented fall sheep grazing treatments in a sagebrush steppe [thesis]. Logan, UT, USA: Utah State University. 82 p.

Stoddart, L.A. 1946. Some physical and chemical responses of *Agropyron spicatum* to herbage removal at various seasons. Logan, UT, USA: Utah Agricultural Experiment Station. Station Bulletin 324. 24 p.

Sturges, D.L. 1986. Responses of vegetation and ground cover to spraying a high elevation, big sagebrush watershed with 2,4-D. *Journal of Range Management*. 39:141-146.

Summers, D.D. 2005. Vegetation response of a Wyoming big sagebrush (Artemisia tridentata ssp. wyomingensis) community to six mechanical treatments in Rich County, Utah [thesis]. Provo, UT, USA: Brigham Young University. 31 p.

USDA, NRCS. 2003. The PLANTS database. 2003. Available at: http://plants.usda.gov. Accessed 1 July 2003.

Utah Climate Summaries. Western regional climate center. 2006. Available at: http://www.wrcc.dri.edu/summary/climsmut.html**.** Accessed 1 February 2006.

Villalba, J.J., F.D. Provenza, and R.E. Banner. 2002. Influence of macronutrients and activated charcoal on utilization of sagebrush by sheep and goats. *Journal of Animal Science*. 80:2099-2109.

Wambolt, C.L. and T.L. Hoffman. 2001. Mountain big sagebrush age distribution and relationships on the northern Yellowstone winter range. *In*: E.D. McArthur and D.J. Fairbanks [EDS.]. Shrubland Ecosystem Genetics and Biodiversity: Proceedings. Ogden, UT, USA: US Department of Agriculture, Forest Service, RMRS-P-21. p. 330-335.

Washington-Allen, R.A. 2003. Retrospective ecological risk assessment of rangeland health using multitemporal satellite imagery [dissertation]. Logan, UT, USA: Utah State University. 389 p.

Weather Underground. Woodruff, UT. 2005. Available at: http://www.wunderground.com/US/UT/Woodruff.html. Accessed 2 March 2005.

Welch, B.L. 2005. Big sagebrush: A sea fragmented into lakes, ponds, and puddles. Fort Collins, CO, USA:US Department of Agriculture, Forest Service, RMRS-GTR-144. 210 p.

Welch, B.L., McArthur E.D., and R.L. Rodriguez. 1987. Variation in utilization of big sagebrush accessions by wintering sheep. *Journal of Range Management*. 40:113-115.

West, N.E. 1983. Western intermountain sagebrush steppe. *In*: N.E. West [ED.]. Temperate deserts and semi-deserts, vol. 5. Ecosystems of the world. Amsterdam: Elsevier. p. 351-374.

West, N.E. 1989. Vegetation types of Utah. *In*: K.L. Johnson [ED.]. Rangeland resources of Utah. Logan, UT, USA: Utah State University, Cooperative Extension Service. p. 18-56.

West, N.E. 1993. Biodiversity of rangelands. *Journal of Range Management*. 46:2-13.

West, N.E. 1996. Strategies for maintenance and repair of biotic community diversity on rangelands. *In*: R.C. Szaro and D.W. Johnston [EDS.]. Biodiversity in managed landscapes: Theory and practice. New York, NY, USA: Oxford Univ. Press. p. 326-346.

West, N.E., Provenza, F.D., Johnson, P.S., and M.K. Owens. 1984. Vegetation changes after 13 years of livestock grazing exclusion on sagebrush semidesert in West central Utah. *Journal of Range Management*. 37: 262-264.

West, N.E. and J.A. Young. 2000. Intermountain valleys and lower mountain slopes. *In*: M.G. Barbour and W.D. Billings [EDS.]. North American terrestrial vegetation. Cambridge, United Kingdom: Cambridge University Press. p. 256-284.

West, N.E. and T.P. Yorks. 2002. Vegetation responses following wildfire on grazed and ungrazed sagebrush semi-desert. *Journal of Range Management*. 55:171-181.

Wirth, T.A. and D.A. Pyke. 2003. Restoring forbs for sage grouse habitat: Fire, microsites, and establishment methods. *Restoration Ecology*. 11:370-377.

Workman, J.P. and J.A. Tanaka. 1991. Economic-feasibility and management considerations in range revegetation. *Journal of Range Management* 44:566-573.

Wright, H.A. 1970. Response of big sagebrush and three-tip sagebrush to season of clipping. *Journal of Range Management*. 23:20-22.

Young, J.A. 1994. Historical and evolutionary perspectives on grazing of western rangelands. *In*: M. Vavra, W.A. Laycock, and R.D. Pieper [EDS.]. Ecological implications of livestock herbivory in the west. Denver, CO, USA: Society for Range Management. p. 1-12.

Young, J.A., Eckert, R.E., and R.A. Evans. 1979. Historical perspectives regarding the sagebrush ecosystem. *In*: The Sagebrush ecosystem: a symposium; April 1978; Logan, UT, USA: Utah State University. p. 1-13.