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Cattle Browsing Sagebrush Steppe During Fall: Effects on Plant Community Structure and Influence of Experience on Cattle Foraging Behavior and Body Weights

Charles A. Petersen
Utah State University

CATTLE BROWSING SAGEBRUSH STEPPE DURING FALL: EFFECTS ON PLANT COMMUNITY STRUCTURE AND INFLUENCE OF EXPERIENCE ON CATTLE FORAGING BEHAVIOR AND BODY WEIGHTS

by

Charles A. Petersen

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Approved:

Frederick D. Provenza, PhD Major Professor	Roger E. Banner, PhD Committee Member
Juan J. Villalba, PhD Committee Member	Randall D. Wiedmeier, PhD Committee Member

Mark R. McLellan, PhD
Vice President for Research and
Dean of the School of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

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ABSTRACT

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by

Charles A. Petersen, Master of Science

Utah State University, 2012

Major Professor: Dr. Frederick D. Provenza
Department: Wildland Resources

Disturbances such as fire and grazing can degrade landscapes, but they can also rejuvenate them. I evaluated: 1) the practicality of strategically timed (fall), high intensity browsing of sagebrush (*Artemisia tridentata ssp. tridentata, ssp. wyomingensis*) by cattle; 2) the foraging behavior and body weights of cattle with varying levels of experience browsing sagebrush; and 3) the ensuing responses of grasses, forbs, and sagebrush to cattle grazing. In spatially and temporally replicated trials from 2007 to 2009, fall grazing by cattle reduced the abundance of sagebrush and promoted production of grasses and forbs. The cattle used in these trials were challenged to learn to eat sagebrush in the unfamiliar circumstance of confinement in small pastures. Throughout the trials from 2007 to 2009, pregnant cows with calves (2007), bred yearling heifers (2008), and first-calf heifer/calf pairs (2009) supplemented with protein and energy – to mitigate the effects of terpenes in big sagebrush – learned to select sagebrush as a significant portion of their diet. In virtually every case, experienced animals consistently used more sagebrush and lost less weight, or actually gained more weight, than naive animals in 2008 and 2009. My research suggests grazing by cattle during fall can be effective, biologically and economically, and can lead to habitat renovation and resilience. Moreover, grazing can create locally adapted systems in ways that landscape manipulations with chemical and mechanical treatments and prescribed fire cannot. These "technological fixes" are increasingly impractical due to environmental concerns, the high costs of fossil fuels, and the need to repeat outcome-based treatments rather than incorporating process-based approaches into managing landscapes. Rather than attempting to convert sagebrush steppe landscapes to grass at extravagant costs, as we have done historically, we must now consider ways to create locally adapted herds of livestock and complementary management practices to ensure long-term health of sagebrush steppe. As many ranchers already feed hay to cows during winter, using sagebrush steppe vegetation as an additional forage resource would allow ranchers to feed roughly half the hay, which would greatly reduce winter feed costs. In addition to financial savings in hay, the secondary benefits from improving sagebrush steppe condition and productivity would result in habitat improvements for both livestock and wildlife.

(104 pages)

PUBLIC ABSTRACT

Cattle Browsing Sagebrush Steppe During Fall: Effects on Plant Community Structure and Influence of Experience on Cattle Foraging Behavior and Body Weights

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Historic and repetitious spring grazing by livestock, combined with altered fire regimes, has increased the density and abundance of big sagebrush and reduced the frequency of perennial grasses and forbs on many western landscapes. Periodic disturbance is critical for maintaining and improving sagebrush ecosystems. Compared with traditional disturbances – chemical, mechanical, and fire – strategic grazing with livestock offers several benefits. They include creating locally adapted cattle that can rejuvenate sagebrush steppe, which reduces costs associated with mechanical and chemical rejuvenation treatments and feeding cattle during winter, the major cost of ranch operation.

I evaluated the practicality of strategically timed (fall) grazing with cattle at high stock densities on land dominated by sagebrush. From 2007 to 2009, I monitored cattle use of sagebrush, cattle performance (body weights), and the ensuing response of grasses, forbs, and sagebrush.

Cow/calf pairs – provided with protein and energy supplements to offset the effects of terpenes in big sagebrush – selected big sagebrush as a significant portion of their diet. Cattle learned to eat sagebrush and the effects occurred in fetuses in utero, in calves early in life, and in adults later in life. Cattle of all ages with experience of

sagebrush lost less weight, or actually gained more weight, than cattle naïve to sagebrush. Fall grazing by cattle reduced the abundance of big sagebrush and promoted production of grasses and forbs. Fall and winter are ideal times for grazing to induce such changes in plant community structure because perennial herbs are largely dormant.

My research suggests grazing by cattle can be a biologically and economically effective way to accomplish habitat renovation. Rather than attempting to convert sagebrush steppe landscapes to grass at extravagant costs, as we have done historically, we must now consider how to create locally adapted herds of livestock and complementary management practices that ensure long-term health of sagebrush ecosystems. As many ranchers already feed hay to cows during winter, using sagebrush steppe vegetation as an additional forage resource would allow ranchers to feed roughly half the hay, which would greatly reduce winter feed costs. In addition to financial savings in hay, the secondary benefits from improving sagebrush steppe condition and productivity would result in habitat improvements for both livestock and wildlife.

DEDICATION

To my late Grandmother Mabel Petersen. Her advice to “never stop learning” provides me inspiration to continue in the search for knowledge and truth. Thanks Bedstemor!

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Chuck Petersen

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INTRODUCTION

The North American sagebrush steppe is one of the largest ecoregions in the United States, encompassing millions of acres in Utah, Nevada, Wyoming, Oregon, Washington, Idaho and Montana (West 1983). The name "sagebrush steppe" comes from the words sagebrush, which is the most abundant shrub in this ecosystem, and "steppe," which is large, dry grassland with few or no trees. The climate is characterized by hot days and cool nights during the spring and summer growing season, and cold days and nights during winter when the majority of the annual precipitation (<300 mm) comes as snow. The predominant vegetation is comprised of various species and sub-species of sagebrush along with other species of shrubs and many species of grasses and forbs that support many species of wildlife (West 1983).

Historically, in attempting to provide forage for livestock during spring and summer, land managers sought to eliminate sagebrush (Winward 1991). Nowadays, people realize the multiple year-around benefits of healthy and productive big sagebrush (*Artemisia tridentata* Nutt.) communities for soil, plants, animals, and people. The upright growth form makes sagebrush available as food above snow, and its relatively high protein levels complement the energy in winter-dormant grasses and forbs as food for wild and domestic herbivores. While sagebrush can certainly compete with other species for space, water, light, and nutrients, sagebrush also: 1) extracts nutrients (Mack 1977) and water (Richards and Caldwell 1987) from deep in the soil profile, making them available to herbaceous plants; 2) creates vertical surface roughness that facilitates snow capture (Sturges 1977); 3) provides micro-sites that favor establishment of various understory plants; 4) can physically protect herbs from excessive grazing; and 5) provides protective cover for many wildlife species (Winward 1991). Contrary to long-standing beliefs, complete removal of sagebrush negatively affects biodiversity and has little long-term benefits on perennial grasses and forbs. Indeed, forage production may eventually decline when sagebrush is completely removed (Winward 1991).

Biodiversity in sagebrush steppe decreases when livestock grazing during spring and summer is managed without considering the physiological requirements of perennial herbs. When grazing during the growing season is too frequent and severe, herbaceous perennial understory species are eventually replaced with less desirable annuals such as cheatgrass (*Bromus tectorum* L.) at the expense of perennial grasses, forbs and shrubs whose seedlings are out-competed for water and nutrients. This results in dramatic and often irreversible changes in both nutrient and water cycles. The resulting shift in plant species favors shrubs such as sagebrush at the expense of perennial herbs. This condition promotes high-intensity wildfires that harm soil and reduce diversity of grasses, forbs, and shrubs. To compound the problem, efforts related to decreasing fire frequency through prevention and suppression eventually lead to more intense fires that adversely affect the ecosystems' ability to realize long-term recovery (Christensen et al. 1988). Collectively, these conditions negatively alter critical ecological processes and increase fire frequencies and return intervals, all of which favor annuals to the elimination of sagebrush and perennial herbs, which are unable to re-establish.

Rejuvenating Sagebrush Steppe

While big sagebrush can dominate landscapes where livestock grazing has been excluded (West and Yorks 2006), historic and repetitious grazing by livestock during the growing season, combined with altered fire regimes, have greatly increased the density and abundance of sagebrush at the expense of perennial grasses and forbs on many western landscapes (Winward 1991). This effect is exacerbated by sagebrush's fibrous surface roots and a deep penetrating taproot that enable sagebrush to effectively out-compete herbs for water and nutrients (Winward 1991). Sagebrush dominance over herbs is further favored by the timing of precipitation, the majority of which occurs during winter and spring in sagebrush steppe ecosystems (Winward 1991).

During the past century, people attempted with massive inputs of fossil fuels to change landscapes dominated by sagebrush to suit perceived requirements of wild and domestic animals during spring and summer. Rather than modifying grazing management practices and challenging land managers and livestock to continually adapt to ever-changing plants and habitats, we've attempted to eradicate "undesirable" species of plants such as sagebrush. Mechanical and chemical methods used historically to rejuvenate landscapes are cost prohibitive even now and dwindling supplies of petroleum-based fuels in the first half of the 21st century make these techniques even less feasible. A low-cost alternative, not explored, is to select for locally adapted animals and systems of management that use sagebrush as fall and winter forage enabling enhanced growth of grasses and forbs during spring and summer (Provenza 2008). To do so, we must learn to apply what has been learned regarding livestock behavior, herd dynamics, and grazing ecology to create livestock locally adapted to use landscapes (Provenza 2003b, 2008).

Disturbances such as fire during spring when the soil temperatures are cool and the soil is moist and grazing during fall and winter can rejuvenate sagebrush steppe by reducing the abundance of sagebrush increasing the abundance of grasses and forbs (Bork et al. 1998). Grazing at appropriate times with locally adapted livestock able to use sagebrush can also rejuvenate sagebrush steppe (Provenza et al. 2003). Sheep have been used to rejuvenate sagebrush-steppe under experimental conditions (Dziba et al. 2007; Woodland 2007), and now under more extensive conditions on rangelands in Utah (Guttery 2010), but many doubt cattle can be used to accomplish this objective. Nevertheless, wild and domestic herbivores can benefit nutritionally from using sagebrush in late fall and winter when terpene concentrations are relatively low and protein concentrations are high compared to senescent grasses and forbs. Indeed, sagebrush is significant in the diets of domestic and wild herbivores during winter, often constituting up to a third of the diet (Gade and Provenza 1986).

Sheep numbers have declined dramatically during the past 50 years, while cattle numbers have increased. This creates an opportunity to develop cattle that use sagebrush as food and improve habitat conditions in the process. Many cattle ranchers across the West – Oregon (Mat Carter, Billy McCormick and Doc Hatfield), Montana (Ray Bannister and David Mannix), and Nevada (Agee Smith) – are beginning to consider using cattle grazing during fall and winter to enhance wildlife habitat, improve ranch economics, and promote rangeland resilience.

Detoxification, Supplements, and Managed Grazing

Terpenes in sagebrush limit how much sagebrush wild and domesticated animals can consume to roughly 30 percent of the diet (Oh et al. 1968; Johnson et al. 1976; Gade and Provenza 1986; Ngugi et al. 1995; Dziba and Provenza 2007). Terpenes inhibit cellulolytic microbes in the rumen and terpenes are toxic to rumen microbes and their host at too high doses (Nagy and Tengerdy 1968; Dziba et al. 2006).

Supplemental nutrients increase intake by enhancing detoxification mechanisms. Sheep and goats supplemented with energy and protein consume nearly two times more sagebrush than do unsupplemented animals, evidently because macronutrients enhance rumen fermentation as well as detoxification processes in the rumen and liver (Banner et al. 2000; Villalba et al. 2002; Dziba et al. 2006, 2007). If nutrient supply is insufficient, tolerance of secondary compounds is diminished; conversely, with sufficient nutrient intakes, animals can withstand acid loads (Illius and Jessop 1995). Animals often benefit from higher ratios of protein to energy in the diet when consuming compounds such as terpenes and tannins (Villalba et al. 2002; Provenza et al. 2003). Detoxification and elimination require additional energy and protein beyond that required for maintenance and production (Foley et al. 1995; Illius and Jessop 1995). The nutritional costs of detoxification occur during a two-step process first of transformation (from fat- to water-soluble compounds) and conjugation (often with nitrogenous compounds such as glycine or glucuronic acid) followed by excretion in the urine of the now-detoxified end products (Foley et al. 1995; Illius and Jessop 1995). Nitrogen is also lost through increased ammonium excretion buffering high acid loads from compounds such as glucuronic acid (Foley et al. 1995). Supplemental nutrients thus increase rates of terpene detoxification and elimination allowing animals to ingest more sagebrush because they are able to maintain terpene concentrations in the central circulation below levels that limit intake and cause toxicity (Provenza et al. 2003; Dziba et al. 2006; Torregosa and Dearing 2009).

Two factors increase the efficiency of using livestock to rejuvenate sagebrush steppe while maintaining their performance. Providing *supplemental nutrients* to livestock and grazing at *high stock densities* both mitigate the adverse impacts of eating too much sagebrush and increases the impact of sagebrush steppe rejuvenation efforts with sheep (Dziba et al. 2007; Woodland 2007). Animal impacts on sagebrush come from foraging and physical effects, and from nutrient inputs to the soil provided by livestock in the form of urine and feces derived from supplements and forages. Increasing resource availability – water, nutrients, sunlight – long-term through inputs of carbon and nitrogen as well as water can enhance the production and nutritional quality of herbaceous plants while reducing terpene concentrations in sagebrush (Bryant et al. 1983; Herms and Mattson 1992).

Grazing management can enhance or diminish the ability of landscapes to sustain life by influencing resource availability. Poorly managed grazing adversely affects land, whereas planned grazing can nurture landscapes by promoting the health of soil, plants, animals, and people (Savory and Butterfield 1999; Gerrish 2004). Grazing for short periods by large herds of wild or domestic herbivores allows time for plants to regrow after grazing, which enables regrowth of shoots aboveground and roots belowground. Through grazing, nutrients obtained by plants from different depths in soil are recycled in feces and urine of herbivores; through trampling, herbivores incorporate organic matter from plants into soil (McNaughton 1984; Bryant et al. 1991; Augustine et al. 2003). By enhancing the addition of organic matter in soil, grazing can increase water-holding capacity, positively influence nutrient release from soil, and enhance the degree to which carbon can be sequestered (Lal 2007; Schipper et al. 2010; White 2010).

Influence of Experience

Historically, we have viewed animals as machines and genes as destiny, without appreciating the degree to which animals and their bodies learn – neurologically, morphologically, physiologically – foraging behaviors (Provenza 2003b). During the past 30 years, we have come to appreciate that experiences in utero and early in life link animals in time and space to the local environments where they are conceived, develop, and then live over many generations (Provenza 2003b).

In mammals, the fetal taste system is fully functional during the last trimester of gestation. As a result, flavors in mother's diet acquaint her fetus with foods it will soon eat and they influence food preferences of the fetus (Simitzis et al. 2008). Flavors of plants such as onion and garlic are transferred in utero and in milk, which increases the likelihood young animals will eat onion and garlic when they begin to forage (Nolte et al. 1992a, b, c). As offspring begin to forage, they further learn what to eat (e.g., Mirza and Provenza 1990, 1992; Thorhallsdottir et al. 1990) and where to go (e.g., Key and MacIver 1980; Howery et al. 1998; Davis and Stamps 2004) from mother.

Exposure with mother to foods for as little as a few days early in life have lifelong influences on what a young animal learns to eat. For instance, lambs fed wheat with their mothers for as little as 1 h/d for 5 d eat more wheat than lambs exposed to wheat without their mothers. Even 3 years later, with no additional exposure to wheat, intake of wheat was nearly 10 times higher if lambs were exposed to wheat with their mothers than if inexperienced lambs were exposed alone or not exposed at all (Green et al. 1984). Following similar brief exposure, food intake and animal performance differed considerably during a 3-yr study that began when cows 5 yrs of age were fed straw as a major part of their diet from December to May (Wiedmeier et al. 2002). Half of the cows ate straw for 2 mo as calves, whereas the other half had never seen straw. Throughout the 3-yr study, experienced cows ate more straw, lost less weight, maintained better body condition, produced more milk, and bred back sooner than cows not exposed to straw. Experience with high-fiber diets in utero enables cattle to better use high-fiber diets by enhancing intake and digestibility of fiber (Wiedmeier et al. 2012).

Experience influences intake of foods high in secondary compounds. Cross-fostering studies show young goats from two different breeds, one that prefers and the other that does not prefer high-tannin browse, eat considerably more high-tannin browse if their foster mother eats high-tannin browse (Glasser et al. 2009). Goats reared from 1 to 4 mo of age with their mothers on blackbrush-dominated rangeland ate over 2.5 times more blackbrush than did goats naive to blackbrush, a shrub low in nutritional quality and high in tannins (Distel and Provenza 1991). Experienced goats consumed 30% more blackbrush than inexperienced goats, even when allowed to choose between the poorly nutritious blackbrush and alfalfa pellets. Rumen volume and ability to cope with tannins were higher for goats reared on blackbrush than for goats reared on a non-tannin diet. Experience also influences intake of plants high in phytochemicals such as saltbrush. Lambs exposed to saltbush in utero grow faster and handle a salt load better than lambs from mothers on pasture. They excrete salt more rapidly, drink less water, and maintain higher intake when eating saltbush (Chadwick et al. 2009a, b, c).

Experience and the availability of alternative familiar foods influenced food choice when the preferences of lambs with 3 months' experience mixing tannin, terpenes, and oxalates were compared with lambs naive to the toxin-containing foods (Villalba et al. 2004). During the studies, all lambs were offered five foods, two familiar to all of the lambs (ground alfalfa and a 50:50 mix of ground alfalfa and ground barley) and three of them familiar only to experienced lambs (a ground ration containing either tannins, terpenes, or oxalates). Half of the lambs were offered the familiar foods ad libitum, while half of the lambs were offered only 200 g of each familiar food daily. Throughout the study, naive lambs ate less of the foods with secondary compounds if they had ad libitum access to nutritious alternatives (66 vs. 549 g/d). Experienced lambs ate less of the foods with secondary compounds if they had ad libitum access to the nutritious alternatives (809 vs. 1497 g/d). In both cases, lambs with experience ate more of the foods containing the secondary compounds than naive lambs, whether access to the alfalfa-barley alternatives was ad libitum (809 vs. 66 g/d) or restricted (1479 vs. 549 g/d). These differences in food preferences and intake persisted during trials 1 year later.

In a companion study, when access to familiar foods was restricted to 10, 30, 50, or 70 percent of ad libitum, animals ate more of the foods with secondary compounds and they gained more weight along a continuum (10% = 30% > 50% = 70%) (Shaw et al. 2006). This study, and practical experiences changing the food and habitat selection behaviors of herbivores (Provenza 2003b), illustrates the reluctance of animals to eat unfamiliar foods high in secondary compounds, even to the point of gaining less weight.

These studies illustrate the challenges likely to be encountered when beginning to train sheep and cattle naïve to sagebrush to eat sagebrush. There is a delicate balance between providing too little supplemental forage to help animals eat sagebrush and providing too much forage so animals rely on the supplement and don’t eat sagebrush.

Impact of Grazing on Plants in Sagebrush Steppe

Supplemental nutrients increase use of sagebrush by sheep (Dziba et al. 2007), which in turn decreases sagebrush cover and increases grass and forb production and forage quality (Staggs 2006; Woodland 2007; Guttery 2010). In a 2-year study following the encouraging results of Staggs (2006) using sheep to rejuvenate sagebrush steppe, Woodland (2007) found 1) the abundance of Wyoming big sagebrush was reduced 66% by grazing with sheep during October; 2) species diversity increased 61%; 3) the relative abundance of herbaceous species increased (grasses 43%, forbs 60%, total herbaceous growth [grasses + forbs] 51%); and 4) distribution of age classes of Wyoming big sagebrush was increased slightly even 1 year following grazing.

Guttery (2010) concluded controlled sheep grazing provides a "new" way to improve sage-grouse brood-rearing habitat. During a 4-year study from 2006 to 2009, he found 1) big sagebrush cover was reduced by 69% by sheep grazing; 2) grass and forb cover decreased below initial levels in 2006 (-10.6% ± 0.84) and 2007 (-8.1% ± 0.61), and then increased in both 2008 (+9.6% ± 0.72) and 2009 (+14.3% ± 1.22).

Summary

In summary, studies with sheep indicate supplemental energy and protein markedly increase their use of sagebrush in confinement in pens and on rangelands. Moreover, sheep provided with supplement consume significantly more sagebrush on rangelands, which reduces the abundance of sagebrush and thereby increases the abundance of grasses and forbs. Unfortunately, sheep numbers have declined to the point that they may not be available in most areas.

As cattle are abundant in the Great Basin, I sought to determine if cattle could be used to rejuvenate sagebrush steppe. If effective, this biological approach to habitat renovation will be an alternative to manipulations with chemicals, mechanical treatments, and fire, which are all increasingly impractical due to environmental concerns, the high costs of fossil fuels, and the need to repeat the treatments rather than integrating "treatments" into the landscape as I propose to do with grazing by sheep and cattle. This research has important implications for what it might mean for cattle to become locally adapted to use plants in the landscapes they inhabit, for managing sagebrush steppe plant communities, and for ranch economics on western landscapes.

Objectives and Hypotheses

My objectives were to evaluate: 1) the practicality of strategically timed (fall), high intensity browsing of sagebrush (*Artemisia tridentata ssp. tridentata, and ssp. wyomingensis*) by cattle; 2) the body weight responses of cattle with varying levels of experience browsing landscapes dominated by sagebrush; and 3) the ensuing responses of grasses, forbs and sagebrush to cattle grazing.

In this thesis, I report the results of spatially and temporally replicated feeding trials that took place from 2007 to 2009. I assessed the effects of fall grazing by cattle on reducing the abundance of big sagebrush and promoting the production of grasses and forbs. I hypothesized cattle grazing could be managed to decrease cover, production and percent composition of sagebrush, and increase cover, production, and percent composition of forbs and grasses. Late fall and winter are good times for grazing to induce changes in sagebrush steppe plant communities – reduce the abundance of sagebrush and increase the abundance of grasses and forbs – because sagebrush is more palatable then than during spring, summer, and early fall and perennial herbs have matured and are largely dormant.

I also hypothesized that cattle can learn to eat sagebrush during fall and winter, when terpene concentrations in sagebrush are relatively low. I determined if cow/calf and heifer/calf pairs strategically supplemented with protein and energy, to mitigate the effects of terpenes in big sagebrush, selected big sagebrush as a significant portion of their diet, and I determined their weight responses. As the study progressed, I assessed the effects of age and increasing experience on preference for sagebrush by calves as they aged. Finally, I compared costs of grazing by livestock with chemical and mechanical treatments as a part of the final analysis of the feasibility of grazing sagebrush.

This research was conducted in collaboration with Agee Smith at the Cottonwood Ranch in Nevada. Agee shares our desire to create cattle locally adapted to use sagebrush during fall and winter and to use strategic grazing by cattle to increase the abundance of grasses and forbs in the sagebrush steppe. His long-term goal is to reduce the cost of operating the Cottonwood Ranch by grazing cattle year-round on meadows during summer and on sagebrush-dominated rangelands during fall, winter and spring.

MATERIALS AND METHODS

Study Area Description

The study was conducted on the Cottonwood Ranch located in O'Neil Basin in Northern Elko County, which is in Northeast Nevada. The study area lies within a mix of Loamy Bottom and Ashy Loam ecological sites near Cottonwood Creek. Soils are variable from deep silt loams on the lower positions to gravelly clay loams on the upper positions (USDA-NRCS 1998). Annual precipitation in the area, which averages 259 mm (10.2 in), comes during winter and spring as snow, with limited growing season precipitation from summer thunderstorms. Wyoming and Basin big sagebrush dominate the site, with Douglas rabbitbrush as a sub-dominant, along with a variety of perennial grasses and forbs and sparse amounts of cheatgrass and annual and mustards. The area supports numerous insects and wildlife species including sage-grouse, mule deer, pronghorn antelope, and many passerine birds.

The study site – within the Bull Pasture at Cottonwood Ranch – was 3.0 ha (7.18 acres) divided by electric fence into 15 cells of 0.2 ha (0.48 acres) each. Each cell was 27 m x 72 m. The predominant current and historical land use for the Bull Pasture is grazing by cattle and horses during summer and fall. During my study, cattle were confined to the small pastures and provided supplements (refer to "Supplementing Cattle" on page 14 and Appendices A & B) to promote use of sagebrush in fall. I monitored use of sagebrush and other plant species by cattle, and the impacts of cattle grazing on sagebrush and herbs. In addition, I assessed animal body weight before and after the grazing trials.

Experimental and Sampling Design

Grazing Trials. The grazing trials occurred on 15 adjacent cells (0.2 ha each) during late October and early November from 2007 to 2009 (Tables 1-3 and Appendix C). I used five cells each year in October/November of 2007, 2008, and 2009. There was an adaptation cell in addition to two replications of two treatments (grazed or not grazed) each year. Cattle grazed in new cells each year for 3 years. The annual selection of cells for adaptation, grazing and control was randomly generated.

Each year, cattle began grazing in an adaptation cell and were then moved to the replicated experimental pastures once they began eating sagebrush with supplements (See Tables 1-3). To encourage consumption of sagebrush, cattle were confined at relatively high stock densities – from 62,501 kg/ha (55,762 lbs/acre) to 76,810 kg/ha (68,528 lbs/acre) live weight – and provided with supplements. To determine how experience affected foraging behavior and cattle production, I placed experienced cattle (ones included in the 2007 trials) with naïve cattle (ones not included in the 2007 trials) in 2008 and 2009 and compared how readily each group ate sagebrush. The cattle – obtained from the Cottonwood Ranch cow/calf herd – were not pure bred and had both Angus and Hereford (among other) influences, sired by multiple range-ready bulls.

Table 1. Project layout for cells 1-5 in 2007.

2007					
Cell Number	1	2	3	4	5
Prescription	Control	Adaptation	Grazed	Grazed	Control
Number of Days	N/A	13	6	6	N/A
Total Cattle	N/A	20 pairs (40 head)	20 pairs (40 head) [1]		N/A
Cattle Class	N/A	Naïve cows w/calves	Naïve cows w/calves	Naïve cows w/calves	N/A
Number and Class Scanned	N/A	10 pairs (20 head)	10 pairs (20 head) [1]		N/A
Stock Density (live weight kg/h)	N/A	62,501	31,250		N/A
Stocking Rate (live weight kg-months)	N/A	5,178	2,390		N/A

[1] 20 pairs (40 head) grazed together – the fence dividing the two replication cells was removed because cattle repeatedly broke the wires between the pastures.

Supplementing Cattle. Grass hay, pelletized (cube) food concentrates, water and salt were fed to cattle throughout all 3 years of the study as follows.

Grass Hay. During the adaptation period, I began by feeding grass hay grown at Cottonwood Ranch at a rate that ranged from 5.9 to 7.3 kg hay per 454 kg (13 to 16 lbs per 1,000 lb as-fed basis) live weight per day. I tapered off the daily amount as cattle began eating sagebrush and other forages. Cattle were fed grass hay on the ground in the morning and evening each day (see Appendix A for a summary of grass hay feeding rates per day by year).

Table 2. Project layout for cells 6-10 in 2008.

2008					
Cell Number	6	7	8	9	10
Prescription	Control	Control	Grazed	Adaptation	Grazed
Number of Days	N/A	N/A	7	11	7
Total Cattle	N/A	N/A	22	44	22
Cattle Numbers and Class	N/A	N/A	4 pairs (8 head) of experienced cows[1] w/calves, 4 pairs (8 head) of naïve cows w/calves, 3 experienced bred heifers[2], 3 naïve bred heifers	7 pairs (14 head) of experienced cows[1] w/calves, 9 pairs (18 head) of naïve cows w/calves, 6 experienced bred heifers[2], 6 naïve bred heifers	3 pairs (6 head) of experienced cows[1] w/calves, 5 pairs (10 head) of naïve cows w/calves, 3 experienced bred heifers[2], 3 naïve bred heifers
Number and Class Scanned	N/A	N/A	2 pairs (4 head) of experienced cows[1] w/calves, 2 pairs (4 head) of naïve cows w/calves, 2 experienced bred heifers[2], 2 naïve bred heifers	4 pairs (8 head) of experienced cows[1] w/calves, 4 pairs (8 head) of naïve cows w/calves, 4 experienced bred heifers[2], 4 naïve bred heifers	2 pairs (4 head) of experienced cows[1] w/calves, 2 pairs (4 head) of naïve cows w/calves2 experienced bred heifers[2], 2 naïve bred heifers
Stock Density (live weight kg/h)	N/A	N/A	38,275	76,810	38,535
Stocking Rate (live weight kg-months)	N/A	N/A	1,707	5,386	1,719

[1] These cows were in 2007 trials.
[2] These were calves in 2007 trials.

Table 3. Project layout for cells 11-15 in 2009.

2009					
Cell Number	11	12	13	14	15
Prescription	Control	Grazed	Adaptation	Grazed	Control
Number of Days	N/A	5	14	5	N/A
Total Cattle	N/A	22	42	20	N/A
Cattle Numbers and Class	N/A	2 "double" experienced heifers[1] w/1st calves (4 head), 3 naïve heifers w/1st calves (6 head), 6 pairs (12 head) of naïve cows w/calves	4 "double" experienced heifers[1] w/1st calves (8 head), 6 naïve heifers w/1st calves (12 head), 11 pairs (22 head) of naïve cows w/calves	2 "double" experienced heifers[1] w/1st calves (4 head) 3 naïve heifers w/1st calves (6 head), 5 pairs (10 head) of naïve cows w/calves	N/A
Number and Class Scanned	N/A	2 "double" experienced heifers[1] w/1st calves (4 head) 3 naïve heifers w/1st calves (6 head)	4 "double" experienced heifers[1] w/1st calves (8 head), 6 naïve heifers w/1st calves (12 head)	2 "double" experienced heifers[1] w/1st calves (4 head) 3 naïve heifers w/1st calves (6 head)	N/A
Stock Density (live weight kg/h)	N/A	34,906	66,139	31,239	N/A
Stocking Rate (live weight kg-months)	N/A	1,112	5,901	996	N/A

[1] These 1st calf heifers were calves in 2007 and bred heifers in 2008.

Pelletized (cube) Concentrates. During the adaptation period, I began feeding a strategically formulated cube (ground mix of 50% beet pulp, 30% corn, 5% soybean meal, and 15% alfalfa hay) at a rate that ranged from 1.4 to 1.8 kg cubes per 454 kg (3 to 4 lbs per 1,000 lb) live weight per day. I maintained that same rate of supplementing cubes throughout the trials to encourage cattle to consume sagebrush. Cattle were fed cubes on the ground in the morning and evening each day (see Appendix B for a summary of cube feeding rates per day by year).

Salt. Natural rock salt (containing trace minerals) was provided ad libitum to cattle during the 2007 grazing trial, but not during the adaptation phase in 2007. Natural rock salt was also provided in both the adaptation and grazing replication phases in 2008. As natural rock salt was not available in 2009, I used white block salt (without trace minerals). In all 3 years, salt was placed on the opposite end of the cells from where the water and the hay and cube supplements were fed.

Water. Quality drinking water was provided ad libitum to cattle in 3,785 l (1,000 gal) troughs in each cell. The water was filled from exiting stockwater pipelines, originating from a ranch well.

Cattle Foraging Behavior

I used scan sampling at 10 min intervals for 9 h/d to monitor diet selection and other behaviors (Altman 1974). Approximately half of the cattle, pre-designated according to class for scan sampling, were marked with specific ear tags each year (Tables 1-3). Their feeding behaviors were classified as: 1) "S" for eating sagebrush foliage and/or twigs/branches at or near the top of the shrub; 2) "B" for eating sagebrush bark from along the trunk of the shrubs; 3) "U" for eating any forage in the plant community understory including grasses, forbs, and Douglas rabbitbrush; and 4) “O” for any other kind of activity such as drinking, licking salt, standing, bedded, or ruminating. Scan sampling did not differentiate between the two subspecies (*Artemisia tridentata ssp. tridentata, and ssp. wyomingensis*) of big sagebrush.

Cattle Response to Grazing

The same cattle scanned for feeding behaviors (Tables 1-3) were also weighed on ranch scales before and after the grazing trials each year. Cattle had access to forage and water prior to weighing. They were weighed un-shrunk in the evening both before and after the grazing trials in all 3 years.

Plant Response to Grazing

I established baseline plant community conditions before the trials began and then documented responses of vegetation to grazing by cattle throughout the study. I monitored plant cover, production, and percent composition (by weight) each summer for 3 years (Table 4).

Point Intercept. Point intercept transects were used to estimate responses in foliar cover and to determine the number of species. Transects were marked with a wooden stake in the middle of the southern edge of each cell. The “0” point was re-established each time by using a pre-determined length from a wooden marker in a northern berring. Data collection protocols – including forms, equipment, and data collection instructions – were according to Herrick et al. (2005).

Table 4. Summary of cells and dates for vegetative monitoring from 2007 to 2009.

	2007	**2008**	**2009**	***Comments***
PHOTOS	Cells 1-5 (baseline) ***5/26/07***	Cells 1-5 (repeat) ***6/21-22/08***	Cells 1-5 (repeat) ***7/3/09***	*Photos taken in conjunction with point intercept transects*
		Cells 6-10 (baseline) ***6/28/08***	Cells 6-10 (repeat) ***6/6/09***	
POINT INTERCEPT	Cells 1-5 (baseline) ***5/26/07***	Cells 1-5 (repeat) ***6/21-22/08***	Cells 1-5 (repeat) ***7/ 3/09***	*Point intercept-yielding foliar cover*
		Cells 6-10 (baseline) ***6/28/08***	Cells 6-10 (repeat) ***6/6/09***	
WEIGHT ESTIMATE	Cells 1-5 (baseline) ***6/6/07***	Cells 1-5 (repeat) ***6/21-22/08***	Cells 1-5 (repeat) ***7/4/09***	*Double sampling*
		Cells 6-10 (baseline) ***6/28/07***	Cells 6-10 (repeat) ***6/13-14/09***	

Weight Estimate (Double Sampling). Weight estimate transects were used to estimate production and percent composition by weight. Transects were delineated and repeated based on a pre-determined and consistent distance and berring from the wooden stake marker located in the middle of the southern edge of each cell. The starting point for the weight estimate transect was re-established each time by using a pre-determined length and berring. Forms, equipment, and data collection instructions for the point intercept method followed protocols in BLM (1996).

Photos. Photos were taken at the “0” end of the point intercept 30.5 m (100 ft) tape looking north. Photo cards were used to record site, date, transect number, cell number, and direction. Photos were repeated when point intercept data were collected in each cell each year (Table 4).

Precipitation. Precipitation data from the Gibbs Ranch weather station, which is at the same elevation as Cottonwood Ranch and located approximately 24 km (15 miles) to the south, were used to adjust calculations of herbage production. Crop year (September – June) precipitation records, along with the long-term crop year average, were used to calculate a precipitation index. The index represents a percentage of "normal" or mean precipitation, which is converted to a yield index used to calculate median herbage production values (USDA-ARS 1983).

Statistical Analyses

Scan Sampling. The repeated measures statistical designs differed each year. In 2007, I was unable to use replicated pastures, so I analyzed effects due to age (cow vs. calf) and day (13 d adaptation and 6 d trial) with animals (n = 10) nested within each age class. In 2008, I had two replicated pastures; I analyzed effects due to replication (2) with experience grazing sagebrush (yes or no) and age (cow vs. yearling (bred) heifer vs. calf) as main effects and day (11 d adaptation and 7 d trial) as the repeated measure. In 2009, I had two replicated pastures and I conducted two separate analyses; one included age (first-calf heifers vs. calf) and the other included experience grazing sagebrush (yes or no); day (14 d adaptation and 5 d trial) was the repeated measure in both analyses. Response variables in all 3 years were percent scans grazing sagebrush leaves, sagebrush bark, and other plants. All data were normally distributed.

Changes in Body Weights. I conducted separate analyses for each year of the trial. In 2007, age (cow vs. calf) was the main effect and animals were nested within each age class (n = 10). In 2008, the main effects were age (cow vs. yearling (bred) heifer vs. calf) and experience grazing sagebrush (yes or no) and animals (n = 4) were nested within age/experience class. In 2009, the main effects were age (first-calf heifer vs. calf) and experience grazing sagebrush (yes or no) and animals (n = 4) were nested within age/experience class. All data were normally distributed.

Vegetation Sampling. The repeated measures statistical design for the analysis of variance had two replications. The main effects were graze (yes or no) and plant type (sagebrush, shrubs, grass, and forbs) and their interactions. As monitoring occurred over a varying number of years for Cells 1-5 (3 years, 2007-2009) and Cells 6-10 (2 years, 2008-2009), I conducted separate analyses for Cells 1-5 and Cells 6-10. Cells 11-15 were used only for the grazing trials in 2009, and no plant response data were collected. Response variables were plant cover (%), production (kg/ha), plant composition (%), and number of species. All data were normally distributed.

RESULTS

Cattle Feeding Behavior

Cows and Calves 2007. During the first 5 days of adaptation, cows and calves used little sagebrush (Appendix D Figure 1A). Rather, they mostly used understory grasses, forbs, and shrubs such as Douglas rabbitbrush (Appendix D Figure 1C). As the amount of understory declined from days 6 to 13, cows and calves steadily increased incidence of use of sagebrush foliage, though not at the same rate (age x day $P = 0.02$). Calves began using sagebrush foliage sooner than cows, but cows (15%) ended up using more sagebrush than calves (12%) for the remainder of the adaptation period (Appendix D Figure 1A). I did not measure use of sagebrush bark during the adaptation period because I did not anticipate cows and calves would use so much bark.

During the trial, when cows and calves were put in two separate pastures (replications), cows repeatedly broke through the electric fence, so I combined all animals into one group that grazed both replications. Cows and calves increased use of sagebrush foliage and decreased use of understory throughout the 5-d trial (Appendix D Figures 1A and C). Compared with cows, calves generally used more sagebrush foliage (11% vs. 7%; age x day $P=0.08$) and less understory (33% vs. 60%; age x day $P=0.67$). Use of sagebrush bark increased throughout the trial, and calves used more bark than cows (56% vs. 33%; $P < 0.01$ (Appendix D Figure 1B). While calves tended to spend more time grazing than did cows during adaptation (19% vs. 9%), cows and calves spent similar time grazing during the trial (Appendix D Figure 1D).

Experienced or Naïve Cows and Yearling (Bred) Heifers 2008. During the 11-d adaptation, incidence of use of sagebrush foliage did not differ by experience, age, or day and their interactions were not significant (*P* = *0.61*; Appendix D Figure 2A). Use of sagebrush bark was greater for experienced (44%) than naïve (30%) cows and yearlings, and age and day interacted (*P* < *0.01,* Appendix D Figure 2B). Use of understory decreased over time during adaptation and the pattern of decline varied by experience, age, and day (*P* = *0.07* for experience x age x day interaction; Appendix D Figure 2C). For total time grazing, experience and day (*P* = *0.01*) and age and day (*P* < *0.01*) interacted (Appendix D Figure 2D).

During the 7-d trial, use of sagebrush foliage increased across days (*P* < *0.01*) (Appendix D Figure 2A). Experience tended to affect use of foliage (*P* = *0.17*), but age did not (*P* = *0.63*). Experience and age tended to interact (*P* = *0.22*) because experienced and inexperienced cows ate similar amounts of foliage (11% vs. 10%), whereas experienced yearling heifers tended to eat more foliage than did inexperienced yearling heifers (13% vs. 5%). Experience and age also interacted for use of sagebrush bark (*P* = *0.06*) (Appendix D Figure 2B). Experienced cows ate more bark than inexperienced cows (52% vs. 33%), while experienced yearling heifers ate somewhat less bark than inexperienced yearling heifers (53% vs. 63%). Use of understory declined with decreased availability over time (*P* < *0.01*), but was not affected by experience or age or their interaction (*P* = *0.33*) (Appendix D Figure 2C). For total time grazing, incidence of foraging was similar for experience and naïve animals on days 1 to 5 of the trial, but higher for experienced animals on days 6 to 11 (Appendix D Figure 2D).

Cows and Calves 2008. During the 11-d adaptation, incidence of eating sagebrush foliage was cyclic for cows. Calves took a little longer to begin eating sagebrush foliage, but their use of sage increased during adaptation (*P* = *0.05*); age and day did not interact (*P = 0.42*; Appendix D Figure 3A). Calves ate more sagebrush bark than cows (53% vs. 26%), and age and day interacted for bark (*P < 0.01*; Appendix D Figure 3B). Calves used understory more than did cows initially, but calves decreased use of understory at the same rate as cows for the balance of adaptation (*P < 0.01*; Appendix D Figure 3C). Age (*P < 0.01*) and day (*P < 0.01*) affected total time grazing (Appendix D Figure 3D).

During the 7-d trial, incidence of use of sagebrush foliage was higher for cows than for calves (*P = 0.08)*. Use did not differ by day (*P = 0.92*), and age and day did not interact (*P = 0.74*; Appendix D Figure 3A). Calves ate more sagebrush bark than did cows (52% vs. 42%) and age and day tended to interact for use of sagebrush bark (*P = 0.13*; Appendix D Figure 3B). Cows and calves decreased intake of understory with time (*P < 0.01*), and neither age (*P = 0.31*) nor age and day (*P = 0.32*) were significant; Appendix D Figure 3C). Total time grazing varied by day (*P < 0.01*), and cows and calves spent the same diminishing amount of time grazing during the trials; age did not affect the response (*P = 0.59*), and age and day did not interact (*P = 0.93*; Appendix D Figure 3D).

Experienced vs. Naïve First-Calf Heifers 2009. Neither experience (*P = 0.96)* nor day (*P = 0.26*) affected use of sagebrush foliage until the end of adaptation, at which time experienced heifers began using much more foliage than did naïve heifers and they continued to do so throughout the trial (11% vs. 1%; *P < 0.01*; Appendix D Figure 4A). Compared with naïve animals, experienced first-calf heifers tended to use more bark during adaptation (40% vs. 33%, *P = 0.15*), and experienced animals tended to use more bark than naïve animals during the trial (16% vs. 9%, *P = 0.27*; Appendix D Figure 4B).

Experienced and naïve animals decreased use of understory during adaptation (*P < 0.01*). While they used similar amounts of understory during adaptation (55% vs. 52%), experienced heifers used less understory forage than did naïve animals during the trial (73% vs. 90%; *P = 0.03*, Appendix D Figure 4C). Experienced heifers spent more time grazing than did naïve heifers during adaptation (15% vs. 7%), but not during the trial (40% vs. 43%; Appendix D Figure 4D). Experience and day interacted for total time grazing during adaptation (*P < 0.01*) but not during the trial (*P = 0.66*).

First-Calf Heifers vs. Calves 2009. During adaptation, first-calf heifers and calves did not differ in use of sagebrush foliage (*P = 0.32,* Appendix D Figure 5A) or bark (*P = 0.95,* Appendix D Figure 5B), but both groups of animals increased use of sagebrush foliage (*P < 0.01*) and bark (*P < 0.01*) with time. During the trial, use of sagebrush foliage increased and age and day interacted (*P = 0.07*); use of bark increased (*P < 0.01*) but use of bark did not differ by age (*P = 0.32*), and age and day did not interact (*P = 0.60*). During adaptation, age and day interacted for use of understory (*P = 0.10,* Appendix D Figure 5C). During the trial, use of understory decreased (*P < 0.01*), but use of understory did not differ by age (*P = 0.74*), and age and day did not interact (*P = 0.83*). Age and day interacted for total time grazing during adaptation (*P < 0.01*), but not during the trial (*P = 0.26*).

Weight Responses of Cattle to Grazing

In 2007, when all animals were inexperienced, cows lost an average of 10.7 kg during adaptation and trials, while calves gained an average of 1.1 kg (*P = 0.04*; Table 5). The percentage change differed for cows (-2.1%) and calves (+0.8%) (*P = 0.09*).

Table 5. Weight responses to grazing in 2007.

2007 Weights Data					
Age	Weight[1]	Change	P≥F	Change (%)	P≥F
Cow	457	-10.7	0.04	-2.1	0.09
Calf	154	+1.1	0.04	+0.8	0.09

[1] Mean beginning weight (kg)

In 2008, roughly one third of the cattle had experience grazing sagebrush in 2007 (Table 6). During adaptation and trials, experienced animals lost less weight than inexperienced animals (-11.7 kg vs. -34.2 kg; *P = 0.01*), and they lost a lesser percentage of initial body weight (-2.1% vs. -9.6%; *P = 0.01*). Age and experience did not interact for weight change (*P = 0.52*), or for percentage weight change (*P = 0.49*). Calves lost less weight than did yearling heifers and yearling heifers lost less weight than did cows (-9.1 vs. -25.5 vs. -34.3 kg; *P= 0.03*). As a percentage of initial body weight, however, calves, yearling heifers and cows did not differ in weight loss (-3.7% vs. -7.8% vs. -6.0%; *P= 0.48*).

Table 6. Weight responses to grazing in 2008.

2008 Weights Data					
Age	Weight[1]	Change	P≥F	Change (%)	P≥F
All Cows	552	-34.3	0.03	-6.0	0.48
Exp Cow	536	-25.0	0.01	-4.5	0.01
Inexp Cow	568	-44.0	0.01	-7.6	0.01
All Calves	156	-9.1	0.03	-3.7	0.48
Exp Calf	138	-1.7	0.01	-0.7	0.01
Inexp Calf	173	-16.4	0.01	-8.2	0.01
All Heifers[2]	335	-25.5	0.03	-7.8	0.48
Exp Heifer[2]	350	-8.5	0.01	-2.4	0.01
Inexp Heifer[2]	320	-42.5	0.01	-13.2	0.01
Experience	Weight[1]	Change	P≥F	Change (%)	P≥F
Exp	342	-11.7	0.01	-2.1	0.01
Inexp	354	-34.2	0.01	-9.6	0.01

[1] Mean beginning weight (kg)
[2] Bred, yearling heifers that were calves in 2007

In 2009, 20% of the first-calf heifers were experienced grazing sagebrush and another 20% of the calves were grazing with experienced mother cows (Table 7). Age (calves vs. first-calf heifers) and past experience eating sagebrush interacted. Calves grazing with experienced cows gained less weight than calves with inexperienced cows (+3.4 vs. +8.7 kg; $P = 0.06$). First-calf heifers with experience grazing sagebrush gained weight while inexperienced first-calf heifers lost weight (+15.9 vs. -7.6 kg; $P = 0.06$). Calves with experienced cows gained a lesser percentage of initial body weight than calves with inexperienced cows (+2.0% vs. +7.1%; $P = 0.09$), whereas first-calf heifers with experience grazing sagebrush gained a greater percentage body weight than inexperienced first-calf heifers (+3.8% vs. -2.1%; *P = 0.09*). I did not scan (for feeding behaviors) or weigh cows in 2009.

Table 7. Weight responses to grazing in 2009.

2009 Weights Data					
Age	Weight[1]	Change	P≥F	Change (%)	P≥F
All Heifers[2]	381	+4.2	0.79	+4.5	0.25
Exp Heifer[2]	393	+15.9	0.06	+3.8	0.09
Inexp Heifer[2]	370	-7.6	0.06	-2.1	0.09
All Calves	117	+6.0	0.79	+0.9	0.25
Exp calf	123	+3.4	0.06	+2.0	0.09
Inexp calf	112	+8.7	0.06	+7.1	0.09
Experience	Weight[1]	Change	P≥F	Change (%)	P≥F
Exp	258	+9.7	0.22	+2.9	0.90
Inexp	241	+0.6	0.22	+2.5	0.90

[1] Mean beginning weight (kg)
[2] Bred, yearling heifers that were calves in 2007

Response of Vegetation to Grazing

Cells 1-5 Cover (%). Cover of grasses increased in grazed compared with ungrazed plots, especially in 2009. Cover of forbs was similar in grazed and ungrazed plots throughout the study. Cover decreased for shrubs including sagebrush in grazed compared with ungrazed plots from 2007 to 2009 (Table 8 and Appendix E).

Table 8. Cells 1-5 vegetation response.

CELLS 1-5						
	2007		2008		2009	
	no graze	graze [1]	no graze	graze	no graze	graze
Cover (%) [2]						
Grass	27	28	29	29	36	50
Forb	9	5	8	9	10	11
Shrub	49	50	41	30	40	26
Sagebrush	42	39	36	22	35	23
Number Species [3]						
Grass	4.5	3.0	3.5	2.5	4.5	4.5
Forb	3.5	2.5	4.5	2.5	4.5	2.5
Shrub	2.5	2.5	2.0	2.0	2.0	2.0
Sagebrush	1.0	1.0	1.0	1.0	1.0	1.0
Production (kg/ha) [4]						
Grass	439	603	251	236	421	774
Forb	162	158	240	234	189	359
Shrub	1225	1046	1366	644	810	417
Sagebrush	1107	920	1196	497	733	251
Composition (%) [5]						
Grass	24	33	13	22	30	50
Forb	9	9	13	22	14	24
Shrub	67	58	74	56	56	27
Sagebrush	61	51	65	42	51	16

[1] Values in this column represent data collected prior to grazing
[2] $P < 0.10$ ($P = 0.099$) for graze x plant x year (sem = 7.6).
[3] $P = 0.09$ for graze (sem = 0.2) and $P < 0.01$ for plant (sem = 0.3).
[4] $P < 0.01$ for graze x plant (sem = 62) and $P = 0.04$ for graze x year (sem = 54).
[5] $P = 0.03$ for graze x plant x year (sem = 5.5).

Cells 1-5 Number of Species. Overall, the number of species did not change much across years for grasses, forbs, or shrubs. Grasses were a bit lower in 2007 and 2008 and forbs from 2007 to 2009 in grazed plots compared with ungrazed plots (Table 8 and Appendix E).

Cells 1-5 Production. Production of grasses and forbs generally increased on grazed compared with ungrazed plots, especially in 2009, while production of shrubs declined in 2008 and 2009 (Table 8 and Appendix E).

Cells 1-5 Composition (%). Grass and forb composition increased from 2007 to 2008 and 2009, while shrub composition declined from 2007 to 2009 (Table 8 and Appendix E).

Cells 6-10 Cover (%). Cover of grasses increased in grazed compared with ungrazed plots in 2009. Cover of forbs was lower in grazed compared with ungrazed plots in 2009. Cover decreased for shrubs including sagebrush in grazed compared with ungrazed plots from 2008 to 2009 (Table 9 and Appendix E).

Cells 6-10 Number of Species. Overall, the number of species did not change for grasses, forbs, or shrubs in grazed compared with ungrazed plots (Table 9 and Appendix E).

Cells 6-10 Production. Production of grasses declined somewhat for grazed compared with ungrazed plots from 2008 to 2009. Production of forbs and shrubs generally decreased from 2008 to 2009 on grazed compared with ungrazed plots (Table 9 and Appendix E).

Cells 6-10 Composition (%). Grass and forb composition increased from 2008 to 2009, while shrub composition declined from 2008 to 2009 (Table 9 and Appendix E).

Table 9. Cells 6-10 vegetation response.

CELLS 6-10				
	2008		2009	
	no graze	graze [1]	no graze	graze
Cover (%) [2]				
Grass	6	15	9	23
Forb	11	6	12	7
Shrub	45	52	49	35
Sagebrush	38	35	45	28
Number Species [3]				
Grass	4.0	5.0	4.5	5.5
Forb	4.0	1.5	3.5	3.5
Shrub	4.5	2.0	2.0	2.0
Sagebrush	1.0	1.0	1.0	1.0
Production (kg/ha) [4]				
Grass	140	195	120	116
Forb	178	217	145	114
Shrub	1140	828	450	242
Sagebrush	1026	688	408	187
Composition (%) [5]				
Grass	10	15	17	24
Forb	12	18	20	24
Shrub	78	67	63	51
Sagebrush	70	55	58	39

[1] Values in this column represent data collected prior to grazing
[2] $P < 0.01$ for graze x plant x year (sem = 5.3).
[3] $P = 0.03$ for graze x plant (sem = 0.27).
[4] $P = 0.03$ for graze x plant (sem = 43).
[5] $P < 0.10$ ($P = 0.095$) for graze x plant (sem = 4.7).

DISCUSSION

I evaluated the practicality of strategically timed (fall), high intensity (high stock densities), grazing by cattle with regard to 1) cattle use of sagebrush and cattle performance when grazing landscapes dominated by sagebrush, and 2) the ensuing responses of grasses, forbs and sagebrush to cattle grazing. I hypothesized cattle could learn to eat sagebrush during fall, when terpene concentrations in big sagebrush are relatively low, and that would affect their body weights. Throughout this 3-year study, I determined if cow/calf pairs, yearling heifers, and first-calf heifer/calf pairs supplemented with protein and energy – to mitigate the effects of terpenes in sagebrush – would select sagebrush as a significant portion of their diet. I also hypothesized cattle grazing could be managed to decrease abundance of sagebrush, and increase cover, production, and percent composition of desirable perennial forbs and grasses (Provenza et al. 2003).

Cattle Feeding Behavior

Role of Experience. The foraging behavior of experienced cows, calves of experienced cows, and experienced yearling heifers were superior to their naïve counterparts. Experienced animals outperformed inexperienced animals with regard to use of sagebrush foliage, bark and understory and both cows and yearling heifers showed a capacity for learning to use sagebrush. Prior to the trials in 2008, experienced yearling heifers were exposed to sagebrush in utero in 2007. Compared with naïve yearling heifers, their greater use of sagebrush suggests exposure in utero in 2007 increased their use of sagebrush in 2008. Cattle learned to use sagebrush during adaptation periods and across years and that affected outcomes during the trials in both 2008 and 2009.

Experiences in utero and early in life link animals in time and space to the local environments where they are conceived, develop, and then live over many generations

(Provenza et al. 2003, Provenza 2008). In mammals, the fetal taste system is fully functional during the last trimester of gestation. As a result, flavors in mother's diet acquaint her fetus with foods it will soon eat and they influence food preferences of the fetus. As offspring begin to forage, they further learn what to eat and where to go from mother. Exposure with mother to foods for as little as a few days early in life have lifelong influences on what a young animal learns to eat.

Experiences early in life can affect gene expression. Epigenetic alterations may interact with animals' consumption of plant secondary compounds by altering critical physiological defense mechanisms in the liver and other tissues (Welch et al. 2012). Epigenetics is the study of inherited changes in phenotype, or gene expression, caused by mechanisms other than changes in the underlying DNA sequence. While cellular alterations such as DNA methylation may remain for multiple generations, the underlying DNA sequence of the organism does not change. Rather, non-genetic factors cause the organism's genes to be expressed differently. In essence, the epigenome is a layer of biological reactions that controls whether or not genes will be expressed. For example, rodents given dietary supplements show epigenetic changes that affect expression of genes which alter their fur color, weight, and propensity to develop cancer. In human medicine, epigenetic alterations are clearly implicated in the development of cancer, cardiac hypertrophy and heart failure.

Role of Supplements. Supplemental protein and energy enhance detoxification processes and better enable sheep and goats to eat sagebrush, and higher ratios of protein to energy are beneficial with many secondary compounds (Villalba et al. 2002; Dziba et al. 2007). The supplemental hay, pellets, and salt I provided undoubtedly helped cattle learn to use sagebrush. The nutritional costs of detoxification occur during the two-step process of conjugation, often with nitrogenous compounds such as glycine or glucuronic acid, and excretion of the now-detoxified products (Foley et al. 1995; Illius and Jessop 1995). Nitrogen can also be lost through increased ammonium excretion buffering high acid loads from compounds such as glucuronic acid (Foley et al. 1995). If nutrient supply is insufficient, tolerance of secondary compounds is diminished, yet at high nutrient intakes, animals can better withstand acid loads (Illius and Jessop 1995).

Sagebrush bark, which was used at high levels throughout these trials, may have helped cattle use sagebrush foliage. Bark at the study site provided some crude protein (4.8%) and energy (61.2%). Use of bark likely increased production of saliva, which would buffer acid loads from detoxifying sagebrush foliage. In addition, bark contains tannins, compounds that enhance protein nutrition and enable animals to eat plants with alkaloids and terpenes (Lyman et al. 2008; Villalba et al. 2011; Owens et al. 2012a, b). By binding with terpenes, tannins in bark may enable domestic and wild herbivores to better cope with the terpene-rich foliage of sagebrush (Mote et al. 2008). Finally, nutrients in sagebrush foliage likely were valuable in the nutrition of cattle, as sagebrush contains high levels of protein and energy, relative to animal requirements, in late fall and early winter (8.4% crude protein and 60% TDN), as well as in late winter and early spring (11.3% crude protein and 74% TDN).

In addition to the supplemental hay, pellets, and salt, complementarities among forages likely influenced foraging behavior as cattle learned to use sagebrush steppe vegetation. The increased proportion of Douglas rabbitbrush in cells 6-16 compared to a lower amount found in cells 1-5, may have decreased use of sagebrush in 2008 (cells 6-

10) and 2009 (cells 11-15) as cattle grazed rabbitbrush before sagebrush. While rabbitbrush at the study site contained only modest levels of crude protein (4.4%), it was high in energy (72% TDN) and may have enabled cattle to better utilize sagebrush (these and other values cited above came from wet-lab analyses of forages obtained from the research site in March, 2006 and December, 2007).

Cattle Weight Responses to Grazing

In 2007, cows lost 10.7 kg during adaptation and trials, while calves gained 1.1 kg compared to their original body weight, and the percentage change differed for cows (-2.1%) and calves (+0.8%) (Table 5). In 2008, experienced animals lost less weight than inexperienced animals (-11.7 kg vs. -34.2 kg; $P = 0.01$), and they lost a lesser percentage of initial body weight (-2.1% vs. -9.6%; $P = 0.01$). Age and experience did not interact for weight change or for percentage weight change: experienced cows (-25 kg, -4.5% respectively) and their calves (-2 kg, -1%) lost less weight than naïve cows (-44 kg, -7.6%) and their calves (-16 kg, -8%), and the same was true for experienced (-9 kg, -2.4%) and naïve yearling heifers (-43 kg, -13.2%). Calves lost less weight than yearling heifers and yearling heifers lost less weight than cows (-9 vs. -26 vs. -34 kg; $P= 0.03$). As a percentage of initial body weight, however, calves, yearling heifers and cows did not differ in weight loss (-3.7% vs. -7.8% vs. -6.0%) ($P= 0.48$) (Table 6). These patterns in both 2007 and 2008 were anticipated because 1) animals differed in experience, and 2) calves were still nursing, which benefited the calves but was detrimental to cows, and yearling heifers were not nursing on cows or nursing a calf.

In 2009, first-calf heifers with experience grazing sagebrush – as calves in 2007 and as yearling heifers in 2008 – gained considerable weight (+16 kg, +3.8%) compared with naive first-calf heifers that lost weight (-7.6 kg, -2.1%). Curiously, calves grazing with experienced first-calf heifers gained less weight (+3.4 kg, +2.0%) than calves grazing with naive first-calf heifers (+8.7 kg and +7.1%), which caused an age x experience interaction ($P = 0.06$ for weight and $P = 0.09$ for %) (Table 7). We speculate this finding could be due to higher terpene concentrations in milk decreasing intake of milk by calves of experienced first-calf heifers that ate considerably more sagebrush than their naïve counterparts.

I did not do scan samples to determine use of plants by experienced and naïve calves in 2009. I speculate that calves with experienced first-calf heifers ate more sagebrush than calves with naive first-calf heifers because their mothers (experienced first-calf heifers) generally used more sagebrush foliage and bark and less understory forage, and they grazed more during the trials than did naïve first-calf heifers (Appendix D Figures 4A-D). If so, their use of sagebrush could have further limited their use of mother's milk due to the satiating effects of terpenes in their diet (Dziba et al. 2006). While naïve calves in all years exhibited exploratory feeding behaviors compared to their moms, calves of experienced cows were likely influenced by their moms who exhibited more conservative feeding behaviors and lost weight in 2008. Though calves of experienced first-calf heifers gained less than calves of naïve first-calf heifers in 2009, the calves of experienced first-calf heifers still gained more weight (+3.4 kg, +2.0%) in 2009 compared with calves of experienced (-2 kg, -1%) or naïve (-16 kg, -8%) cows in 2008. Calves of both experienced cows and experienced first-calf heifers increased weights from 2008 to 2009.

Responses of Vegetation to Grazing

Cells 1-5. Cover, production and percent composition of herbs (grasses and forbs) initially maintained or dropped slightly from 2007 to 2008 but then rebounded sharply in 2009 to much higher levels than in 2007 or 2008. A corresponding reduction in shrub cover, production and percent composition accompanied the increase in herbs. Cattle stripped bark which caused some mortality in sagebrush. A significant and expected increase in herbaceous cover, corresponding with a large drop in shrub cover, occurred from 2008 to 2009 in the grazing replications (Appendix F Photographs). Pastures grazed in fall 2007 had adequate recovery time and increased nutrient inputs (dung and urine) from the supplements and animal impacts. A significant and expected increase in herbaceous production, corresponding with a large drop in shrub production, occurred in cells 1-5 from 2008 to 2009. While grass production fell initially below 2007 baseline figures in 2008, grass production in 2009 more than tripled while shrub production continued to decline (Appendix F Photographs). Percent composition (by weight) was similar to production: herbs increased, following a recovery period in 2008, while shrubs showed large drops in percent composition over time.

Cells 6-10. Annual vegetative growth varied due in part to differences in precipitation. Monitoring data in control cells varied more than what might be expected with annual growth fluctuations due to inconsistencies in the annual placement of transect origin locations that often occur with the weight estimate (double sampling) technique. Increases in herb composition corresponding to decreases in shrubs in ungrazed cells may reflect the increase in precipitation from 2008 to 2009. Crop year precipitation, which is measured from September of the preceding year through June of the following year, increased from 173 mm in 2007 to 198 mm in 2008, to 291 mm in 2009.

A significant and expected increase in herbaceous cover, corresponding with a large drop in shrub cover, occurred from 2008 to 2009 in the grazing replications (Appendix F Photographs). An increase in number of herbs from 2008 to 2009 likely reflects increased nutrient inputs (dung and urine) as well as increased precipitation levels from 2008 to 2009. The reduction in herbaceous production from 2008 to 2009 was similar to that in cell 1-5 grazed from 2007 to 2008. Herbs in cell 6-10 fell below baseline (2008) figures, exhibiting the same pattern that occurred in cell 1-5 from 2007 to 2008. Predictably, shrub production dropped from 2008 to 2009 (Appendix F Photographs). The pattern in composition was similar to that cell 1-5 from 2008 to 2009 in that herbs increased significantly in cell 6-10 from 2008 to 2009, while shrubs showed large drops in percent composition.

My findings, as well as those of Guttery (2010), show that intensive fall grazing can decrease production of perennial herbs the year following grazing. However, production increased in subsequent years. Conversely, Woodland (2007) found that the relative abundance of grasses increased 43% and forbs increased 60% the year following grazing. These differences may have been due to different growing conditions in spring, summer, and fall of the three studies.

Fall and winter are good times to use livestock to improve plant community structure because perennial herbaceous plants are less morphologically and physiologically vulnerable to grazing than during active growth seasons such as spring and summer. However, severe and repeated fall/winter grazing can harm dormant buds in the crowns of grasses and forbs. Fall and winter grazing can also remove green tillers that initiated growth during late summer and early fall that would otherwise overwinter as green foliage. Both factors can reduce the vigor of plants the following spring and summer (Briske and Richards 1994). Thus, livestock should not graze the same areas year-after-year during fall and winter due to cumulative adverse impacts on over-wintering tillers and subsequent growth and health of grasses and forbs. Given the amount of sagebrush landscape that needs rejuvenating during winter, that should not be an issue.

Economic Considerations

Table 10 summarizes costs of conventional methods of sagebrush control. These traditional brush management methods are not only cost-inefficient (resulting in little "bang for the buck"), they are usually cost-ineffective (must be repeated at high cost) as sagebrush re-establishes. In addition, fire is either risky or poses a public safety conundrum due to threat of wildfire and pollution from smoke. Mechanical and chemical practices can be detrimental to ecological health, they depend on fossil fuel inputs, and they are often risky from a public safety standpoint. Alternatively, livestock can serve as a disturbance substitute for these treatments, which are cost prohibitive and environmentally insensitive.

Table 10. Costs of various methods of controlling big sagebrush.

Sagebrush Control Method					
Treatment Method	Rx Fire	Mechanical (rotary or renovator)	Herbicide	Chaining	Disking

Estimated cost/hour	$110	$100	$70	$190	$170

Source: Nevada NRCS

Livestock as a Management Alternative

As many ranchers already feed hay to cows during winter, using sagebrush steppe as a forage source could allow ranchers to feed roughly half the hay (7 vs. 13 kg/head/d), which would greatly cut winter feed costs (Gerrish 2010; see the Integrating Cattle Into Landscapes section on page 49 below). In addition, while the manager is saving money, the tremendous secondary benefits from improved rangeland condition and productivity would result in more resilient local ecosystems that provide sustainable, long-term habitat benefits to both wildlife and livestock (Provenza 2008).

The timing of breeding/calving will determine if cattle can be used for winter grazing and brush management treatments. For people who calve in winter, this approach is less likely to work due to high demands for energy and nutrients during late gestation and lactation. For people who calve in late spring and early summer, however, cattle would be in their first and second trimesters of pregnancy during fall and winter, so their nutritional requirements would be low. Native herbivores such as deer and elk that calve in May and June eat as much as one-third of their diet as sagebrush during winter.

In addition, my data indicate experience greatly affected the responses of cows, and with selection over time for locally adapted cattle that winter on sagebrush steppe, the responses of cattle are likely to further improve. Indeed, if cows forage on sagebrush steppe during winter, their calves would begin to be exposed to sagebrush in the womb, which could have benefits, as my data suggest. In the process of learning to accept sagebrush as part of their diet cattle learn, by necessity, to mix a wider variety of herbaceous and woody foods including sagebrush bark to mitigate sagebrush terpenes and thereby harvest nature's sustainable supplement in its natural form. The ensuing increases in perennial herbs and shrubs subsequently provide additional forage for livestock, enabling the use of less feed (supplement) during fall and winter.

The Importance of Becoming Locally Adapted

It is becoming increasingly apparent that the days of low-cost energy are near an end, and the reductions in conventional energy supplies are not likely to be alleviated by alternative sources of energy in the near future. While supplies may be maintained, costs may be prohibitive, which will create opportunities for communities to benefit from foods produced locally (Provenza 2008). There also will be a need, as in times past before our heavy reliance on fossil fuels, to produce livestock in ways that match seasonally available forages with production needs, and that match animals anatomically, physiologically and behaviorally to local landscapes. Reduced inputs of fossil fuels will increase profitability by matching animal needs to forage resources, selecting animals adapted to local environments, culling animals unable to reproduce with minimal help from humans, and creating grazing systems that enhance the health of soils, plants, herbivores, and people.

My research has important implications for what it means for cattle to be locally adapted to using plants in the habitats they inhabit, for managing sagebrush steppe plant communities, and for ranch economics on western landscapes. My data show cattle with experience ate more sagebrush foliage and bark and that they consistently did better in terms of weight responses. Physiological, morphological and behavioral variations that occur among individuals play vital roles in the ability of each animal to perform at a local level (Provenza 2008). Animals best able to use sagebrush during fall and winter can be selected as replacements to create locally adapted herds of animals. Exposing young and older cattle not experienced with sagebrush during fall and winter, when terpene concentrations are low, creates an opportunity for animals to learn to use sagebrush as part of a more diverse diet that includes reduced supplemental feeds as well as other herbs and shrubs that ameliorate terpenes in sagebrush.

"Graze It to Save It"

Livestock grazing has contributed to sagebrush steppe degradation historically (Schroeder et al. 1999; Beck and Mitchell 2000). However, much improvement in grazing management has occurred since the 1950's (Winward 1991). Although the impacts of past grazing practices are still evident today, increased understanding of ecosystem dynamics, especially related to plant community functionality, has lead to the idea that livestock grazing can be managed to provide ecosystem benefits (Provenza et al. 2003). Intensively managed sheep grazing during fall reduces sagebrush cover and greatly increases desirable grass and forb production that can benefit both livestock and wildlife including species such as sage grouse (Staggs 2006; Woodland 2007; Guttery 2010). Grazing at appropriate times with locally adapted livestock that have the ability to use sagebrush effectively reduces the abundance of big sagebrush (Provenza et al. 2003).

I demonstrate that intensively managed cattle grazing can increase production of grasses and forbs that provide benefits for wildlife and livestock alike. This approach relies on the use of livestock grazing to facilitate the management of processes such as the water cycle, nutrient cycle and individual species performance. Unlike other outcome-based brush management methods that often need to be repeated, and pay little or no attention to managing processes, grazing can be integrated into the annual cycles of livestock and landscape management in ways that can create mosaics across landscapes to improve habitat for wildlife including sage grouse (Guttery 2010). While grazing by cattle can kill some shrubs, it also prunes shrubs that can the respond favorably to moisture, resulting in reduced shrub cover while retaining live shrubs. Using livestock mouths, rather than steel or chemicals, is a way to benefit plants, animals and people.

The key to maintaining and improving sagebrush ecosystems is disturbance, which my results suggest can be accomplished with cattle as well as sheep. The removal of fire as a major disturbance vector, combined with historic and current livestock grazing during the critical growth stages of perennial herbs, has resulted in major shifts in composition of sagebrush steppe plant and animal communities (Winward 1991). We have removed the main disturbance vectors that shaped steppe ecosystems historically, namely fire and large herbivores, leading to much of what we see today – a loss of ecological integrity and ability for rangeland systems to respond favorably to imminent wildfire and other natural disturbances. These shifts are exhibited in the dominance of sagebrush biomass at the expense of perennial grasses and forbs. When plant communities dominated by sagebrush burn, they are at risk of converting to annual grasslands as they are in low state of resilience. While attempts to completely suppress fire are effective, it is really not a question of if sagebrush steppe communities will burn but when they will burn.

Many areas in the sagebrush steppe have either had most of their natural disturbance regimes changed or eliminated or lost their ability to respond favorably to natural or traditional human disturbance. Livestock can serve as a surrogate to the large herds of bison, elk, antelope, and deer that once roamed these landscapes. They can also substitute for altered or removed natural fire-disturbance regimes to renew resilience of at-risk plant communities with remnant perennial herbs that can respond favorably to fall and winter grazing of sagebrush. Therefore, one might say when it comes to sagebrush we must "graze it with livestock to save it."

MANAGEMENT IMPLICATIONS

The application of strategic intensive cattle grazing creates opportunities for land managers to use a “new tool” for improving and maintaining the quality of soil, plants, herbivores, and people who depend upon sagebrush steppe ecosystems. Carefully and intensively managed sheep grazing can be used effectively for plant community disturbance and renovation. I showed that cattle have the same capabilities, and furthermore likely have an increased capacity to do so as a result of their larger size which can produce more efficient and effective treatment results. This approach requires careful consideration be given to managing various factors and will necessitate paradigm shifts by those who implement such habitat-enhancement practices. One such consideration is the need to recognize grazing may be inappropriate for areas that have crossed an ecological threshold and have low potential for resilience (e.g. cheatgrass monoculture under heavy sagebrush canopy). Nonetheless, changes in perceptions and attitudes regarding the need for locally adapted systems – from soil and plants through herbivores and people – are making this approach a possibility (Provenza 2008).

Land managers are not keeping pace with increases in sagebrush cover and density resulting from reduced fire impacts. Prescribed fire in addition to natural disturbances such as insects, floods and droughts, are not having an adequate impact on the sagebrush steppe lands to promote appropriate proportions of woody and herbaceous plants and corresponding resilient conditions. Moreover, prescribed fire is risky, poses a threat to other resource values and can’t keep pace with the need to treat adequate amounts of steppe landscapes (Winward 1991). Other sagebrush thinning methods or disturbance surrogates must be considered, such as that presented in this thesis. The question is not if there is enough livestock to accomplish this goal. Rather how can the cattle we have be used at the best times and places to rejuvenate plant communities. We should also consider how strategic supplementation to influence food and habitat selection by deer and elk can be used to rejuvenate landscapes (Mangus 2011).

Goals and Strategies

As there is good evidence sheep can rejuvenate sagebrush steppe (Dziba et al. 2007; Woodland 2007; Guttery 2010), one of the most important objectives of my project was to determine if cattle could do so too and if they exhibited learned foraging behaviors. They clearly increased use of sagebrush within and among years in a free-choice rangeland environment, and their weight responses improved as well, indicating they were learning how to use sagebrush steppe. As my studies show, cattle grazing can thus be used to promote diversity on the steppe landscape as they select sagebrush and other forages as a portion of their diet in a fall and winter grazing scenario. Grazing by cattle can be used to improve and maintain ecological site health and resilience.

My long-term goal is to help livestock producers select for cattle locally adapted to use sagebrush, and in the process, continually rejuvinate landscapes that have become disproportionately dominated by sagebrush. Cattle grazing can accomplish sagebrush steppe renovation. Creating positive results necessitates managing the following processes: 1) changing livestock foraging behavior to enable local adaptation involving neural, morphological, physiological and behavioral changes (Provenza 2008); 2) managing timing, duration, and intensity of grazing to promote growth of perennial grasses and forbs and reduce sagebrush; 3) grazing sites that have not crossed an ecological threshold, which will allow for propagation and expression of previously perennial grasses and forbs; 4) creating greater perennial ground cover and diversity to promote higher rates of water infiltration, hydrologic function, and plant growth; 5) promoting accumulation of organic matter that holds water and slowly releases soil nutrients; and 6) managing grazing impacts to increase inputs of dung and urine into soil creating more productive environments.

Application Considerations

In the course of using cattle to enhance biodiversity in sagebrush steppe, careful consideration should be given to the life cycle and nutritional requirements of the animals. The cows used in the project were bred in September and calved in June, which enabled them to meet high nutritional requirements during lactation by eating high-quality forages during May and June in high desert (~6,000 ft. elevation). While nutritional demands are high during breeding, late gestation, and lactation, cows have lower demands during the first and second trimesters of gestation. Indeed, some loss of weight and body condition is acceptable during winter. As nutritional demands are lower, the need for supplementation is reduced. While supplementation is not always the answer to good cattle health and function, it is an integral component of the strategy to help cattle on landscapes dominated by sagebrush. Diet diversity is critical for generalist herbivores such as cattle as secondary compounds such as terpenes in sagebrush limit their intake of sagebrush to roughly one-third of the diet. Supplements and alternative forages that complement one another help cattle not only use sagebrush without developing a strong aversion to it, but learn to like sagebrush in the process. Providing supplemental hay to cattle during late fall and winter is a common practice throughout much of the West. Thus, the primary changes in management are providing macronutrient supplements such as hay to cattle on sagebrush steppe land that needs rejuvenating thereby encouraging use of sagebrush by cattle.

Grazing in fall maximizes impacts on sagebrush and minimizes impacts on herbs. However, severe and repeated fall/winter grazing can harm dormant buds in the crowns of grasses and forbs. Fall and winter grazing can also remove green tillers that initiated growth during late summer and early fall that would otherwise overwinter as green foliage. Both factors can reduce the vigor of plants the following spring and summer (Briske and Richards 1994). Resting areas that were recently grazed would eliminate the possibility of grazing the same areas repeatedly as well as creating a planning tool that uses cattle to create mosaics across the landscape, rotating them each year to rejuvenate sagebrush across large tracts of land.

Integrating Cattle into Landscapes

In attempting to increase forage availability and use for livestock, many land managers have improperly managed big sagebrush communities in the past, especially by poorly managing grazing during spring and seeking to eliminate sagebrush in many instances with chemical and mechanical treatments. However, views of sagebrush plant communities have changed in recent years as managers have come to realize the many values of sagebrush steppe ecosystems. Contrary to long-standing beliefs, complete removal of sagebrush negatively affects biodiversity and has little positive long-term benefits for perennial grass production (Winward 1991).

From a practical standpoint, the scale of concern is the landscape. Ranchers feed livestock during fall and winter anyway, and livestock fed at lower rations will learn to make the transition to eating sagebrush, as my results illustrate. While the practice is not yet widespread, ranchers across the West – Agee Smith in Nevada, Mat Carter in Oregon, David Mannix in Montana, and Ray Bannister in Montana – are now showing that landscape-scale results can be realized by feeding only half of the daily hay requirement. Furthermore, preliminary results from a Western Sustainable Agriculture Research and Education Program (Western SARE) grant show the outcomes observed in my study plots can be realized using cattle to graze during winter on sagebrush and other unconventional forages at the Cottonwood Ranch in Nevada.

While efforts to rehabilitate fire-affected rangelands have been the primary focus of land treatments to improve wildlife habitat, we must maintain existing sagebrush habitat that has not crossed an ecological threshold to domination by cheatgrass and the vicious cheatgrass-fire cycle that maintains annual grasslands subject to erosion. The main reason to "strike while the iron is hot" is that many of the sagebrush acres are in jeopardy of losing their resilience due to current fire-disturbance regimes.

Rather than attempting to convert sagebrush steppe landscapes to grass at extravagant costs, as we have done historically, we must now consider how to create locally adapted herds of livestock and complementary management practices to ensure long-term health of sagebrush steppe. The selection of a wide variety of foods with primary compounds (nutrients) and secondary compounds (pharmaceuticals) challenges untrained animals to "think outside the conventional feed trough/box." This has the result of benefiting cattle nutritionally and pharmaceutically, enhancing plant community attributes, and improving diets of consumers (Provenza 2008). My studies show cattle can learn to "think outside the feed row" during fall and winter.

Most of the pertinent literature (Kelsey et al. 1982; Welch et al. 1981; Welch and McArthur 1986; McArthur 2005; Wamboldt 1996; Sheehy and Winward 1981) supports the notion animals will be most challenged attempting to consume Basin big sagebrush (*Artemisia tridentata ssp. tridentata*) and Wyoming big sagebrush (*Artemisia tridentata ssp. wyomingensis*), as their concentrations of terpenoids makes consuming these subspecies much more difficult compared to Mountain big sagebrush (*Artemisia tridentate ssp. vaseyana)*. As the big sagebrush subspecies in my research were the ones reportedly most challenging for livestock to consume, using Mountain big sagebrush would presumably be even easier for cattle.

At Home on the Range

Let's consider the domestic bovine (I'll just refer to her as "cow"). Where does cow live? What does cow's house look like? What are contents of each room in her house? How does she find her food? How does cow make her food "purchases"? What are the contents of her fridge? What risks does she face in making food selections?

The collective answer is that contemporary cow is spoiled and we are her enablers, all subsidized by formerly inexpensive and abundant fossil fuels. Largely out of convenience and what we think is best for us, we tell cow what is food, we provide food for her, and she gladly obliges. We have not challenged her to learn to make choices most beneficial to her and ultimately to us. In the process of putting cattle feed preferences in a "box" for them, have we not reinforced livestock behaviors that lead them to "graze the best and leave the rest" (Provenza et al. 2003)? We have essentially trained them to do this by telling them what they should eat and attempting to provide that for them, with little regard for the fact that natural systems have biophysical parameters that set limits on what is possible that not even humans can overcome.

Challenged to do so, livestock can become locally adapted to the landscapes they inhabit. However, we have clearly played a part in limiting the ability of livestock to be anatomically, physiologically, and behaviorally adapted to the landscapes they have historically inhabited by separating them from collective benefits acquired by their previous generations. The choices livestock have are increasingly influenced by financial interests (political, industrial, academic), causing them and us to be dependent on fertilizers, herbicides, and pesticides to produce plants in monocultures; on antibiotics and anthelmintics to ensure livestock health; and on pharmaceuticals, and nutritional supplements to maintain the health of people. The cost of such approaches is high with regard to soil health, herbivores, and people, as these technological fixes treat symptoms of food-related ailments (obesity, diabetes, heart disease, and cancer) that are reflective of unhealthy societies. Copious amounts of studies in the fields of biology, anatomy, physiology, biochemistry, oncology, pharmacology,…, are constantly undertaken without consideration for the idea that the body already integrates and manifests all these processes. This oversight causes us to underestimate the body's complexity and to be unappreciative of what every wild creature "knows" from experience: the body was the first anatomist, physiologist, molecular biologist, geneticist, as well as the first pharmacist, nutritionist, and physician (Provenza 2008).

My project included cows and heifers that were part of the brood herd. As they constitute the majority of the herd, they are the animals most able to train their offspring over generations, they have the greatest potential for plant community impact, and they will not be used as market animals.

While market animals that are temporarily a part of the herd may mimic feeding behaviors previously learned by cows, I recognize incorporating unconventional foods such as sagebrush will produce different meat quality and flavor. At this time, the strategy relies only on the use of heifer calves, not market animals. To be sure, the average beef consumer has a particular product in mind and cattle that are not fed to meet that ideal would probably not fit the American dietary mold, but all of these behaviors are learned (Provenza 2008). However, people learned to like the flavor of "grain-fed beef" during the latter half of the past century, and they can learn to like the flavors of locally produced beef in the first half of this century.

Locally Adapted People and Animals

We live in a time when people are not willing to take the time to prepare nutritious foods that lead to a balanced, healthy diet. The result related to the costs for treating increased disease frequency is astounding. We have conditioned ourselves, with our ever-increasing pace, to accept that forgoing healthy food choices is facilitating our rat-race mentality, promoting the "fast food society." We make such choices in feeble attempts to maintain or even incrementally increase affluence, but that is not working for most of the population, who are doing less well economically by the year. We have been used to getting what we wanted, and often times what we wanted was counterproductive to our own well-being and to that of our children (Provenza 2008). Can we keep up the ever increasing frantic pace and, if so, what will be the cost?

From the standpoint of diet, modern lifestyle choices have lead to a dramatic decrease in the abundance and diversity of nutrients we incorporate on a day-to-day basis, thereby resulting in a narrowing in our diet breadth. Our food preferences have been geared to satisfy short-term gratification at the expense of assimilating a wide variety of primary and secondary compounds that further promote a willingness to incorporate foods that provide healthy complementarities (Provenza 2008).

I contend we have been thrusting these myopic choices not only upon ourselves, but on domesticated animals in our care as well. We tell them what to eat, instead of challenging them to show us what they are capable of eating. Our paradigms related to what we feed livestock and what the resulting meat product look and taste like are causing us to severely limit our options with regard to nutrient diversity. The approach described in this thesis and other related research, provides a stepping stone for creating locally adapted systems that offers multi-tiered and closely connected benefits. That includes appreciating what it means to be locally adapted to the landscapes nature *actually* provides, rather than attempting at great cost to alter entire landscapes to fit our perceptions of what nature *should* provide, and appreciating the diverse roles of primary and secondary compounds (nature's pharmucopia) in the health of soil, plants, herbivores and people (Provenza 2008). This approach also embraces local food systems, which are less reliant on high priced, reduced supply, energy sources, expected to represent de-globalization as our food and energy systems are likely built on a weak foundation of band-aids and unrealistic expectations (Pollan 2006, 2008).

Implications for Further Study

This research leads to many questions related to developing and using locally adapted cattle to benefit landscapes, wildlife and people. Primarily, the notion of developing local adaptation not only in livestock but also in people has caused me to consider how little we know of the limits of what might be possible. In other words, have we just begun to entertain what it means to be locally adapted and are we on the brink of seeing how other behavioral modifications can lead to further understanding? Furthermore, are we willing and able to recognize and act upon and identify cattle best able to use sagebrush within herds? Will the further acknowledgements of variations within individuals promote alternative thoughts and actions with regard to future management approaches?

We also have much to learn from the standpoint of sagebrush. In particular, we should assess how chemical defenses (terpenes) in sagebrush change seasonally due to livestock impacts including browsing as well as inputs of feces and urine, both of which will change soil characteristics that will undoubtedly affect plant chemistry and herbivore responses. In turn, we need to determine how feeding choices are affected, from a chemical defense standpoint, as soil and sagebrush plants respond to herbivory (Bryant et al. 1983; Herms and Mattson 1992). Finally, we should study what kinds of complementarities, in the form of other forages and bark, can be obtained in the diets of herbivores that better enable use of sagebrush foliage.

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APPENDICES

APPENDIX A. Hay Feeding Rates

2007				
Cell(s)	Day in Cell(s)	Hay Bales/day	Kg hay/day	Kg hay/454 kg live cattle wt/day
2-A	1	7	198.1	7.42
2-A	2	7	198.1	7.42
2-A	3	6	169.8	6.36
2-A	4	4	113.2	4.24
2-A	5	4	113.2	4.24
2-A	6	4	113.2	4.24
2-A	7	2	56.6	2.12
2-A	8	4	113.2	4.24
2-A	9	4	113.2	4.24
2-A	10	4	113.2	4.24
2-A	11	3	84.9	3.18
2-A	12	3	84.9	3.18
2-A	13	3	84.9	3.18
3-R, 4-R	1	3	84.9	3.18
3-R, 4-R	2	2	56.6	2.12
3-R, 4-R	3	2	56.6	2.12
3-R, 4-R	4	2	56.6	2.12
3-R, 4-R	5	2	56.6	2.12
3-R, 4-R	6	2	56.6	2.12

NOTES: A=Adaptation Cell, R=Grazing Replication Cell. Cattle were unintentionally combined into replication cells 3 & 4 in 2007. 454 kg = 1,000 lbs.

2008				
Cell(s)	Day in Cell(s)	Hay Bales/day	Kg hay/day	Kg hay/454 kg live cattle wt/day
9-A	1	7	198.1	6.04
9-A	2	6	169.8	5.18
9-A	3	5	141.5	4.31
9-A	4	5	141.5	4.31
9-A	5	5	141.5	4.31
9-A	6	5	141.5	4.31
9-A	7	4	113.2	3.45
9-A	8	4	113.2	3.45
9-A	9	4	113.2	3.45
9-A	10	4	113.2	3.45
9-A	11	3	84.9	2.59
8-R / 10-R	1	1.5 / 1.5	42.4 / 42.5	2.59 / 2.58
8-R / 10-R	2	1 / 1	28.3 / 28.3	1.73 / 1.72
8-R / 10-R	3	1 / 1	28.3 / 28.3	1.73 / 1.72
8-R / 10-R	4	1 / 1	28.3 / 28.3	1.73 / 1.72
8-R / 10-R	5	1 / 1	28.3 / 28.3	1.73 / 1.72
8-R / 10-R	6	1 / 1	28.3 / 28.3	1.73 / 1.72
8-R / 10-R	7	1 / 1	28.3 / 28.3	1.73 / 1.72

NOTES: A=Adaptation Cell, R=Grazing Replication Cell. 454 kg = 1,000 lbs.

2009				
Cell(s)	Day in Cell(s)	Hay Bales/day	Kg hay/day	Kg hay/454 kg live cattle wt/day
13-A	1	6	190.8	6.76
13-A	2	6	190.8	6.76
13-A	3	5	159.0	5.63
13-A	4	5	159.0	5.63
13-A	5	5	159.0	5.63
13-A	6	5	159.0	5.63
13-A	7	4	127.2	4.50
13-A	8	4	127.2	4.50
13-A	9	4	127.2	4.50
13-A	10	3	95.4	3.38
13-A	11	3	95.4	3.38
13-A	12	3	95.4	3.38
13-A	13	3	95.4	3.38
13-A	14	3	95.4	3.38
12-R / 14-R	1	1.5 / 1.5	48.6 / 46.8	3.26 / 3.51
12-R / 14-R	2	1 / 1	31.8 / 31.8	2.13 / 2.38
12-R / 14-R	3	1 / 1	31.8 / 31.8	2.13 / 2.38
12-R / 14-R	4	1 / 1	31.8 / 31.8	2.13 / 2.38
12-R / 14-R	5	1 / 1	31.8 / 31.8	2.13 / 2.38

NOTES: A=Adaptation Cell, R=Grazing Replication Cell. 454 kg = 1,000 lbs.

APPENDIX B. Cube (Pelletized Supplement) Feeding Rates

2007				
Cell(s)	Day in Cell(s)	Cube Sacks/day	Kg Cubes/day	Kg cubes/454 kg live cattle wt/day
2-A	1	2	45.4	1.70
2-A	2	2	45.4	1.70
2-A	3	1.6	36.32	1.36
2-A	4	2	45.4	1.70
2-A	5	2	45.4	1.70
2-A	6	2	45.4	1.70
2-A	7	1.9	43.13	1.62
2-A	8	2	45.4	1.70
2-A	9	2	45.4	1.70
2-A	10	2	45.4	1.70
2-A	11	2	45.4	1.70
2-A	12	2	45.4	1.70
2-A	13	2	45.4	1.70
3-R, 4-R	1	2	45.4	1.70
3-R, 4-R	2	2	45.4	1.70
3-R, 4-R	3	2	45.4	1.70
3-R, 4-R	4	2	45.4	1.70
3-R, 4-R	5	2	45.4	1.70
3-R, 4-R	6	2	45.4	1.70

NOTES: A=Adaptation Cell, R=Grazing Replication Cell. Cattle were unintentionally combined into replication cells 3 & 4 in 2007. 454 kg = 1,000 lbs.

2008				
Cell(s)	Day in Cell(s)	Cube Sacks/day	Kg Cubes/day	Kg cubes/454 kg live cattle wt/day
9-A	1	2	45.4	1.38
9-A	2	2	45.4	1.38
9-A	3	2	45.4	1.38
9-A	4	2	45.4	1.38
9-A	5	2	45.4	1.38
9-A	6	2	45.4	1.38
9-A	7	2	45.4	1.38
9-A	8	2	45.4	1.38
9-A	9	2	45.4	1.38
9-A	10	2	45.4	1.38
9-A	11	3	68.1	2.08
8-R / 10-R	1	1.5 / 1.5	33.95 / 34.15	2.08 / 2.08
8-R / 10-R	2	2 / 2	45.4 / 45.4	2.78 / 2.76
8-R / 10-R	3	2 / 2	45.4 / 45.4	2.78 / 2.76
8-R / 10-R	4	2 / 2	45.4 / 45.4	2.78 / 2.76
8-R / 10-R	5	2 / 2	45.4 / 45.4	2.78 / 2.76
8-R / 10-R	6	2 / 2	45.4 / 45.4	2.78 / 2.76
8-R / 10-R	7	2 / 2	45.4 / 45.4	2.78 / 2.76
8-R / 10-R	8	1 / 1	22.7 / 22.7	1.39 / 1.38

NOTES: A=Adaptation Cell, R=Grazing Replication Cell. 454 kg = 1,000 lbs.

2009				
Cell(s)	Day in Cell(s)	Cube Sacks/day	Kg Cubes/day	Kg cubes/454 kg live cattle wt/day
13-A	1	4	90.8	3.22
13-A	2	2	45.4	1.61
13-A	3	2	45.4	1.61
13-A	4	2	45.4	1.61
13-A	5	2	45.4	1.61
13-A	6	2	45.4	1.61
13-A	7	2	45.4	1.61
13-A	8	2	45.4	1.61
13-A	9	2	45.4	1.61
13-A	10	2	45.4	1.61
13-A	11	2	45.4	1.61
13-A	12	2	45.4	1.61
13-A	13	2	45.4	1.61
13-A	14	2	45.4	1.61
12-R / 14-R	1	2 / 2	46.7 / 44.1	3.13 / 3.31
12-R / 14-R	2	2 / 2	45.4 / 45.4	3.05 / 3.4
12-R / 14-R	3	2 / 2	45.4 / 45.4	3.05 / 3.4
12-R / 14-R	4	2 / 2	45.4 / 45.4	3.05 / 3.4
12-R / 14-R	5	2 / 2	45.4 / 45.4	3.05 / 3.4
12-R / 14-R	6	1 / 1	22.7 / 22.7	1.52 / 1.7

NOTES: A=Adaptation Cell, R=Grazing Replication Cell. 454 kg = 1,000 lbs.

APPENDIX C. Trials Design

<u>2007</u>

Adaptation Cell (cell 2): 13 days

Total: 20 pairs (40 head) of naïve cows w/calves

Scanned: 10 pairs (20 head)

Replication Cells (cells 3 & 4): 6 days

Total: 20 pairs (40 head) ran together - fence dividing the two replication cells was removed due to repeated cattle control problems.

Scanned: 10 pairs (20 head - same 10 pairs as adaptation cell)

<u>2008</u>

Adaptation Cell (cell 9): 11 days

Total: 7 pairs (14 head) of experienced cows w/calves (these cows were in 2007 trials)
9 pairs (18 head) of naïve cows w/calves
6 experienced yearling, bred heifers (these were calves in 2007 trials)
6 naïve yearling, bred heifers

Scanned: 4 pairs (8 head) of experienced cows w/calves (these cows were in 2007 trials)
4 pairs (8 head) of naïve cows w/calves
4 experienced yearling, bred heifers (these were calves in 2007 trials)
4 naïve yearling, bred heifers

Replication Cells (cells 8 & 10): 7 days

Cell 8 Total: 4 pairs (8 head) of experienced cows w/calves (these cows were in 2007 trials)
4 pairs (8 head) of naïve cows w/calves
3 experienced yearling, bred heifers (these were calves in 2007 trials)
3 naïve yearling, bred heifers

Cell 8 Scanned: 2 pairs (4 head) of experienced cows w/calves (these cows were in 2007 trials)
2 pairs (4 head) of naïve cows w/calves
2 experienced yearling, bred heifers (these were calves in 2007 trials)
2 naïve yearling, bred heifers

Cell 10 Total: 3 pairs (6 head) of experienced cows w/calves (these cows were in 2007 trials)
5 pairs (10 head) of naïve cows w/calves
3 experienced yearling, bred heifers (these were calves in 2007 trials)
3 naïve yearling, bred heifers

Cell 10 Scanned: 2 pairs (4 head) of experienced cows w/calves (these cows were in 2007 trials)
2 pairs (4 head) of naïve cows w/calves
2 experienced yearling, bred heifers (these were calves in 2007 trials)
2 naïve yearling, bred heifers

2009

Adaptation Cell (cell 13): 14 days

Total: 4 "double" experienced heifers w/1st calves (8 head)
(These 1st calf heifers were calves in 2007 and bred heifers in 2008)
6 naïve heifers w/1st calves (12 head)
11 pairs (22 head) of naïve cows w/calves

Scanned: 4 "double" experienced heifers w/1st calves (8 head)
(These 1st calf heifers were calves in 2007 and bred heifers in 2008)
6 naïve heifers w/1st calves (12 head)

Replication Cells (cells 12 & 14): 5 days

Cell 12 Total: 2 "double" experienced heifers w/1st calves (4 head)
(These 1st calf heifers were calves in 2007 and bred heifers in 2008)
3 naïve heifers w/1st calves (6 head)
6 pairs (12 head) of naïve cows w/calves

Cell 12 Scanned: 2 "double" experienced heifers w/1st calves (4 head)
(These 1st calf heifers were calves in 2007 and bred heifers in 2008)
3 naïve heifers w/1st calves (6 head)

Cell 14 Total: 2 "double" experienced heifers w/1st calves (4 head)
(These 1st calf heifers were calves in 2007 and bred heifers in 2008)
3 naïve heifers w/1st calves (6 head)
5 pairs (10 head) of naïve cows w/calves

Cell 14 Scanned: 2 "double" experienced heifers w/1st calves (4 head)
(These 1st calf heifers were calves in 2007 and bred heifers in 2008)
3 naïve heifers w/1st calves (6 head)

APPENDIX D. Figures

Figure 1A-D. Incidence (% of scans) of cows and calves grazing sagebrush foliage, sagebrush bark, and understory 2007.

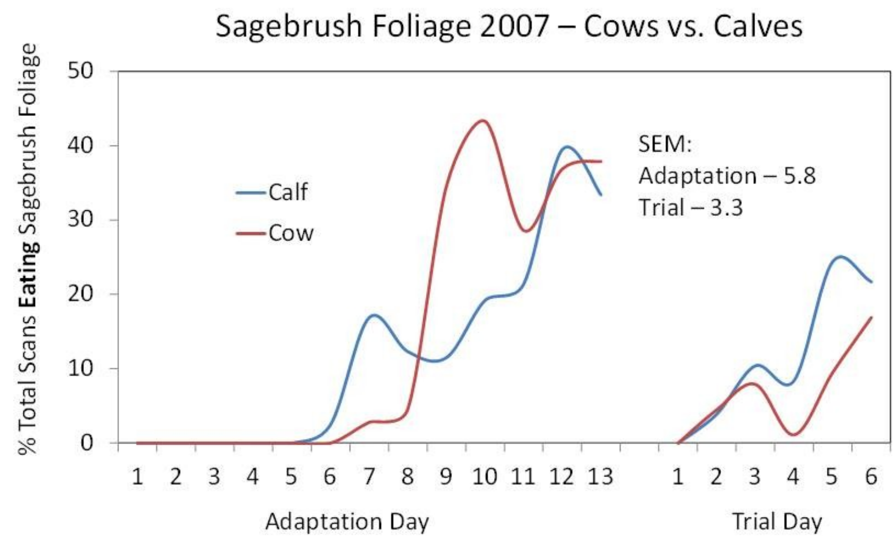


Figure 1A

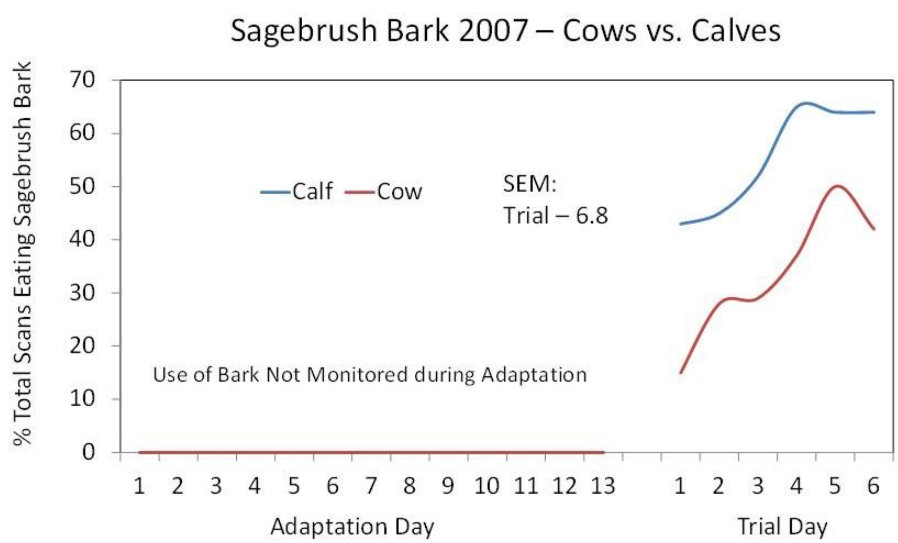


Figure 1B

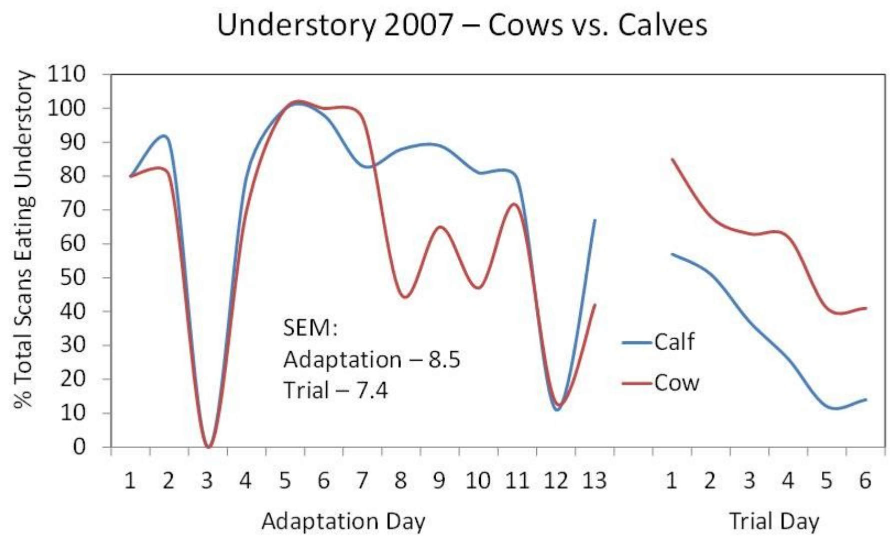


Figure 1C

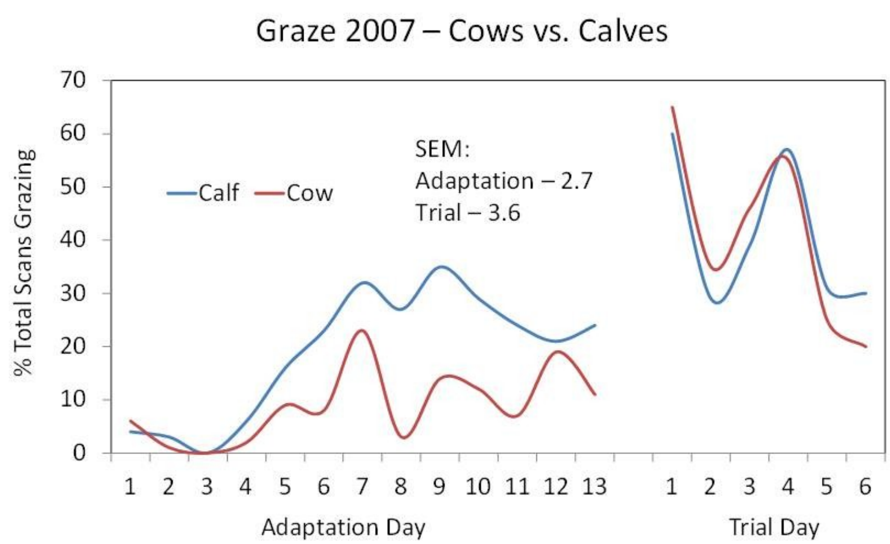


Figure 1D

Figure 2A-D. Incidence (% of scans) of experienced and naïve animals (cows and yearling heifers) grazing sagebrush foliage, sagebrush bark, and understory in 2008.

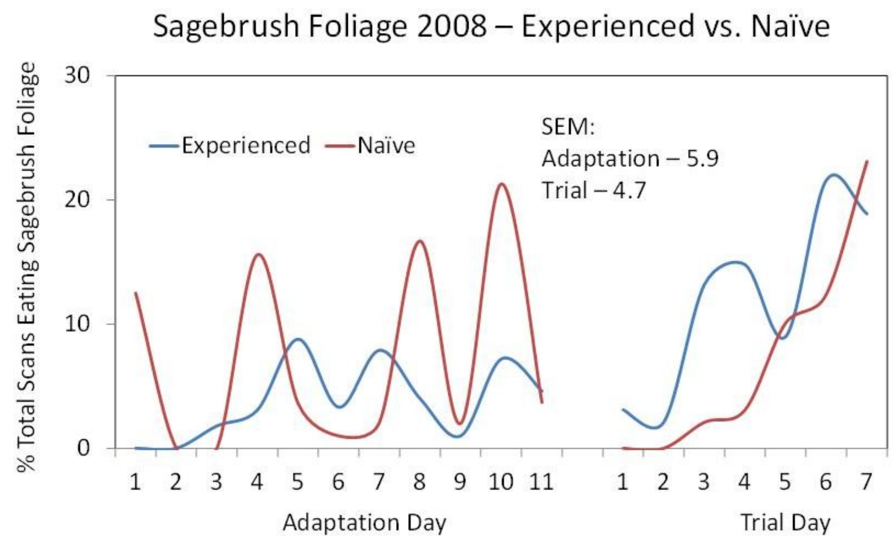


Figure 2A

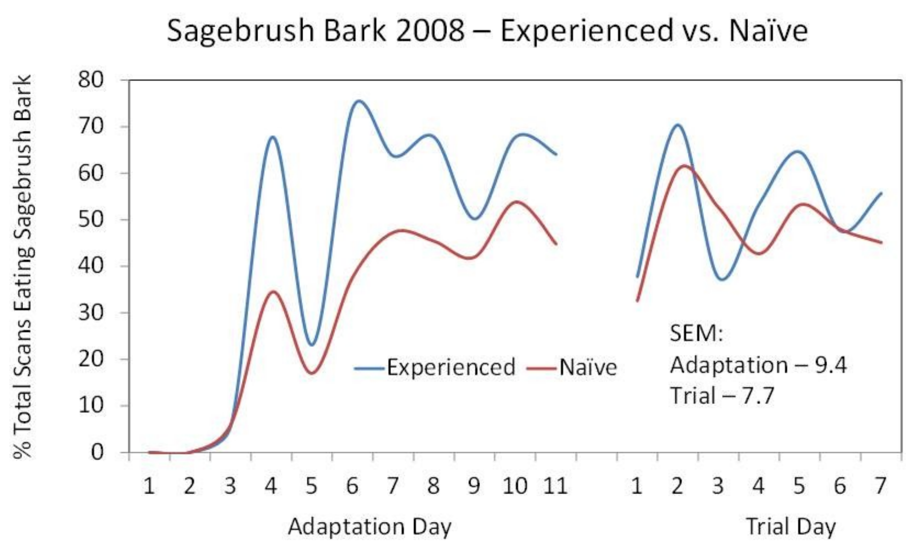


Figure 2B

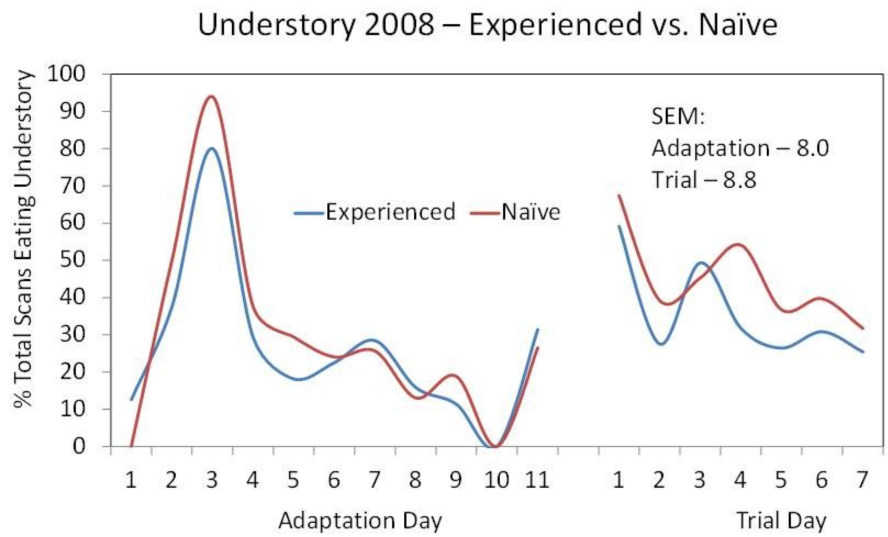


Figure 2C

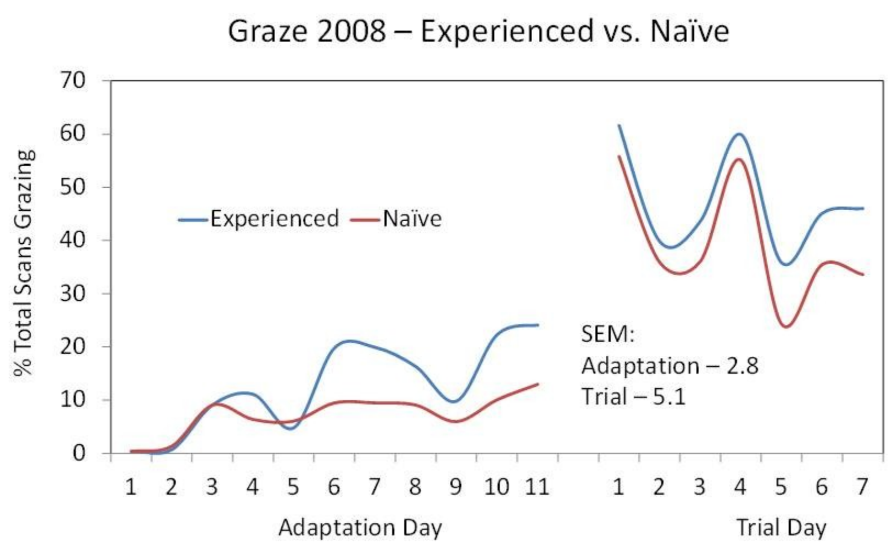


Figure 2D

Figure 3A-D. Incidence (% of scans) of cows and calves grazing sagebrush foliage, sagebrush bark, and understory in 2008.

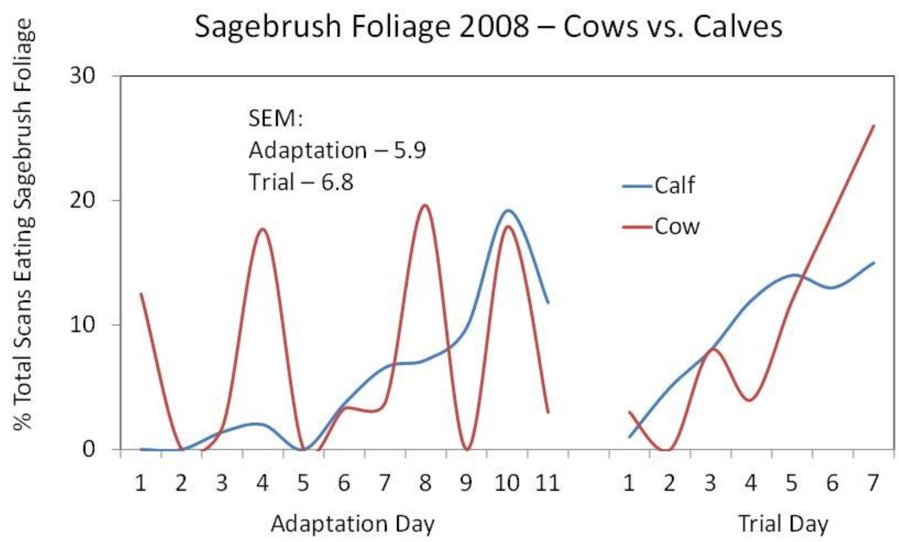


Figure 3A

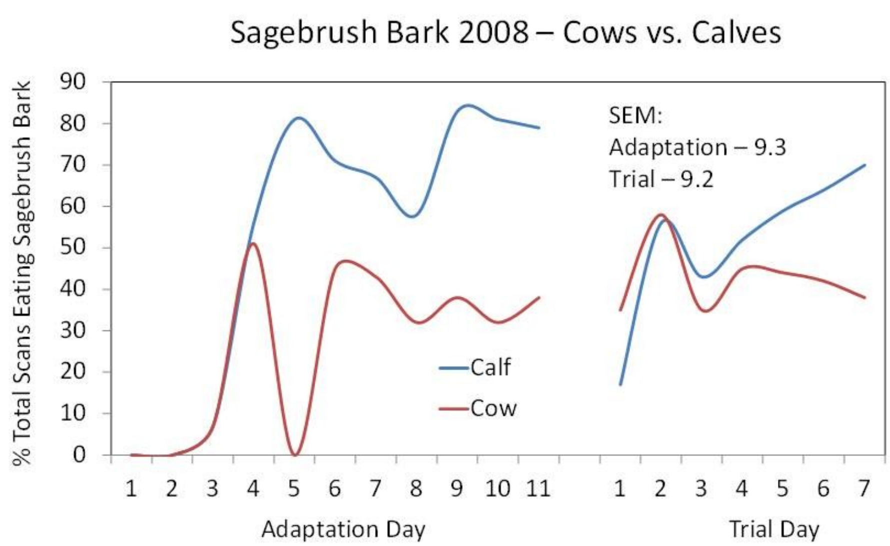


Figure 3B

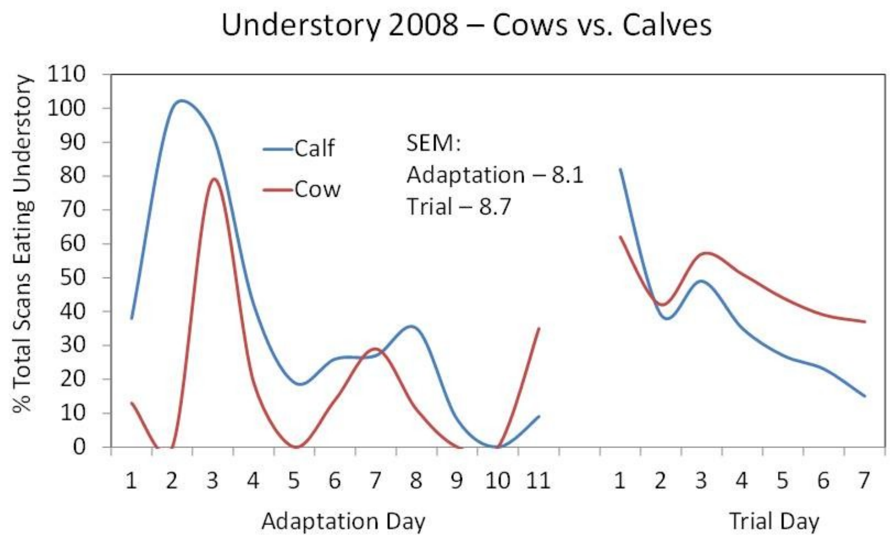


Figure 3C

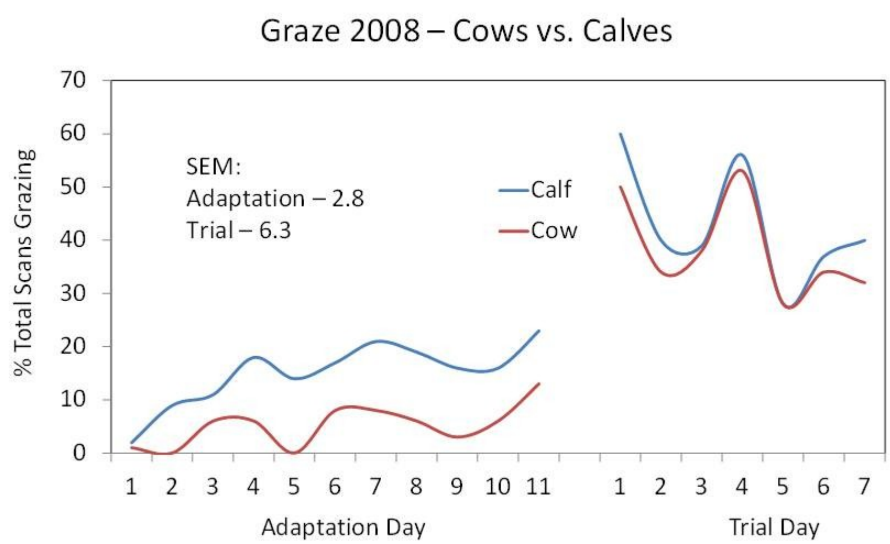


Figure 3D

Figure 4A-D. Incidence (% of scans) of experienced and naïve first-calf heifers grazing sagebrush foliage, sagebrush bark, and understory in 2009.

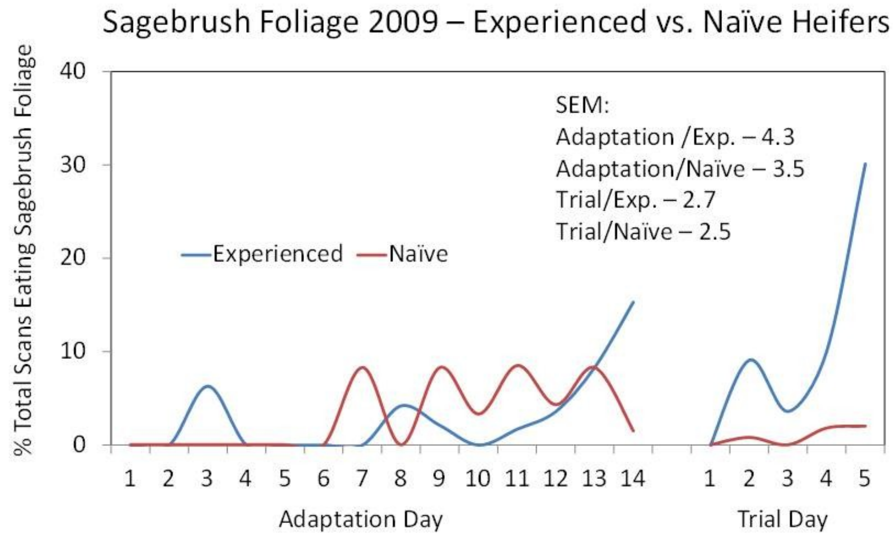


Figure 4A

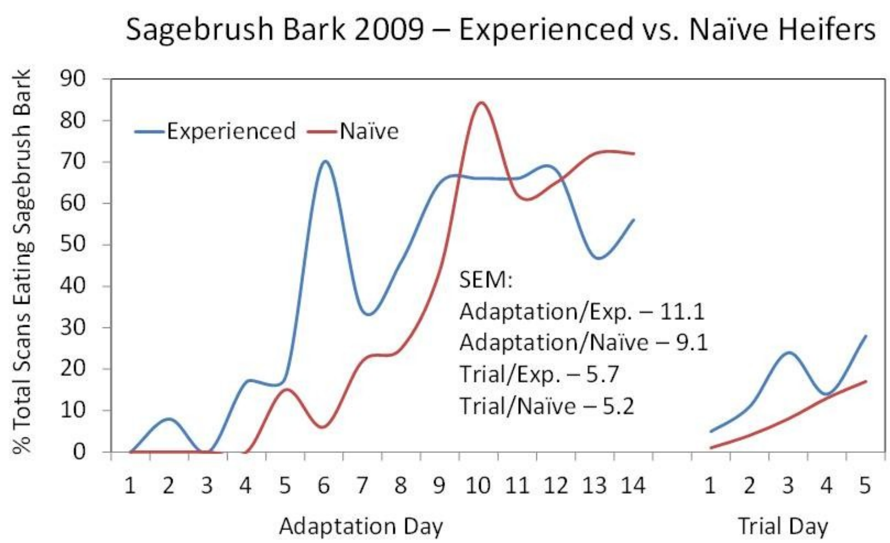


Figure 4B

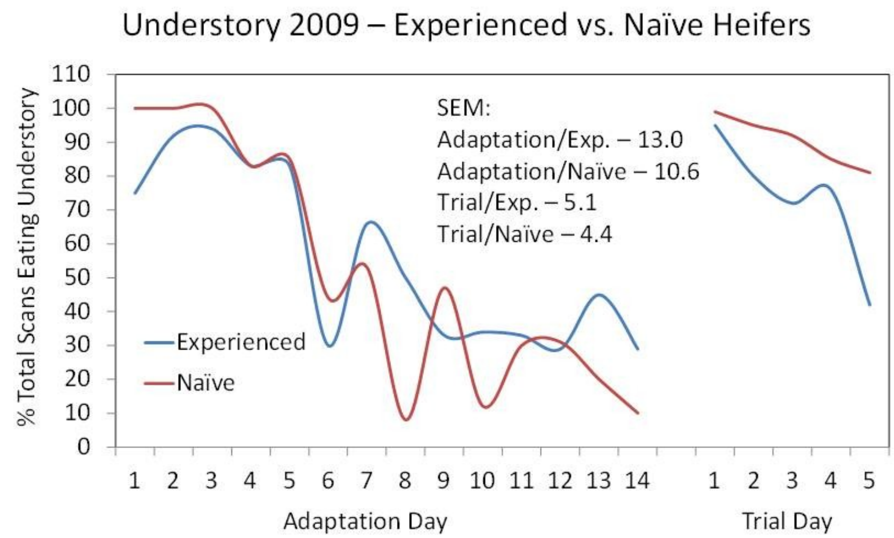


Figure 4C

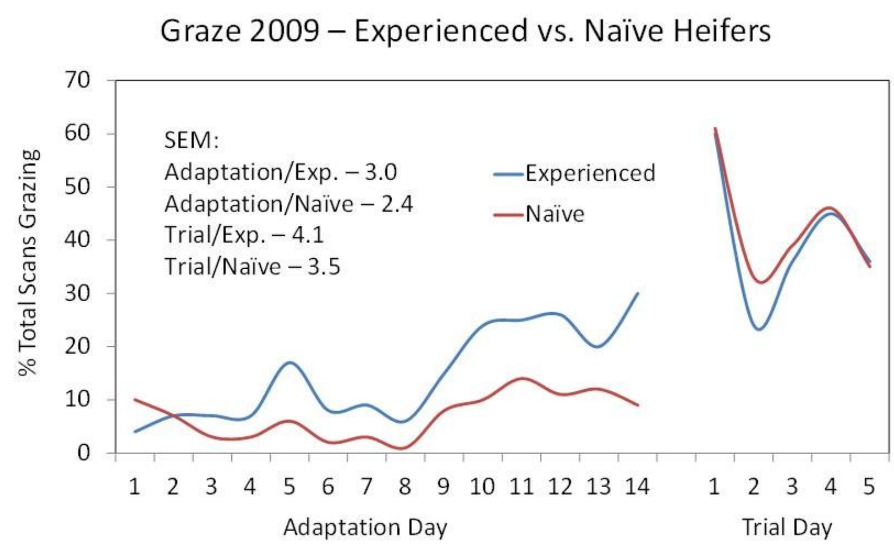


Figure 4D

Figure 5A-D. Incidence (% of scans) of first-calf heifers and calves grazing sagebrush foliage, sagebrush bark, and understory in 2009.

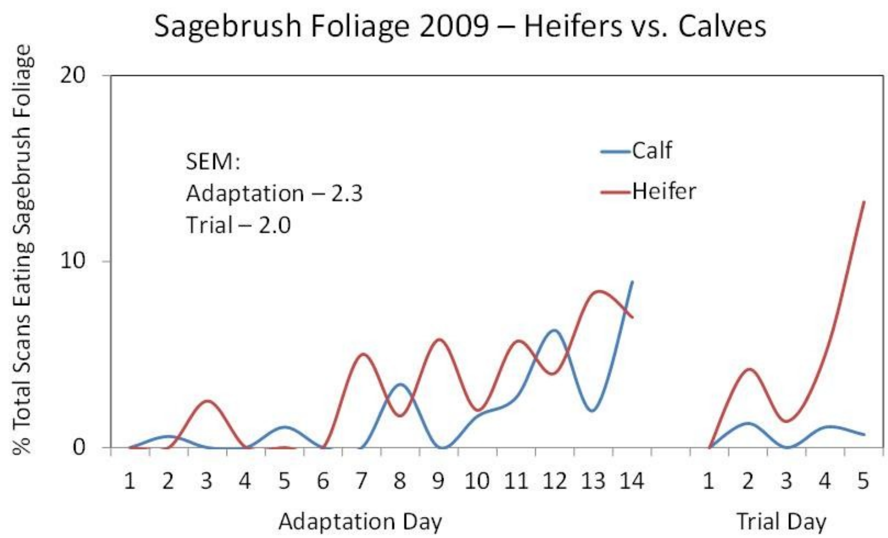


Figure 5A

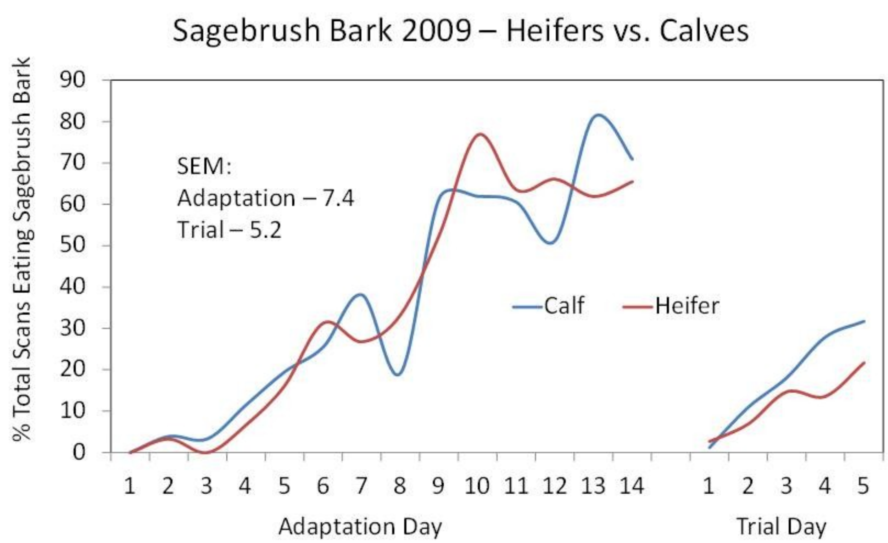


Figure 5B

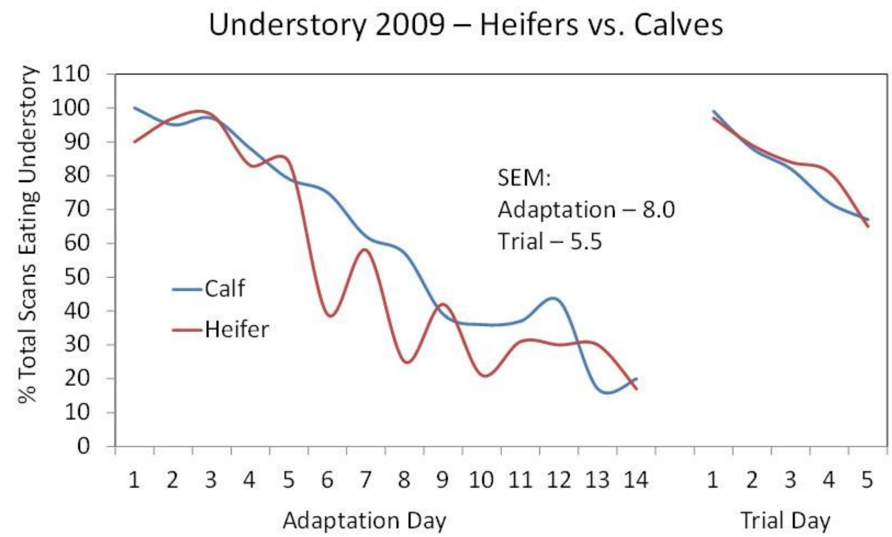


Figure 5C

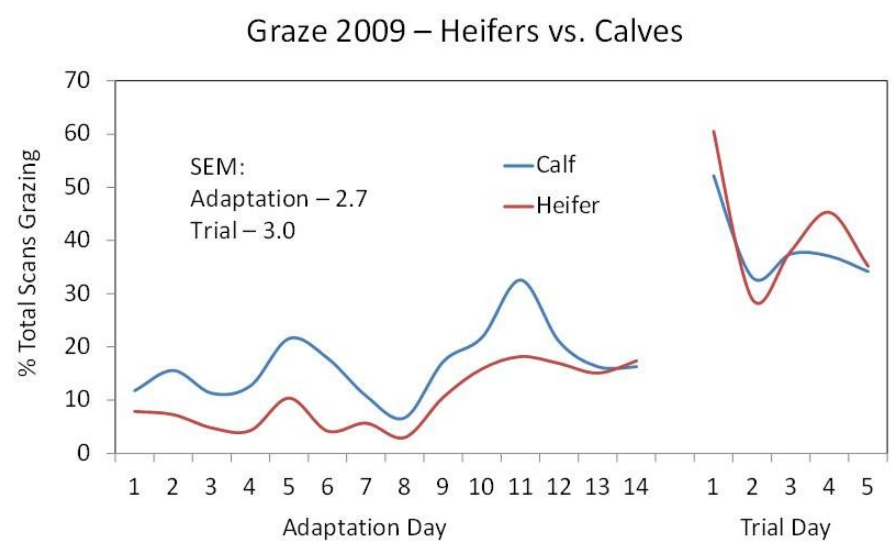
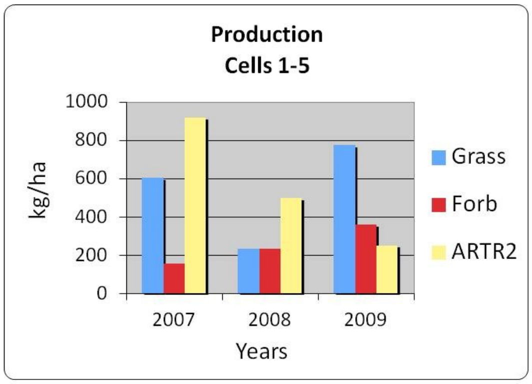
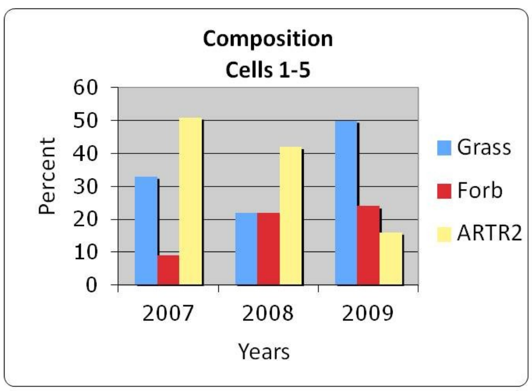
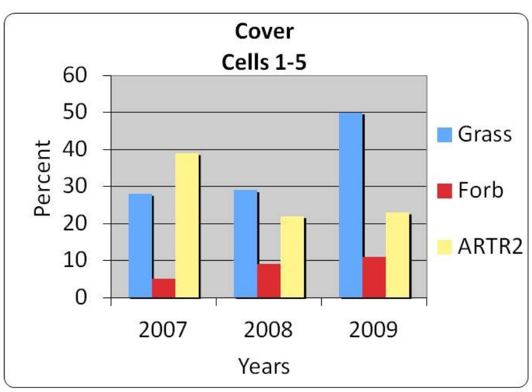


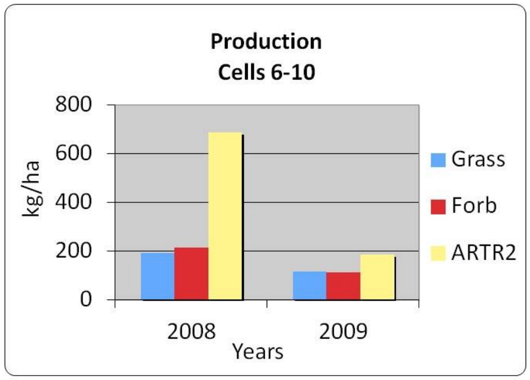
Figure 5D

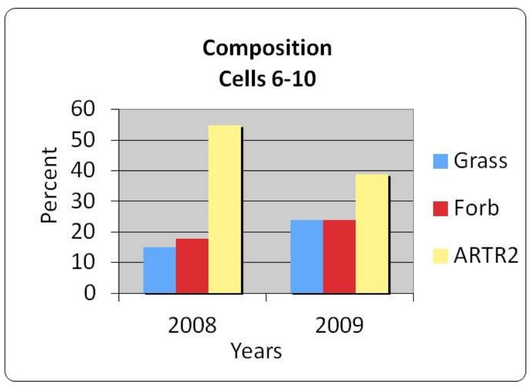
APPENDIX E. Response of Vegetation to Grazing

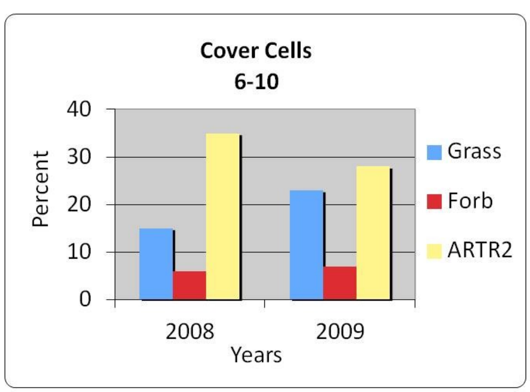

Production
Cells 1-5
kg/ha
1000
800
600
400
200
0
2007
2008
2009
Years
Grass
Forb
ARTR2


Composition
Cells 1-5
Percent
60
50
40
30
20
10
0
2007
2008
2009
Years
Grass
Forb
ARTR2


Cover
Cells 1-5
Percent
60
50
40
30
20
10
0
2007
2008
2009
Years
Grass
Forb
ARTR2


Production
Cells 6-10
800
600
400
200
0
kg/ha
Grass
Forb
ARTR2
2008
2009
Years

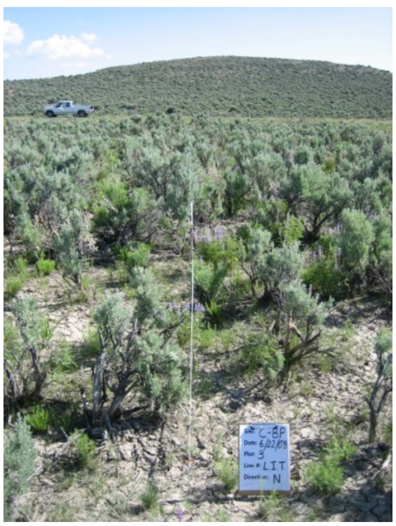

Composition
Cells 6-10
60
50
40
30
20
10
0
Percent
Grass
Forb
ARTR2
2008
2009
Years


Cover Cells
6-10
40
30
20
10
0
Percent
Grass
Forb
ARTR2
2008
2009
Years

APPENDIX F. Photographs

CELL 3 (2007 GRAZING REPLICATION) PHOTO PROGRESSION

Pre-Graze
(6/26/07)



1st Year
Response
(6/22/08)

2nd Year
Response
(7/3/09)

CELL 4 (2007 GRAZING REPLICATION) PHOTO PROGRESSION

Pre-Graze
(6/26/07)

1st Year
Response
(6/22/08)

2nd Year
Response
(7/3/09)

CELL 2 (2007 ADAPTATION) PHOTO PROGRESSION

Pre-Graze (5/26/07)

Post-Graze (11/11/07)

1st Year Response (6/21/08)

1st Year Response (6/21/08)

2nd Year Response (7/3/09)

2nd Year Response (7/3/09)

CELL 13 (2009 ADAPTATION) – VISUAL EXAMPLE OF STOCK DENSITY (66,139 kg/h)