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The Effects of Bison on Cattle Winter Range in the Henry Mountains of South Central Utah: Resolving a Conflict

Ian M. Ware

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THE EFFECTS OF BISON ON CATTLE WINTER RANGE IN THE HENRY MOUNTAINS OF SOUTH CENTRAL UTAH: RESOLVING A CONFLICT

by

Ian M. Ware

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

of

MASTER OF SCIENCE

in

Ecology

Approved:

Peter B. Adler Major Professor	Johan du Toit Committee Member
Janis L. Boettinger Committee Member	Mark R. McLellan Vice President for Research and Dean of the School of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2012

ABSTRACT

The Effects of Bison on Cattle Winter Range in the Henry Mountains of South Central Utah: Resolving a Conflict

by

Ian M. Ware, Master of Science

Utah State University, 2012

Major Professor: Dr. Peter B. Adler
Department: Wildland Resources

The American Bison in the Henry Mountains are one of the last free-roaming, genetically pure herds of bison remaining in North America. Over the last decade, the herd has used a cattle winter range during the summer and early fall, creating a conflict between the wildlife officials who manage the bison population, and BLM officials and local ranchers who manage the rangeland. At the heart of this conflict is the question of whether bison are negatively impacting the rangeland resource. Negative impacts could include reduced forage availability in the short term and undesired changes in plant species composition in the long term. The objectives of this study, which is focused on long-term changes in composition and production, are to (i) determine whether bison have altered the structure of the salt desert plant community in the cattle winter range, (ii) use NDVI/remote sensing data to help confirm that any spatial differences I document reflect temporal trends, and (iii) help resolve the conflict between wildlife managers and ranchers over the limited winter range resource by replacing perceptions with data.

Vegetation surveys were conducted over two growing seasons to characterize plant species composition, cover, species richness, and grazing intensity on three adjacent, geomorphologically similar mesas, one bison and cattle grazed, one cattle only, the third ungrazed. I used a 28-year remote sensing time series to test for temporal shifts in vegetative productivity.

I found higher grazing intensity on the two dominant forage species, *Achnatherum hymenoides* and *Pleuraphis jamesii*, on the bison plus cattle grazed mesa in fall, before the cattle were turned out to winter pasture. Despite the different grazing histories of the three mesas, I found few differences in species composition and cover consistent with grazing-related degradation. There was also no difference in the NDVI time series across the three grazing types. My results indicate that high intensity summer bison grazing, while probably causing short-term reductions in forage availability, has yet to alter plant community composition and productive potential. Shifts in community composition can take years to unfold and just as long to correct; therefore, continued monitoring of the combined effects of cattle and bison is important. My results may ease the tension of the present conflict by objectively characterizing the extent of bison impacts on the cattle winter range.

(51 pages)

PUBLIC ABSTRACT

The Effects of Bison on Cattle Winter Range in the Henry Mountains of South Central Utah: Resolving a Conflict

Ian M. Ware

The American Bison in the Henry Mountains are one of the last free-roaming, genetically pure herds of bison remaining in North America. Over the last decade, the herd has used a cattle winter range during the summer and early fall, creating a conflict between the wildlife officials who manage the bison population, and Bureau of Land Management officials and local ranchers who manage the rangeland. At the heart of this conflict is the question of whether bison are negatively impacting the rangeland resource, potentially reducing the abundance of preferable plant species. Negative impacts could include reduced forage availability in the short-term and undesired changes in plant species composition in the long-term. The objectives of this study are to (i) determine whether bison have negatively altered the structure and composition of the grass-shrubland plant community in the cattle winter range, and (ii) help resolve the conflict between wildlife managers and ranchers over the limited winter range resource by replacing perceptions with data.

Vegetation surveys were conducted over two growing seasons to characterize plant species composition, abundance of present plant species, and grazing intensity on three adjacent, mesas with the same plant communities to assess potential changes induced by recent bison use. Each mesa has a different grazing history, one being grazed by bison and cattle, the second being grazed by cattle only, and the third being ungrazed. I used 28-years of satellite imagery to detect possible shifts in vegetative productivity for each mesa.

During the fall on the bison plus cattle grazed mesa, before the cattle were turned out to winter pasture, I found higher grazing intensity on two important dietary plant species. Despite the different grazing histories of the three mesas, I found few differences in species composition and cover consistent with grazing-related degradation. There was also no difference in the satellite imagery estimations of plant productivity through time across the three grazing types. My results indicate that high intensity summer bison grazing has yet to significantly alter plant community composition. Shifts in community composition can take years to unfold and just as long to correct; therefore, continued monitoring of the combined effects of cattle and bison is important.

This project was partially funded by the Berryman Institute, which is dedicated to improving human-wildlife relationships and resolving human-wildlife conflicts through teaching, research, and extension. My results may ease the tension of the present conflict by providing objective data to characterize the extent of bison impacts on the cattle winter range.

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I would like to thank my advisor, Peter Adler, for the instruction, help, and patience throughout the entirety of my thesis. Peter's guidance greatly improved my efficiency, knowledge, and confidence as an independent and collaborative researcher. Thank you, Peter, for investing your time and knowledge: my time at USU as a part of your lab was a wonderful experience and I am very grateful.

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Ian M. Ware

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INTRODUCTION

The Henry Mountains of southeastern Utah, located on the Colorado Plateau in between Capitol Reef National Park and Canyonlands National Park, are home to one of the last free-roaming, genetically pure herds of American bison (*Bison bison*) left on public land. The Henry Mountain bison herd was first established in 1941, with fifteen cows and three bulls transplanted from Yellowstone National Park, Wyoming. Five more bulls were added to the herd in 1942 (Van Vuren 1979). Over the last decade, a portion of the now 300+ bison herd has begun using the cattle wintering rangelands on the foothills and salt-shrub desert west of the Henry Mountain ridges during the late summer and early fall, before the cattle are put out onto the allotments in late fall. This recent bison behavior has created a conflict between the Utah Division of Wildlife Resources, the Bureau of Land Management, and the local ranchers. At the heart of this conflict is the question of whether bison are negatively impacting the rangeland resource.

Negative impacts could take two forms. In the short term, the addition of bison summer use could reduce forage available to livestock and other wildlife. Over the long term, these higher stocking rates could eventually lead to negative changes in plant community composition. Long-term compositional changes might include a decrease in palatable forage species, such as perennial grasses, an increase in unpalatable species and weeds, and ultimately a loss of productivity (Adler et al. 2005, Fernandez et al. 2008).

Past grazing studies have shown that large herbivore populations (including livestock) can lead to “chronic trampling and herbivory,” changing grasslands into sagebrush-dominated ecosystems (Schlesinger et al. 1990, Schwinning et al. 2008). Augustine and McNaughton (1998) state that changes in species abundances due to herbivory depend on intensity and temporal pattern of tissue loss (herbivore foraging behavior interacting with plant morphology) and each species' response to defoliation. Heavy, unselective herbivory at high densities may also lead to increases in grazing-tolerant or un-preferred plant species (Gordon et al. 2004), increasing the frequency of soil degradation, leaving only several tolerant plant species, which could overall reduce diversity (Milchunas et al. 1988). Conversely, large herbivores can increase plant diversity through utilization of low quality forage, aiding seed dispersal, elevated urine deposition, and "frequent, small disturbances" (intermediate disturbance hypothesis), all of which can increase spatial heterogeneity in the soils and the plant community (Olff and Ritchie 1998). Illius and O'Connor (1999) also argue that changes in plant species composition in semiarid grazing systems, much like the my sites on the Colorado Plateau, are more likely to reflect abiotic factors such as climatic variability, but can be intensified by grazing.

Managers have good reasons to worry that the recent bison summer use of cattle winter range could have negative impacts. The plant communities of the Colorado Plateau evolved with low grazing pressure from large ungulates which may mean that Colorado Plateau rangelands are dominated by plant species poorly adapted to heavy grazing pressure (Mack and Thompson 1982, Damhoureyeh and Hartnett 1997). A small number of studies have been performed to compare the differences of 'relict' ungrazed landscapes against grazed landscapes (Asner et al. 2003, Huenneke et al. 2002), and even fewer on the Colorado Plateau specifically (Fernandez et al. 2008, Neff et al. 2005). These studies support the idea that the Colorado Plateau is sensitive to grazing, with lower cover and lower productivity of key functional groups in grazed sites, (Fernandez et al. 2008). Both Fernandez et al. (2008) and Neff et al. (2005) also found lower levels of soil organic matter (soil organic carbon and nitrogen) and higher levels of erosion in grazed sites, both negatively impacting productive potential.

The seasonality of grazing can also have an important long-term effect on the plant community. Growing season grazing may allow removal of reproductive structures before seed dispersal, reducing seed production and a plant's ability to tolerate environmental stress. In sagebrush ecosystems, spring grazing can reduce the abundance of perennial grasses, and in turn lead to increases in shrub abundance and bare ground cover (Laycock 1967, Kitchen and Hall 1996, Adler et al. 2005). Ganskopp (1998) observed that grazing of Thurber needlegrass (*Achnatherum thurberianum*) during early boot stage, the transitional stage from vegetative to reproductive growth, had the largest negative effect, reducing the reproductive potential of the grass. If desirable Henry Mountain forage species, like Indian Ricegrass, *Achnatherum hymenoides,* and Galleta grass, *Pleuraphis jamesii,* do not have a chance to complete the reproductive cycle in the spring and summer and cannot compensate for grazing effects, they may suffer increased mortality and an overall reduction in abundance.

Little is known about whether bison have a different effect than cattle on Colorado Plateau plant communities. In the Great Plains, studies have shown that both bison and cattle "differentially altered some vegetation components," but overall differences between bison grazing and cattle grazing were minor in comparison to differences between grazed and ungrazed pastures (Towne et al. 2005). Specifically, moderate grazing by both bison and cattle causes an increase in spatial heterogeneity (Towne et al. 2005), and in turn species richness (Hickman et al. 2004, Towne et al.

2005). In Van Vuren's (1979) report on bison ecology and behavior, one of the first ecological studies on the Henry Mountains, he noted that the diet preference of bison and cattle were similar, both foraging on "grass and grass-likes." How bison and cattle move and aggregate on the landscape can also influence changes in community composition. Cattle distributions are dependent on distance from water and shade, potentially concentrating grazing impacts, while bison movements are much less inhibited by such factors, allowing a herd to graze a much larger area (Plumb and Dodd 1993, Van Vuren 2001). Similarly, in the Yellowstone shrublands, the seasonal migration and gregarious nature of a bison herd potentially increased unselective foraging, consequently limiting negative effects on desired forage species and controlling the abundance of "unpalatable" species (Augustine and McNaughton 1998). In the Henry Mountains, Van Vuren (1979) found that the migrational behavior of the gregarious herd was seasonal, moving "northward in summer to higher elevations, and southward in winter to lower elevations." However, the specific seasonal location of the herd was unpredictable, and bison sometimes occurred off the mountain in lower elevation flats in summer months (Van Vuren 1979). Thus, while bison and cattle diets are likely to be similar, their use of the landscape may differ. Similarity in diet would increase bison impact on forage availability, while differences in landscape use might diminish the potential impacts.

Such arguments have set the stage for conflicts between managers, ranchers, and conservation biologists on how to properly develop and implement grazing management strategies to protect the remaining rangeland resource. My null hypothesis was that the bison have had no significant effect on the plant species composition of the cattle winter range (e.g., Fernandez et al. 2008). I tested this hypothesis by comparing plant community composition, plant cover, and soil parameters on three separate mesas with different grazing histories: bison and cattle grazed, cattle grazed, and ungrazed. To complement the spatial comparison across the three mesas, I used a 28-year time series of a NDVI, a measure of vegetative activity closely correlated with productivity. This time series could confirm that current differences in plant species composition reflect changes in bison use that began around the year 2000, when the bison began notably utilizing the cattle winter range. Failure to reject my hypothesis will reassure ranchers that bison summer grazing does not appear to have altered the productive potential of their grazing allotments. Alternatively, the data could show that the bison have caused negative long-term changes in vegetation and soils in the cattle winter range. In either case, this information will help inform future management decisions on the Henry Mountains.

METHODS

Site selection

The Henry Mountains are part of the Rocky Mountains in southeastern Utah (38°6.53’N, 10°48.82’W). The semi-desert grass shrublands, on the western flank of the Henry Mountains, have a mean annual temperature of 11.8°C, a mean annual precipitation of 142.75 mm (Hanksville, UT weather station), and the ecological site is Semi-desert Sandy Loam (Four-wing Saltbush) (Soil Survey Staff, NRCS 2012). My study takes advantage of three adjacent, geomorphologically similar mesas at approximately 1600 m elevation on the west side of the mountain range. Little Thompson Mesa is the ungrazed mesa that offers no water source for grazers and is difficult to access. Wildcat Mesa is grazed primarily by cattle during the winter months, and Steven’s Mesa is grazed by cattle during the winter and by bison in late summer and early fall. To select sampling locations, I first used Web Soil Survey (Soil Survey Staff, NRCS 2012) to identify areas with similar soils across the three mesas. Within areas delineated as the soil map units of Yarts fine sandy loam, 3-8% slopes, and Begay fine sandy loam, 2-8% slopes, I selected random points to locate my sampling plots. I sampled 32 plots across the three mesas.

Soil sampling

To describe variation in the soil characteristics across three mesas, soil samples were collected from 0-15 cm depth, and pooled for each of the 32 sampling plots. The soils were dried and sieved to attain the soil fraction less than 2 mm before chemical and physical analysis. Soil texture was determined using the hydrometer method (Gee and Bauder 1979) and soil pH with the 1:1 soil: water method (Kalra 1995).

Large ungulates can cause soil compaction, which can restrict water filtration, root growth and microorganism activity (Herrick et al. 2009). To assess soil compaction, soil resistance was measured with a pocket penetrometer at twelve predetermined random points along both 50 meter transects. I planned to determine soil aggregate stability but the soils were too sandy and had weak to no aggregation.

Grazing intensity

I used two techniques to provide indirect estimates of grazing intensity. The first involved fecal pellet and pat counts. Quarter m^2 quadrats were placed every five meters to count lagomorph fecal pellets to estimate present densities. Another 1m x 50m belt transect was used to count individual bison and cattle fecal pats for the same purpose. Bison and cattle fecal pats cannot be distinguished from one another, for this reason fecal pats were counted in the early summer, not long after the cattle were removed from the allotment, and in the fall, after the bison were believed to have moved onto the cattle winter range, in an attempt to explain the timing of bison use. An increase in fecal pat densities from the summer to the fall would help indicate the presence and seasonality of bison utilization.

After the cattle were removed from the winter grazing allotment in the early summer of 2011, the intensity of defoliation was estimated, in June, on randomly selected individuals of the two dominant grass species, *Pleuraphis jamesii* and *Achnatherum hymenoides*, at all plots on Steven’s Mesa (B&C) and Wildcat (Cattle) Mesas. The defoliation index is scored as followed: 0, no tillers defoliated; 1, one tiller defoliated; 2, more than one but not all tillers defoliated; and 3, all tillers defoliated (Adler et al. 2005). The grazing intensity estimates were repeated in early October of 2011, when the bison were personally observed on Steven's Mesa (B&C) (cattle winter range), before the cattle were released.

Plant community composition

I sampled all 32 plots in the summer of 2010, during July and August. At each plot, two fifty meter transects were laid out in the cardinal directions, starting from a common origin (Plate 1). The Point Intercept Method was applied to estimate the basal and canopy cover of the plant species present along each transect, systematically measuring every half-meter. One m^2 quadrats were distributed every 5m along each transect to estimate frequency and density of all the plant species within each quadrat. One meter by fifty meter belt transects were used a to estimate shrub densities. In June 2011, frequency and density measurements were repeated on Steven's (B&C) and Wildcat (Cattle) Mesa to more accurately assess diversity, which can vary in time (Adler and Lauenroth 2003). Basal and canopy cover were not re-measured. Logistical problems prevented a return trip to Little Thompson Mesa (Ungrazed) in 2011.

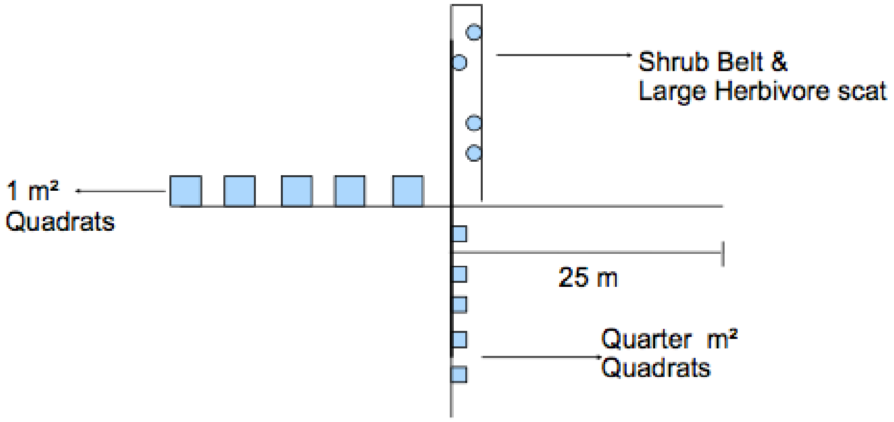


PLATE 1. All techniques were measured along the entirety of each transect.

Remote sensing

Landsat 5 remote sensing imagery from each June from 1984 to 2011 (Table A1) was used to generate biweekly values of the Normalized Difference Vegetation Index (NDVI). The COST correction was used to atmospherically correct the Landsat 5 imagery (USU RS/GIS 2012) before calculating the NDVI. NDVI is a satellite-based vegetation index that correlates strongly with aboveground net primary productivity (Pettorelli et al. 2005), and can be used to assess land degradation by estimating changes in the levels of productivity or by increases in the amount of vegetation lost or bare ground present (Holm et al. 2003). For the areas corresponding to the common soil types on the three mesas, Yarts fine sandy loam, 3-8% slopes, and Begay fine sandy loam, 2-8% slopes, the biweekly NDVI values were averaged for each area of interest on the three corresponding mesas. The pixel size for both the Landsat imagery was 30 meters by 30 meters. The NDVI generated a trend of relative mean greenness for each mesa throughout the yearly time series, capturing peak June productivity of the grass-shrublands after spring precipitation events. Table A1 supplies the acquisition data for the Landsat imagery. The NDVI time series created a historical reference to examine any recent declines in relative vegetation activity due to recent bison use of the cattle winter range. A decline or divergence in community level "greenness" on Steven's Mesa (B&C) could potentially occur if the recent bison use had led to any negative changes in productivity, such as increasing the amount of bare ground by reducing plant cover.

Statistical analyses

I used ANOVA to test for significant differences across the three mesas in univariate response variables, including grazing intensity indices, soil parameters, total basal cover and canopy cover, and plant species richness. I used Tukey's HSD test (honest significant differences) as a post-hoc statistical test in conjunction with an ANOVA to determine which means were significantly different from one another. Basal and canopy cover data were analyzed by species, plant functional type, and overall total cover. Plant functional types included dominant grasses: *Bouteloua gracilis* (Blue Grama), *Achnatherum hymenoides* (Indian Ricegrass), *Pleuraphis jamesii* (Galleta grass), *Hesperostipa comata* (Needle and Thread); dominant shrubs: *Artemisia bigelovii* (Bigelow sagebrush), *Gutierrezia sarothrae* (Broom Snakeweed), *Ephedra viridis* (Morman Tea), *Opuntia fragilis* (Brittle Prickly Pear), *Atriplex spp.* (Saltbushes) *Chrysothamnus viscidiflorus* (Yellow Rabbitbrush); and non-natives: *Salsola tragus L.* (Russian Thistle).

To test for potential differences in plant species composition across Steven's (B&C), Wildcat (Cattle), and Little Thompson (Ungrazed) Mesas, I used a permutational multivariate analysis of variance, PERMANOVA (Anderson 2001). I used a species by site matrix of standardized canopy cover and density data for comparison of plant community composition. Cover and density data for the dominant plant species was mixed to utilize the best estimate for each species in the species by site matrix. Plant species that occurred in over twenty percent of the plots were considered dominant plant species. The data were standardized by subtracting the mean for each species from each raw data estimate and then dividing by the standard deviation of each species. The dissimilarity matrix was based on Euclidean distance. I included sand fraction as an environmental covariate. To complement the PERMANOVA analysis and graphically show differences in plant community composition, I used Non-metric Multidimensional Scaling (NMDS), a distance-based ordination method.

To analyze the NDVI time series I used a “Before-After-Control-Impact” analysis (BACI), to distinguish differences in estimated productivity for each grazing treatment through time. In this analysis I used a nonparametric analysis of covariance (smANCOVA) to test for mesa differences through the productivity time series, with the null hypothesis being that there was no difference between estimated productivity through time across the mesas. A p-value of 0.05 indicated significant differences for all analyses. Analyses were performed in R (R Development Core Team 2012).

RESULTS

Soils

Average soil pH, ranging from 8.48 to 8.56, was similar across all three mesas ($F = 1.45$, df = 2,29, $P = 0.251$), and soil resistance values were similar across Steven's Mesa (B&C) and Wildcat Mesa (Cattle) ($F = 0.6634$, df = 1,31, $P = 0.415$). The only significant difference detected was a difference in soil texture, with a higher sand fraction on Little Thompson Mesa, putting most of these samples in the loamy sand texture class, in comparison to Steven's (B&C) and Wildcat (Cattle) Mesa ($F = 10.99$, df = 2,29, $P = 0.0002$, mean sand fraction: Steven's (B&C), 72.3%; Wildcat (Cattle), 71.7%; Little Thompson (Ungrazed), 81.9%).

Grazing intensity

There was no significant difference in average lagomorph pellet densities across mesas, for summer 2010 ($F = 1.047$, df = 2,29, $P = 0.364$), summer 2011 ($F = 0.651$, df = 1,31, $P = 0.426$), and fall 2011 ($F = 1.604$, df = 1,31, $P = 0.215$), as seen in the Figure 1A, C, and E below. In August 2010, large ungulate fecal pat densities were significantly higher on Steven's Mesa (B&C) than Wildcat (Cattle) and Little Thompson (Ungrazed) Mesa ($F = 31.028$, df = 2,29, $P < 0.000001$). It is important to note that zero fecal pats were counted on Little Thompson Mesa (Ungrazed), confirming that it is ungrazed by cattle and bison. In June 2011, large ungulate fecal pat densities were significantly higher on Wildcat Mesa (Cattle) than Steven's Mesa (B&C) ($F = 6.349$, df = 1,31, $P = 0.017$). In October of 2011, there was a marginally significant difference, with higher fecal pats per square meter on Steven's Mesa (B&C) than Wildcat Mesa (Cattle) ($F = 4.093$, df = 1,31, $P = 0.0517$).

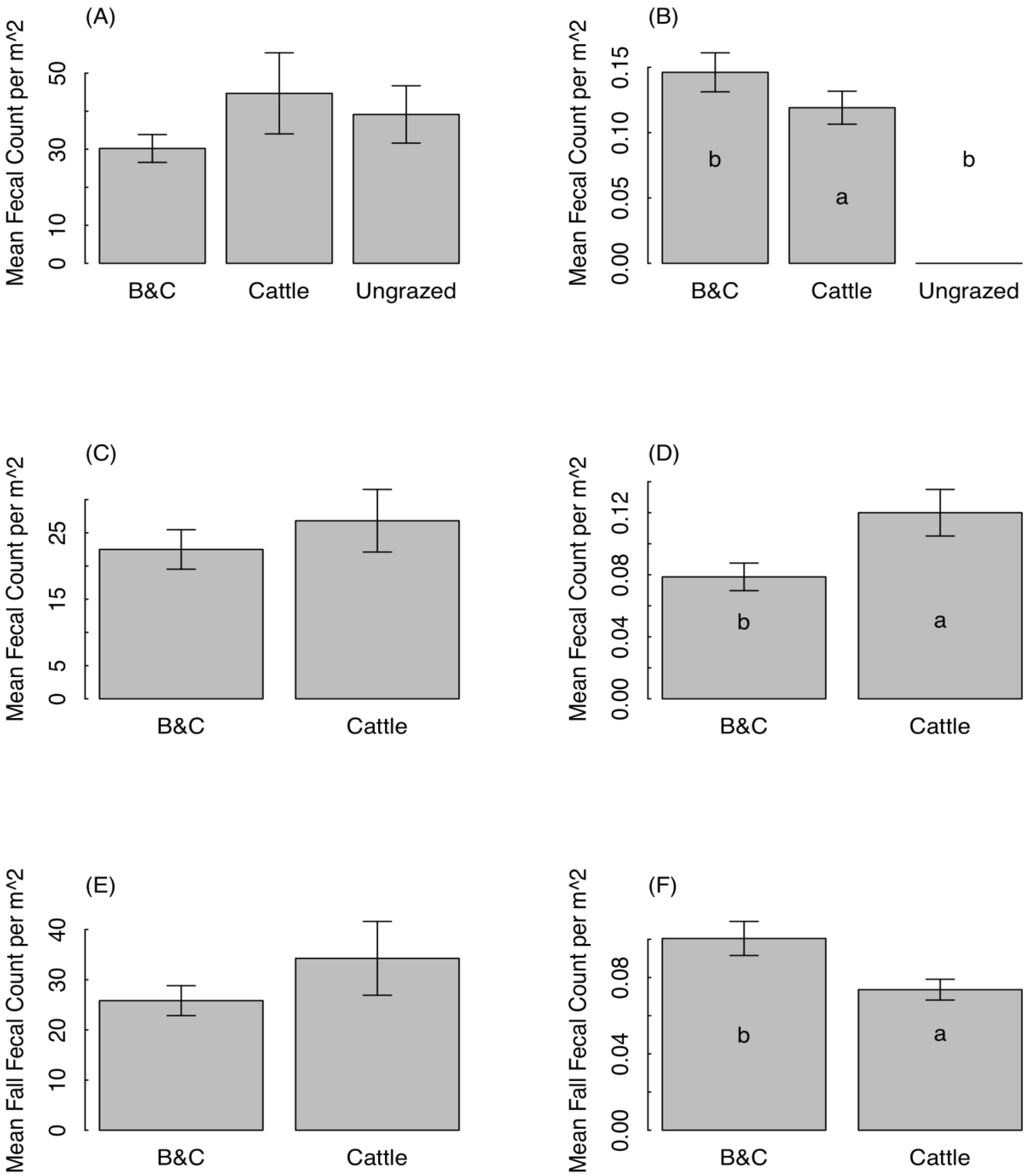


FIG. 1A-F. Average lagomorph pellet densities and bison/cattle fecal pats per square meter on each mesa. August 2010 counts are shown for lagomorphs (A) and bison plus cattle (B). Bars sharing lower case letters are not statistically different. June 2011 counts are shown for lagomorphs (C) and bison plus cattle (D). October 2011 counts are shown for lagomorphs (E) and bison plus cattle (F).

Summer (June) 2011 defoliation measurements showed no significant difference in grazing intensity between the two ungulate grazed mesas, Wildcat (Cattle) and Steven's (B&C) (F = 0.0116, df = 1,651, P = 0.914; see Appendix Fig. A1). Fall (October) 2011 defoliation (Fig. 2) measurements showed that there was a significant difference for both grass species, *Pleuraphis jamesii* and *Achnatherum hymenoides*, each showing a higher mean grazing intensity on Steven's Mesa (B&C) (F = 954.63, df = 1,650, $P < 0.0001$).

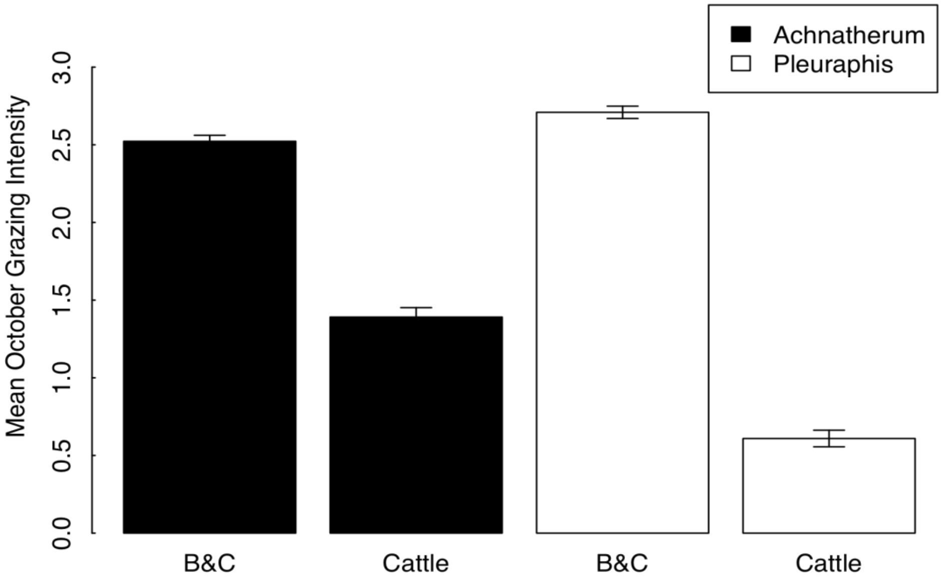


FIG. 2. Mean estimated fall grazing intensity on Indian Ricegrass, *Achnatherum hymenoides* (black bars), and Galleta Grass, *Pleuraphis jamesii* (white bars) based on a defoliation index. The defoliation index is scored as followed: 0, no tillers defoliated; 1, one tiller defoliated; 2, more than one but not all tillers defoliated; and 3, all tillers defoliated (Adler et al. 2005).

Plant community composition

Steven's Mesa (B&C) and Wildcat Mesa (Cattle) had a significantly higher number of plant species per 1 m^2 than Little Thompson Mesa (Ungrazed) (Fig. 3) (F =

8.312, df = 2,29, $P = 0.001402$). There were no differences in plant species richness between the two grazed mesas, Steven's Mesa (B&C) and Wildcat Mesa (Cattle). I did however find that *Gutierrezia sarothrae* (GUSA, Broom Snakeweed) had higher densities on Steven's Mesa (B&C) than both Wildcat (Cattle) and Little Thompson (Ungrazed) Mesas (Fig. 4 and Table A2) ($F = 9.707$, df = 2,29, $P = 0.0006$).

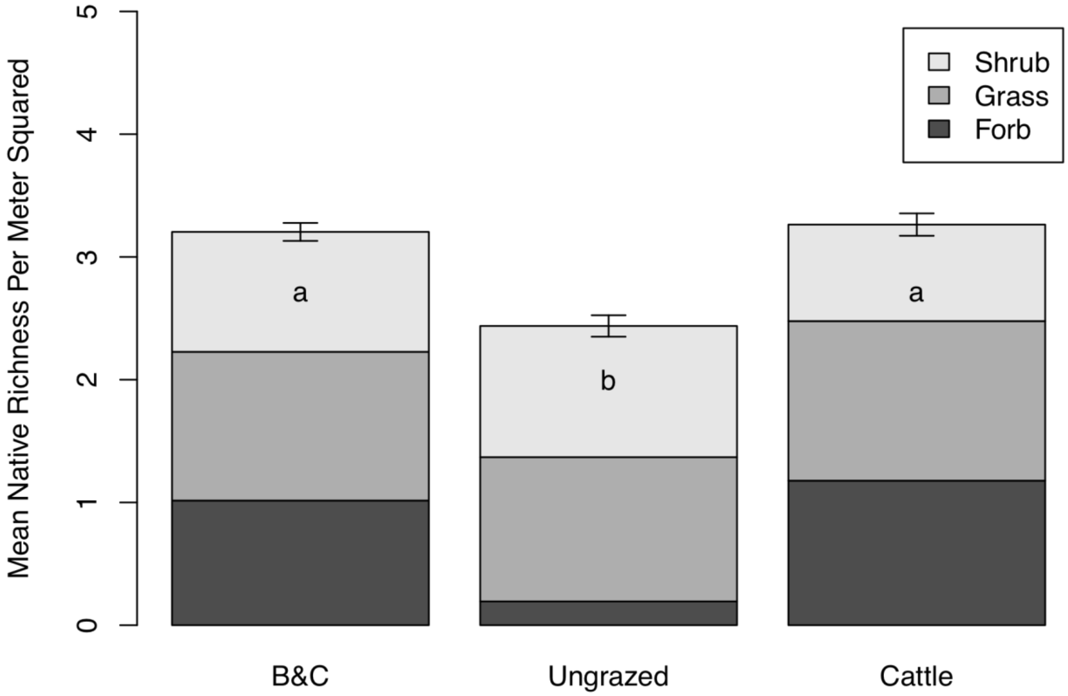


FIG. 3. Plant species richness on Steven's Mesa (B&C) and Wildcat Mesa (Cattle) was similar, but was significantly higher than on Little Thompson Mesa (Ungrazed) (bars sharing the same letter are not significantly different).

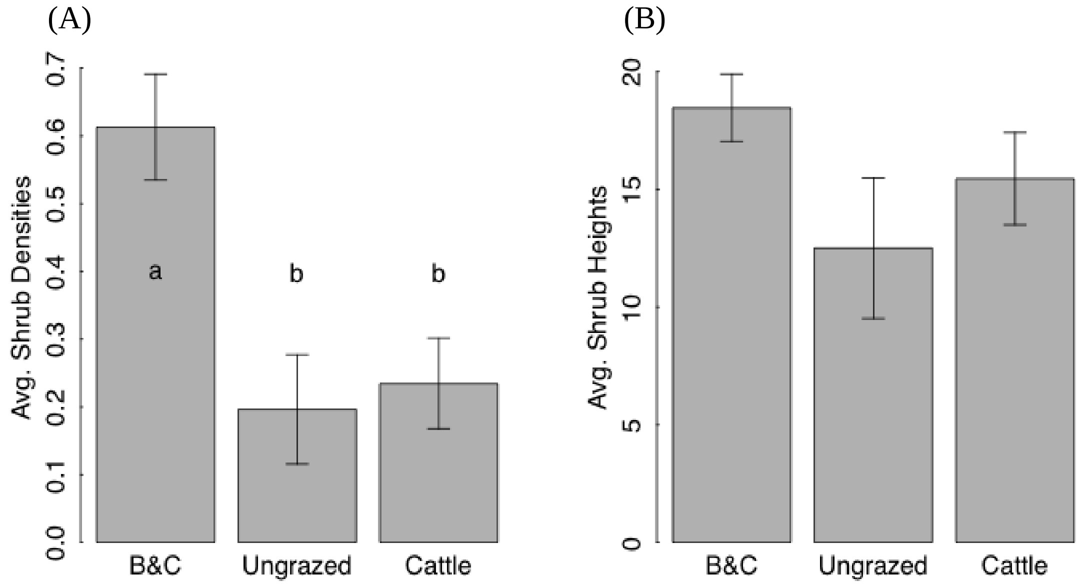


FIG. 4. *Gutierrezia sarothrae* (GUSA, Broom Snakeweed) density (A) on Wildcat (Cattle) and Little Thompson (Ungrazed) Mesas was similar, but was significantly higher on Steven's Mesa (B&C) (bars sharing the same letter are not significantly different).

PERMANOVA showed a significant difference in species composition across the three mesas (F = 3.29, df = 2,28, R^2 = 0.185, P =0.001). Pairwise PERMANOVA test were run for each combination of mesas, each mesa had a significantly different species composition (Steven's vs. Wildcat: F = 2.54, df = 1,22, R^2 = 0.104, P = 0.002; Steven's vs. Thompson: F = 3.76, df = 1,19, R^2 = 0.165, P = 0.001; Thompson vs. Wildcat: F = 2.85, df = 1,17, R^2 = 0.144, P = 0.004). To provide a graphical interpretation of the PERMANOVA results, I used an NMDS ordination to help visualize patterns in community composition across the mesas. Sites on Steven's (B&C) and Wildcat (Cattle) Mesas largely overlap in the ordination space, while the offset position of sites on Thompson (Ungrazed) mesa reflects differences in soil texture (Fig. 5).

In contrast to the PERMANOVA results, ANOVAs on functional groups and important species showed few significant species level differences in cover between

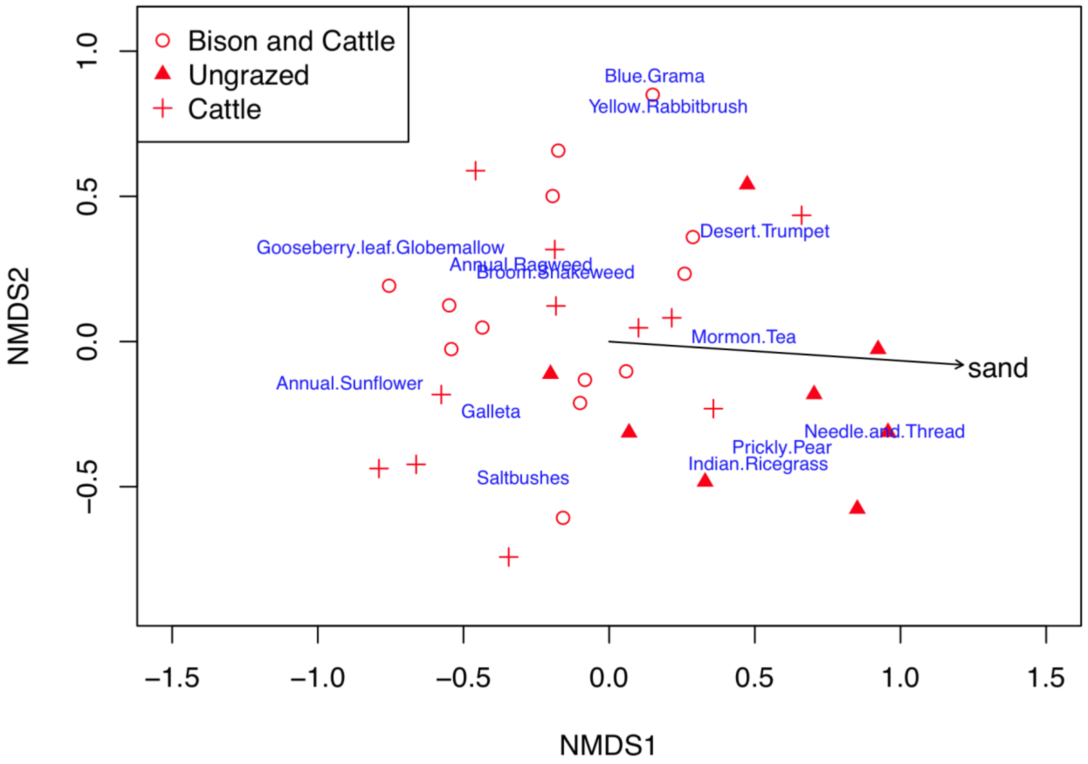


FIG. 5. NMDS showing the plant species associated with each mesa. The black arrow represents a positive correlation of the first axis and increasing sand content.

Steven's (B&C) and Wildcat (Cattle) Mesa. *Bouteloua gracilis* canopy (*F* = 0.167, df = 2,29, *P* = 0.8468) and basal (*F* = 1.55, df = 2,29, *P* = 0.228) cover did not differ across all three mesas. *Achnatherum hymenoides* canopy cover (*F* = 4.183, df = 2,29, *P* = 0.02) and basal cover (*F* = 4.586, df = 2,29 *P* = 0.019) were both significantly higher on Little Thompson Mesa (Ungrazed) than Steven's Mesa (B&C), but cover estimates were not significantly different between Little Thompson (Ungrazed) and Wildcat (Cattle) Mesas, or between Wildcat (Cattle) and Steven's (B&C) Mesas. *Hesperostipa comata* canopy cover was significantly higher on Little Thompson Mesa (Ungrazed) than Steven's Mesa (B&C) (*F* = 4.175, df = 2,29, *P* = 0.0254), but there was no difference between Steven's (B&C) and Wildcat (Cattle) Mesas, or Little Thompson (Ungrazed) and Wildcat (Cattle)

Mesas; basal cover was not significantly different across the three mesas (*F* = 1.464, df = 2,29, *P* = 0.248). *Pleuraphis jamesii* canopy cover was significantly higher on Steven's (B&C) and Wildcat (Cattle) Mesa than Little Thompson Mesa (Ungrazed) (*F* = 6.521, df = 2,29, *P* = 0.004); basal cover did not differ across the three mesas (*F* = 1.334, df = 2,29, *P* = 0.279). No significant difference was detected in the basal cover of the dominant perennial grass species summed together (*F* = 0.7538, df=2,29, *P* = 0.479), but there was a significant difference in canopy cover for the dominant perennial grasses (*F* = 3.333, df = 2,29, *P* = 0.0497) with higher grass cover percentages on Wildcat Mesa (Cattle) than Thompson Mesa (Ungrazed) (Tukey HSD; *P* = 0.04). There was no difference in dominant grass canopy cover between Steven's (B&C) and Thompson (Ungrazed) (Tukey HSD; *P* = 0.561), or Steven's (B&C) and Wildcat (Cattle) (Tukey HSD; *P* = 0.216).

ANOVA results also showed no significant differences in canopy cover or basal cover of *Gutierrezia sarothrae* (Canopy: *F* = 0.185, df = 2,29, *P* = 0.832; Basal: *F* = 0.299, df = 2,29, *P* = 0.743), *Ephedra viridis* (Canopy: *F* = 1.477, df = 2,29, *P* = 0.245; Basal: *F* = 1.942, df = 2,29, *P* = 0.162), *Atriplex spp.* (Saltbushes were grouped together) (Canopy: *F* = 0.103, df = 2,29, *P* = 0.903; Basal: *F* = 1.412, df = 2,29, *P* = 0.259), and *Chrysothamnus visidiflorus* (Canopy: *F* = 0.451, df = 2,29, *P* = 0.641; Basal: *F* = 0.718, df = 2,29, *P* = 0.496). *Opuntia fragilis* had higher canopy cover on Little Thompson Mesa (Ungrazed) than Wildcat (Cattle) and Steven's (B&C) Mesas (*F* = 7.08, df = 2,29, *P* = 0.003); basal cover was also higher on Little Thompson Mesa (Ungrazed) than Steven's Mesa (B&C) (*F* = 5.669, df = 2,29, *P* = 0.008; Tukey HSD, *P* = 0.006) but was marginally higher than Wildcat Mesa (Cattle) (Tukey HSD; *P* = 0.06). No significant difference was found in canopy cover of dominant shrub species across the mesas (*F* = 2.0692, df = 2,29, *P* = 0.1445), but a difference in dominant shrub basal cover (*F* = 3.672, df = 2,29, *P* = 0.0379) with higher cover on Steven's Mesa (B&C) compared to Little Thompson Mesa (Ungrazed) (Tukey HSD; *P* = 0.0366). Non-native canopy cover showed no significant difference across all three mesas (*F* = 1.985, df = 2,29, *P* = 0.1556), showing very low cover percentages. Basal cover percentages for non-natives were very low across all three mesas. Total overall plant cover was measured by summing all of the observed plant species together. No significant differences were determined for total basal cover across the three mesas (*F* = 0.8231, df = 2,29, *P* = 0.449). However, there was a significant difference in overall canopy cover with higher cover on Wildcat Mesa (Cattle) than Little Thompson Mesa (Ungrazed) (Tukey HSD; *P* = 0.015). There were no significant differences between Thompson (Ungrazed) and Steven's (B&C) Mesas (Tukey HSD; *P* = 0.147) or for Steven's (B&C) and Wildcat

(A)

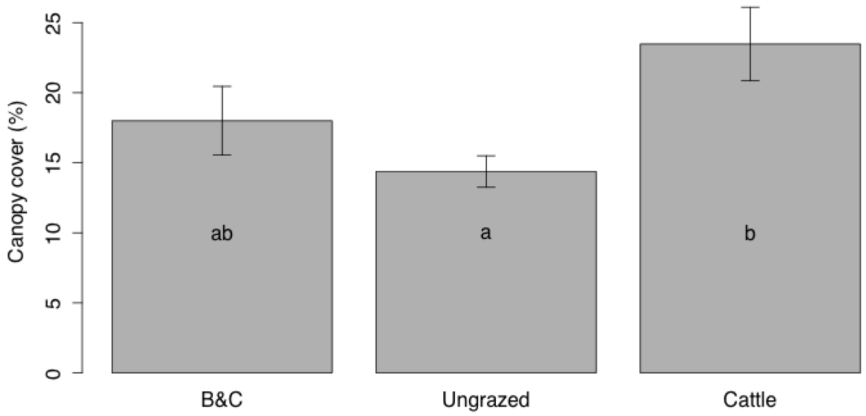
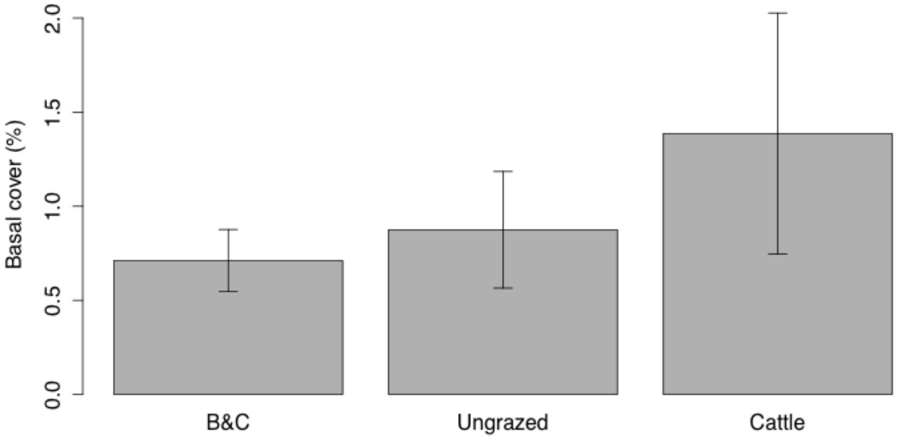
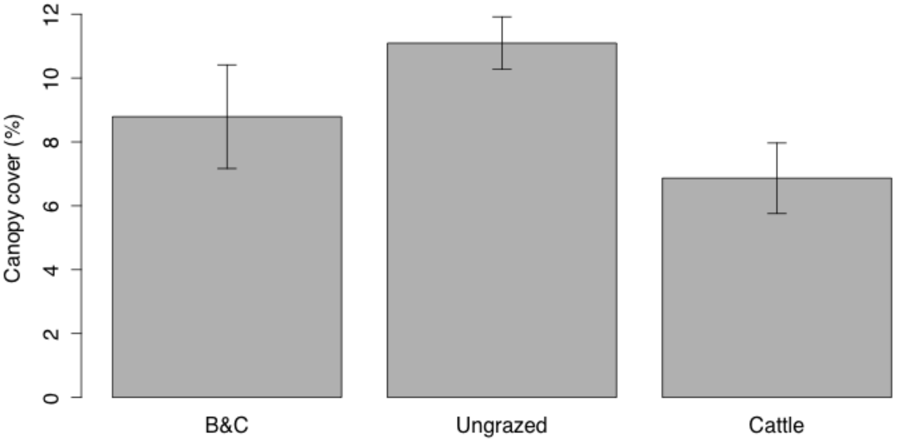


FIG. 6A-F. Canopy (A) and basal (B) cover of dominant perennial grass species pooled together on the three mesas. Canopy cover of dominant shrubs pooled (C) and non-native species pooled (D) on the three mesas. Total plant canopy (E) and basal (F) cover on the three mesas. Bars sharing the same letter are not significantly different.

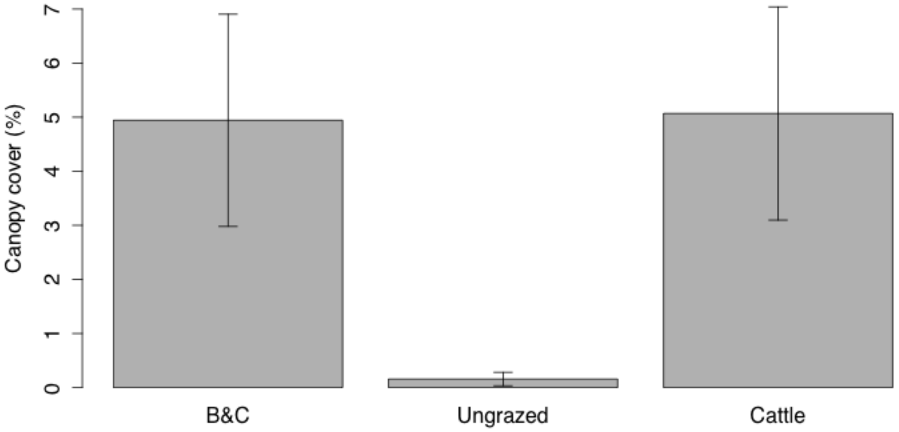
(B)

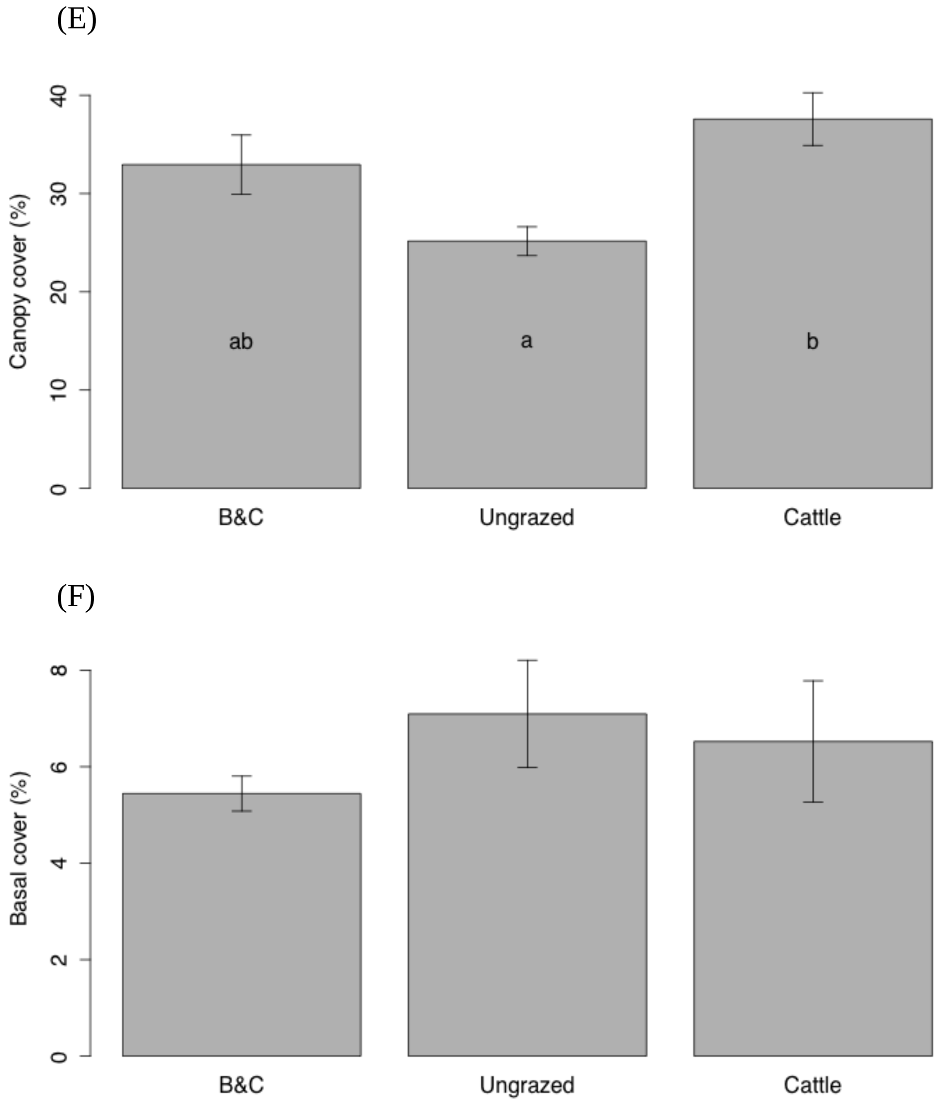

Basal cover (%)
0.0
0.5
1.0
1.5
2.0
B&C
Ungrazed
Cattle

(C)


Canopy cover (%)
0
2
4
6
8
10
12
B&C
Ungrazed
Cattle

(D)


Canopy cover (%)
0
1
2
3
4
5
6
7
B&C
Ungrazed
Cattle



(Cattle) Mesas (Tukey HSD; *P* = 0.429). All of the statistics for individual species can be found in the appendix in Tables A3 and A4.

Temporal trends in NDVI

I found no differences in the NDVI time series across the three mesas, (Fig. 7; Fig. A2-3). Each mesa's NDVI time series never escaped the confidence intervals of the Before and After Control Impact (BACI) tests (*P* = 1;Young and Bowman 1995).

Although the high interannual variability of NDVI values most likely reflect variation in annual or spring (April through June) precipitation, both annual and spring precipitation data from the nearest weather station in Hanksville, Utah, did not correlate with the NDVI of the Henry Mountain mesas (Annual: *T* = 0.5511, df = 23, *P* = 0.587, Spring: *T* = 1.676, df = 23, *P* = 0.107).

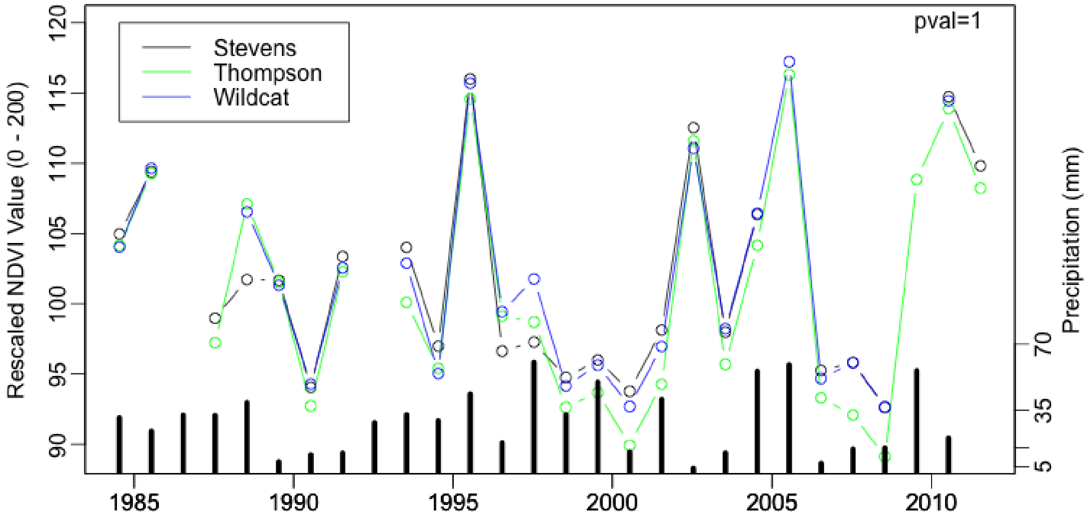


FIG. 7. NDVI time series trends for Steven's (B&C), Little Thompson (Ungrazed), and Wildcat Mesas (Cattle Only).

DISCUSSION

Rangeland degradation may involve multiple characteristics of the plant community and ecosystem. By sampling soil parameters, grazing intensity, plant community composition, and a remotely sensed productivity index, I was able to address perceptions that the Henry Mountain bison herd has negatively impacted cattle winter range. A higher fall grazing intensity was detected on the bison-cattle grazed mesa, indirectly confirming a reduction in forage availability attributed to higher stocking rates. However, despite this difference in grazing intensity and seasonality, almost all my results support the null hypothesis that the additional bison utilization of the cattle winter range has yet to cause degradation of the Henry Mountain rangelands.

Soils

The increase in effective stocking rate, with the addition of bison on the winter range, has not decreased the productive potential of the soil. There was no evidence for herbivore induced soil compaction through trampling across the three mesas, however the common soil types across the three mesas are likely too sandy to detect differences in soil compaction. Bison are creating wallowing areas, which have been shown to increase regional diversity by providing disturbed areas for short-lived annuals and early-successional plant species; however, once these wallows are abandoned the native community should be able to reestablish (Polley and Collins 1984). I did not find large expanses of degraded, unstable bare ground in my study areas.

Grazing intensity

A short-term effect of grazing was detected, as grazing intensity did vary seasonally, with bison utilizing the rangeland in the late summer and fall and the cattle using it as winter range, where they remain until early spring. Such results are consistent with concerns about the amount of available winter forage left on the allotments. Early summer defoliation measurements (Fig. A1) showed no significant difference in grazing intensity between the two ungulate grazed mesas, suggesting the bison had not yet arrived on Steven's Mesa (B&C). Higher late summer and fall fecal pat densities (Fig. 1B and 1F) and higher fall grazing intensities (Fig. 2) help map the migration of the bison onto Steven's Mesa (B&C) in late summer or early fall. These seasonal differences in fecal pat densities and defoliation intensity help clarify the pattern in the seasonality of bison use, implying a break in ungulate utilization from the time the cattle are removed in late April until bison move down in early fall. This break in grazing in the late spring and early summer months may allow the desirable forage species to grow and reproduce, preventing or slowing changes in species composition.

Plant community composition

Despite the three mesas having three different grazing regimes and differences in grazing seasonality, I found weak overall evidence of any negative long-term effects of herbivore-induced degradation in the three-mesa comparison. Even though the PERMANOVA test showed significant differences in species composition across the three mesas, the test does not indicate which species were driving this pattern. My single species analyses suggest that those mesa differences are not consistent with grazing induced degradation: there were no important differences in canopy and basal cover of key individual species or functional groups. The NMDS suggests that the differences in species composition may reflect subtle differences in sand content across the mesas, rather than differences in grazing history.

While the majority of the results still indicate that the cattle winter range has not been degraded by the additional bison utilization, there is one result that should serve as a caveat. *Gutierrezia sarothrae* (GUSA, Broom snakeweed) is a native, largely unpalatable sub-shrub that is viewed as an undesirable "grazing increaser." Because its population densities can increase when desirable plants experience notable defoliation, high densities may be indicative of overgrazing (Ralphs 2011). As shown in Figure 4, *Gutierrezia sarothrae* has significantly higher densities on the bison and cattle grazed mesa than both the cattle only and ungrazed mesas. On the other hand, *Opuntia fragilis* (prickly pear), also considered a grazing increaser, is more abundant on Little Thompson Mesa (Ungrazed) but had similar densities on Steven's (B&C) and Wildcat (Cattle) Mesas. Similarly, *Chrysothamnus visidiflorus* (yellow rabbitbrush), another grazing increaser, had similar densities and cover across all three mesas.

The ecological site description (ESD) for the Semi-desert Sandy Loam (Four-Wing Saltbush) indicates, "as ecological condition deteriorates due to overgrazing, the perennial bunchgrasses decrease while *Gutierrezia sarothrae* (broom snakeweed), *Chrysothamnus visidiflorus* (yellow rabbitbrush), and *Opuntia fragilis* (prickly pear) increase" (Soil Survey Staff, NRCS 2012). Despite higher densities of *Gutierrezia sarothrae* on Steven's Mesa (B&C), differences in other measures of abundances were largely non-significant, including no differences in *Gutierrezia sarothrae* canopy and basal cover, no decrease in perennial bunchgrasses, and no increase in *Chrysothamnus visidiflorus* (yellow rabbitbrush) or prickly pear. Thacker et al. (2008) implies that if "robust perennial bunchgrasses" (i.e. *Achnatherum hymenoides* & *Hesperostipa comata*) are maintained, they can provide "resilience" to *Gutierrezia sarothrae* expansions. Similarly, there is evidence suggesting that competition from cool season grasses, such as *Achnatherum hymenoides* and *Hesperostipa comata*, can also prevent the establishment of *Gutierrezia sarothrae* seedlings (Thacker et al. 2009).

Plant species richness was higher on the two grazed mesas, Steven's Mesa (B&C) and Wildcat Mesa (Cattle), suggesting a similar grazing pressure on the two grazed mesas despite increased bison use. A higher number of plant species on the grazed plots is evidence supporting the intermediate disturbance hypothesis, where a moderate level of disturbance in a stable plant community can actually increase plant species richness (Hobbs and Huenneke 1992, Hickman et al. 2004, Towne et al. 2005). Overall, the results suggest that high intensity summer bison grazing has yet to significantly alter plant community composition.

Regarding the effects of cattle and bison grazing on the Colorado Plateau, it is hard to tease out bison specific effects since cattle also graze the bison grazed area. It is plausible to think that bison and cattle have similar effects on this specific Colorado Plateau plant community, much like in the Great Plains research (Towne et al. 2005), since cattle grazed and bison-cattle grazed mesas had similar species composition and nearly equal mean species richness.

My findings of few differences in species composition and no obvious trends in cover reduction between grazed and ungrazed areas contrasts with the findings of a study by Fernandez et al. (2008), which took place in Canyonlands National Park, just east of the Henry Mountains, largely in areas of fine sandy loams, and in Basin Big Sagebrush and Four-Wing Saltbush ecological sites. Similar soil types and ESDs allows for a nice comparison to my study area. While Fernandez et al. (2008) found lower grass cover, shrub cover, and total cover on the grazed mesas, I found no negative trends in cover of the dominant functional types. Fernandez et al. (2008) also concluded that the grazed sites had become less productive due to grazing, which my NDVI data suggests has not yet occurred on the Henry Mountain rangelands. Overall, this comparison suggests that the grazed grasslands in the Fernandez et al. (2008) study may have experienced a heavier grazing pressure compared to current conditions on the Henry Mountain mesas. Under present grazing intensities and seasonality of grazing events, the dominant forage species have not yet experienced a negative effect from the addition of bison into the grazing system.

Temporal trends in NDVI

A decline or divergence in NDVI on Steven’s Mesa could have occurred if the recent bison use had reduced leaf area or productivity. With nearly identical trends in vegetation activity, this data provides supporting evidence that the addition of bison into the system has not yet altered the productive potential of the winter rangelands. The lack of differences in the vegetation activity time series further weakens evidence for bison degradation on the productive potential of the Henry Mountain grass-shrublands, in support of my overall conclusions.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Grazing-induced shifts in plant community composition can take years to unfold and just as long to reverse (Fernandez et al. 2008). Although I did not detect large changes in species composition or production, the high fall grazing intensity on Steven's Mesa caused by bison could eventually cause negative long-term changes. The increase in *Gutierrezia sarothrae* result does suggest that managers should pay special attention to maintaining healthy perennial grass populations.

Therefore, continued monitoring of the combined effects of cattle and bison is important to the conservation of the Henry Mountain winter range and the Semi-desert Sandy Loam ESD. My results may reassure local ranchers that bison grazing has yet to cause a significant change in productive potential or plant community composition on the cattle winter range. Hopefully these conclusions will help provide a platform for future cooperation between the Utah Division of Wildlife Resources, the Bureau of Land Management, and local ranchers in maintaining a healthy public rangeland.

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APPENDIX

TABLE A1. Path 37, and Rows 33 and 34 were used to acquire these images.

Download Location	Download file name	Acquisition date		
		Year	Month	Day
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USGS	LT50370341984170XXX09	1984	June	18
USGS	LT50370341985156PAC00	1985	June	5
USGS	LT50370341985172PAC03	1985	June	21
USGS	LT50370341986159XXX03	1986	June	8
USGS	LT50370341986175XXX03	1986	June	24
USGS	LT50370341987162XXX02	1987	June	11
USGS	LT50370341987178XXX02	1987	June	27
USGS	LT50370341988165XXX03	1988	June	13
USGS	LT50370341988181XXX03	1988	June	29
USGS	LT50370341989167XXX02	1989	June	16
USGS	LT40370341989175XXX03	1989	June	24
USGS	LT50370341990154XXX03	1990	June	3
USGS	LT50370341990170XXX03	1990	June	19
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USGS	LT50370341991173XXX03	1991	June	22
USGS	LT50370341992160XXX02	1992	June	8
USGS	LT50370341992176XXX02	1992	June	24
USGS	LT50370341993162AAA04	1993	June	11
USGS	LT50370341993178AAA04	1993	June	27
USGS	LT50370341994165XXX02	1994	June	14
USGS	LT50370341994181AAA02	1994	June	30
USGS	LT50370341995152AAA01	1995	June	1
USGS	LT50370341995168XXX02	1995	June	17
USGS	LT50370341996155XXX02	1996	June	3
USGS	LT50370341996171AAA01	1996	June	19
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USGS	LT50370341997173XXX02	1997	June	22
USGS	LT50370341998160AAA01	1998	June	9
USGS	LT50370341998176XXX02	1998	June	25
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USGS	LT50370342001168XXX02	2001	June	17
USGS	LT50370342002155LGS01	2002	June	4
USGS	LT50370342002171LGS01	2002	June	20
USGS	LT50370342003158LGS01	2003	June	7
USGS	LT50370342003174LGS01	2003	June	23

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USGS	LT50370342005163PAC01	2005	June	12
USGS	LT50370342006150PAC01	2006	May	30
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USGS	LT50370342007169PAC01	2007	June	18
USGS	LT50370342008172PAC01	2008	June	20
USGS	LT50370342009174PAC01	2009	June	23
USGS	LT50370342010161EDC00	2010	June	10
USGS	LT50370342010177PAC01	2010	June	26
USGS	LT50370342011164PAC01	2011	June	13
USGS	LT50370342011180EDC00	2011	June	29

TABLE A2. Descriptive statistics for the mean density of dominant shrub species.

Dominant Shrub Species	Mean Density Steven’s Mesa (per m^2)	Mean Density Wildcat Mesa (per m^2)	Mean Density Little Thompson Mesa (per m^2)	F Stat	Df	Pval
Artemisia bigelovii	0.002	0.011	0.05	2.757	2,29	0.0801
Gutierrezia sarothrae	0.613	0.235	0.196	9.707	2,29	0.0006*
Ephedra viridis	0.4	0.235	0.019	0.504	2,29	0.609
Opuntia fragilis	0.013	0.055	0.276	13.18	2,29	<.0001*
Atriplex spp.	0.174	0.161	0.115	0.164	2,29	0.8496
Chrysothamnus visidiflorus	0.208	0.051	0.106	0.588	2,29	0.562

Table A3. Descriptive statistics for the average cover of dominant grass species.

Dominant Grass Species	Cover Type	Mean % Cover Steven’s Mesa	Mean % Cover Wildcat Mesa	Mean % Cover Little Thompson Mesa	F stat	Df	Pval
Bouteloua gracilis	Canopy	0.0577	0.0909	0.0938	0.167	2, 29	0.8468
Bouteloua gracilis	Basal	0	0	0.0312	1.55	2, 29	0.228
Achnatherum hymenoides	Canopy	1.096	2.182	5.125	4.183	2, 29	0.02 *
Achnatherum hymenoides	Basal	0	0.0455	0.2187	4.586	2, 29	0.019 *
Hesperostipa comata	Canopy	0.173	0.3864	1.938	4.175	2, 29	0.0254 *
Hesperostipa comata	Basal	0.0385	0.0681	0.3438	1.464	2, 29	0.248
Pleuraphis jamesii	Canopy	16.673	20.818	7.219	6.521	2, 29	0.004 *
Pleuraphis jamesii	Basal	0.6731	1.2727	0.2812	1.334	2, 29	0.279
Dominant Perennials Pooled	Canopy	18.0	23.477	14.375	3.333	2, 29	0.0497 *
Dominant Perennials Pooled	Basal	0.7115	1.3864	0.875	0.7538	2, 29	0.479

Table A4. Descriptive statistics for the average cover of dominant shrub species.

Dominant Shrub Species	Cover Type	Mean % Cover Steven’s Mesa	Mean % Cover Wildcat Mesa	Mean % Cover Little Thompson Mesa	F stat	Df	Pval
Gutierrezia sarothrae	Basal	0.0769	0.0682	0.1250	0.299	2, 29	0.743
Gutierrezia sarothrae	Canopy	2.3076	1.9091	1.8125	0.185	2, 29	0.832
Ephedra viridis	Basal	0.0769	0.0455	0.1875	1.942	2, 29	0.162
Ephedra viridis	Canopy	2.50	2.0455	4.3750	1.477	2, 29	0.245
Atriplex spp.	Basal	0.0577	0.1364	0.0313	1.412	2, 29	0.259
Atriplex spp.	Canopy	2.0577	1.8636	1.50	.103	2, 29	0.903
Chrysothamnus visidiflorus	Basal	0.1154	0.0227	0.1563	0.718	2, 29	0.496
Chrysothamnus visidiflorus	Canopy	1.7692	0.6364	1.7813	0.451	2, 29	0.641
Opuntia fragilis	Basal	0	0.0909	0.3438	5.669	2, 29	0.008 *
Opuntia fragilis	Canopy	0.0769	0.4091	1.1250	7.08	2, 29	0.003 *
Dominant Shrubs Pooled	Basal	0.3269	0.4091	0.8750	3.672	2, 29	0.038 *
Dominant Shrubs Pooled	Canopy	8.7885	6.8636	11.094	2.069	2, 29	0.145

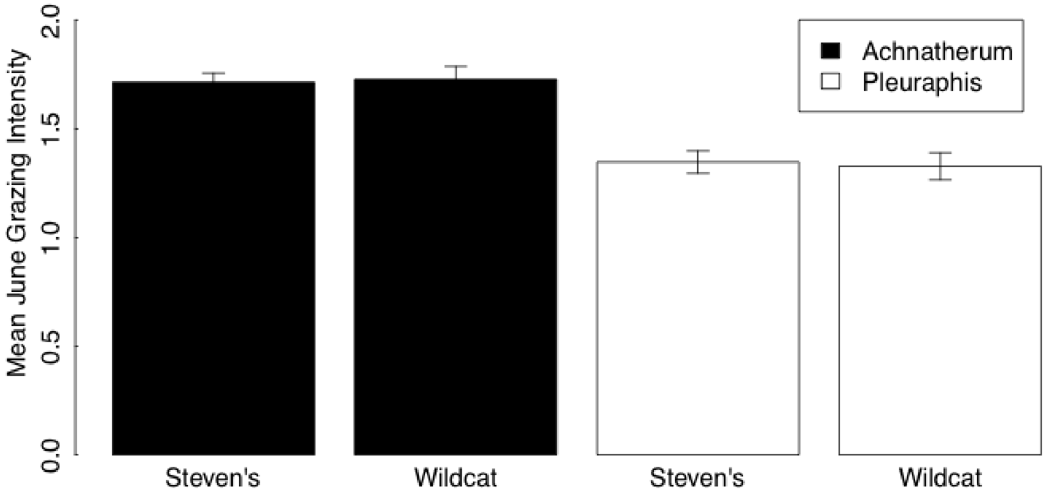

FIG. A1. This histogram shows the mean estimated summer 2011 grazing intensity on Indian Ricegrass, *Achnatherum hymenoides* (black bars), and Galleta Grass, *Pleuraphis jamesii* (white bars) based on a defoliation index. The defoliation index is scored as followed: 0, no tillers defoliated; 1, one tiller defoliated; 2, more than one but not all tillers defoliated; and 3, all tillers defoliated (Adler et al. 2005).

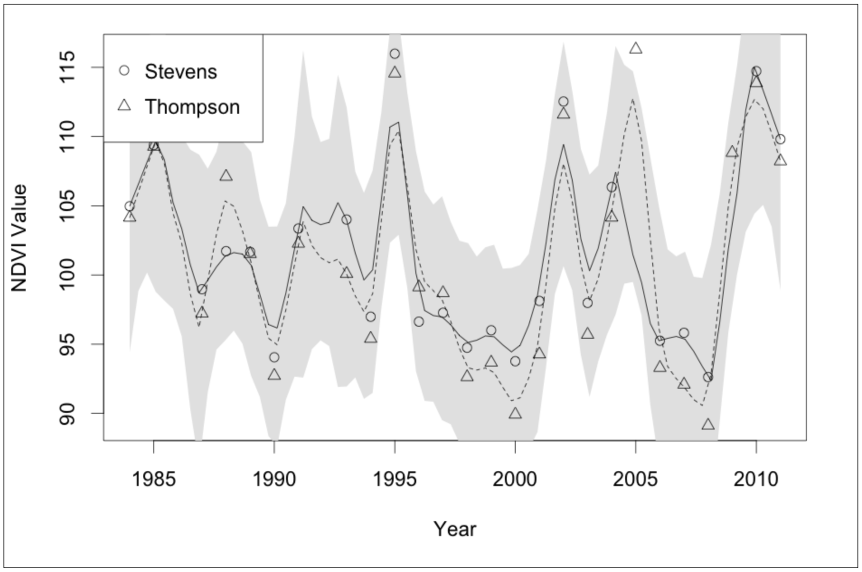

FIG. A2. Steven’s Mesa vs. Thompson Mesa: BACI analyses

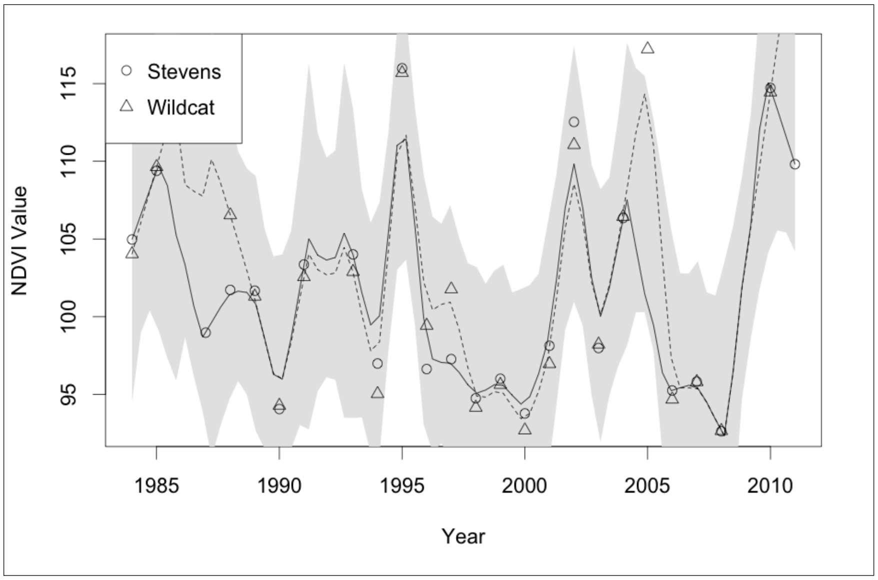

FIG. A3. Steven’s Mesa vs. Wildcat Mesa: BACI analyses