Grassland quality in response to water and nutrient addition across grazing regimes

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ABSTRACT

Grassland, which composes a large portion of the land surface of the earth, is often used for grazing. If managed properly, it can support biodiversity and ecosystem services as undisturbed grassland does. Many grasslands in the United States are disturbed so that invasive species and species unpalatable overtake the land, or the land is threatened by desertification. Some reasons for this disturbance may be nitrogen or water addition to rangeland. I compared two sites in which grassland is managed for both conservation of land and for grazing in their responses to irrigation and nitrogen fertilizer addition. I found trends for an increase in biomass, biodiversity, and species richness in fertilized and watered plots versus control plots on the National Bison Range. The opposite trend was apparent in plots on the Tribal Lands, there was a trend for more palatable species on the Tribal Lands, and there were significantly more invasive palatable species at the Tribal Lands plots, while the Bison Range had more native palatable species. Grazing may help decrease the biomass of invasive species at Tribal Lands but will not decrease the biomass of unpalatable species also present.

Historical grasslands provide food for a variety of grazers and are maintained as rangeland to promote populations of these species, including bison, deer, and pronghorn antelope in wild land and horses, cattle, and sheep. Rangeland, which takes up 61% of land surface in the United States and 70% of the land surface globally, can provide space for native grassland species, if managed properly. If not, species can become endangered; more grassland birds than any other types of birds are endangered in the United States (Fuhlendorf and Engle 2001). Grasslands are also susceptible to desertification as a result of overgrazing (An *et al.* 2007). Land used by National Bison Range (NBR) the Confederated Salish and Kootenai tribes (CSKT) is managed with the joint goals of conservation of native grassland and use by bison and cattle, and as such it is an example of the potential of ranchland to generate diverse, native species and also provide sufficient biomass of palatable species for grazers.

A number of exotic species have been introduced to grasslands in Montana, often for ornamental or grazing purposes (Taylor and Lacey 1994). Exotic species can invade due to their low palatability, better ability to withstand extreme temperatures or lack of precipitation, or their opportunistic, shallow root growth habits; their roots may spread across the top layer of the ground and uptake precipitation that would otherwise reach roots of native, perennial plants (Lackschewitz 1991, Greenhalgh 2008). These invasive species are prominent in grazing lands including the NBR and CSKT tribal lands.

Managed grasslands also may have applications of a high amount of fertilizer or receive intensive irrigation (Drawe and Box 1969). The effects of fertilizer and irrigation on the quality (here measured by the species diversity and native species biomass, and palatable species composition) of these grasslands is uncertain; studies of grasslands have found mixed results on how different grassland species respond to nitrogen addition. In degraded grasslands, Bai *et al.* (2009) found that nitrogen addition over four years caused productivity. In undisturbed grasslands, there was a more dramatic change in community structure; nitrogen addition caused a loss in perennial species, replaced by annuals, leaving the chance for invasive species to establish. At both degraded and undisturbed sites, nitrogen addition caused a decrease in species richness, although the difference was smaller in degraded sites. Fanselow *et al.* (2011) did not find a shift in species composition with irrigation or nitrogen addition; only grazing pressure caused a shift, to favor C4 grass.

Irrigation and fertilization early in the season are common activities in grassland managed for grazing (Drawe and Box 1969). My study's comparisons will identify whether fertilizer and irrigation are anthropogenic impacts that decrease grassland quality, and what aspects of grassland quality—species diversity, percent invasive species, or biomass of palatable species—are affected by irrigation or fertilizer application.

I hypothesize that with fertilizer application and irrigation, species richness and species diversity will decrease. I hypothesize that total biomass and invasive species biomass will increase, while native biomass will remain the same or decrease. The different evolutionary histories of invasives and native species may influence the conditions under which they can become dominant. I expect that some native species will be less able to take advantage of conditions that are unusual for Palouse prairie, namely increased nutrition and water availability, giving introduced species a chance to establish. Invasive species are more likely to be species adapted to and able to take advantage of a variety of growing environments, allowing them to live in areas of low nutrient and water availability and also to grow faster with additions of water and fertilizer (Davidson *et al.* 2011).

METHODS

I created 6 plots in the NBR and 6 CSKT tribal land. Each plot is in an area that has previously been grazed and has feces as an indicator of previous large ungulate grazing. I divided each plot into three treatments, control, watered, and fertilized. In the watered plots, I added 5L/m^2 of water in early July. In the fertilized plots, I added the same amount of water with MiracleGro delivering 20g/m^2 nitrogen, a application of nitrogen similar to the high application levels used by Bai *et al.* (2010). in which 0.1m^2 sections of land are clipped. Each treatment is one meter from the next, to avoid neighboring treatments being affected, but to ensure no drastic changes in microhabitat.

After 23-28 days, I clipped grasses within 1cm of the ground in 0.1m^2 (0.1m by 1m) rectangular sections of each treatment of the plot. I sorted and identified the grasses to genus or, in most cases, species, dried each species separately at 100˚C and recorded the dry mass and the number of species at that plot and treatment.

Statistics Using the invasive species and native species biomasses and calculating ANOVAs using SYSTAT, I will determine whether there is a difference in species richness, species diversity, total biomass, native species biomass, introduced species biomass, or palatable species biomass between sites or treatments. I used biomass as a proxy for abundance of species to calculate the Shannon diversity indices of fertilized, watered, and control sites. I ran additional ANOVAs by groups if there appeared to be different trends at NBR and CSKT sites.

RESULTS

Diversity There was greater species richness at NBR plots versus CSKT plots (Treatment: $F_{2,30}$ = 0.069, P=0.93; Site: $F_{1,30}$ = 6.3, P=0.02; Interaction: $F_{2,30}$ = 0.28, P=0.76; Figure 1). There was also greater Shannon diversity at NBR plots (Site: $F_{1,39}$ = 15, P=0.0004; Figure 2). A two-way ANOVA by groups (BR and TL) determined that there was no site-specific difference in total Shannon diversity between fertilized, watered, and control plots, although there is a trend for fertilization and watering to decrease diversity at TL sites and increase diversity at BR sites (TL: $F_{2,18}$ = 0.71, P=0.51; BR: $F_{2,15}$ = 1.6, P=0.24; Figure 2).

Biomass Total plant biomass did not vary with treatment, site, or interaction (Treatment: $F_{2,30}$ = 0.12, P=0.89; Site: $F_{1,30}$ = 1.6, P=0.22; Interaction: $F_{2,30}$ = 1.02, P=0.37). There was, however a significant difference in biomass between sites when separated into native and introduced species, though they did not vary significantly with treatment or interaction. Native biomass was higher on NBR sites (Treatment: $F_{2,30}$ = 1.7, P=0.21; Site: $F_{1,30}$ = 4.9, P=0.03; Interaction: $F_{2,30}$ = 0.17, P=0.85; Figure 4). Introduced biomass was higher on CSKT sites

(Treatment: $F_{2,30}$ = 0.68, P=0.51; Site: $F_{1,30}$ = 9.7, P=0.004; Interaction: $F_{2,30}$ = 0.76, P=0.48; Figure 5).

Total palatable biomass did not vary with site, treatment, or interaction, but there is a trend for more palatable species in CSKT plots (Treatment: $F_{2,30}$ = 0.12, P=0.89; Site: $F_{1,30}$ = 2.1, P=0.16; Interaction: $F_{2,30}$ = 1.2, P=0.31; Figure 6). When palatable biomass was divided into native and invasive species, it was significantly higher in the CSKT sites for introduced, palatable species, but higher at NBR sites for native, palatable species (Native vs. Invasive: $F_{1,74}$ = 1.2, P=0.27; Site: $F_{1,74}$ = 1.2, P=0.27; Interaction: $F_{1,74}$ = 17.5, P=0.00008; Figure 7).

At the CSKT tribal lands plots, the increase in biomass of introduced species with fertilizing approached significance (Native vs. Invasive: $F_{1,30}$ = 0.52, P=0.48; Treatment: $F_{2,30}$ = 0.42, P=0.66; Interaction: $F_{1,74}$ = 2.4, P=0.10; Figure 8) The native species biomass was greater in NBR plots through all three treatments (Native vs. Invasive: $F_{1,30}$ = 12.0, P=0.002; Treatment: $F_{2,30}$ = 0.91, P=0.41; Interaction: $F_{2,30}$ = 0.76; P=0.48; Figure 9).

DISCUSSION

Species richness and diversity was greater in NBR plots, which is understandable if the NBR manages more strongly against invasive species encroachment (Figures 1,2,4,5). The trends of more biomass and more palatable species on CSKT land may be explained by the greater amount of plants such as *Agropyron cristatum*, *Plantago,* and *Medicago* that are both palatable and invasive species (Figures 3,6,7). The species that tend to grow at the CSKT plots include plants good for ranchlands, which are introduced, so they tend to produce more biomass (Blossey and Kamil 1996). In order to control these palatable, introduced species more frequent or regular grazing may help. However, this grazing would not discourage less palatable, introduced species common at these sites such as *Bromus tectorum, Potentilla recta, and Centaurea maculosa*. Overgrazing might give them a competitive advantage (McFarland 2008).

Moderate grazing can also be important for facilitating the regeneration of some plant species, which utilize the feces for development (Kratochwil *et al.* 2002). Grassland plants are adapted to gazing by large ungulates (Fuhlendorf and Engle 2001).

The high amount of palatable species may be an indicator that the CSKT site is at lower risk for desertification; however, the site is not currently being grazed, and the number of palatable species would likely decrease with grazing (An *et al.* 2007, Figure 6). The high number of palatable species could mean that the site is less grazed recently and the palatable species are recovering well from having a time without of grazing Allowing land time without grazing pressure can improve the species composition, even if it has relatively low species diversity at the beginning (Zhang and Dong 2009, Figures 1 and 2). How quickly it can recover and whether it can successfully recover from grazing is another metric of grassland quality, which I was unable to measure. Heavy grazing may have caused species shifts in the past, and since nitrogen addition can set mature grasslands back in to earlier successional stages, and since it is difficult for perennial species to re-establish in areas where early successional, low-palatability species have come to dominate, caution should be used in using nitrogen in grazing land (Bai *et al.* 2009, McFarland *et al.* 2008).

The trend of greater biomass of palatable species in CSKT plots indicates that smaller invasive biomass does not necessarily mean greater native species biomass; a lack of invasive biomass simply means that the area has been sprayed to remove/control invasives, but no native species has been able to take the niche and bring primary production to the level it was at with invasives (Firn 2008; Figures 3, 4, 5).

There were no significant differences between the three treatment types; this may be due to the grasslands being mainly composed of cool-season plants which had senesced before the water and nitrogen additions in early July (Taylor and Lacey 1994). The trend most closely approaching significance in difference in treatment was an increase in invasive species at the Tribal Land sites with nitrogen application (Figure 8). This increase may be due to the larger number of invasive species at the Tribal Lands plots; these introduced species seem to respond more positively to nitrogen addition (Figure 5, Blossey and Kamil 1996). Since introduced species can take advantage of nitrogen fertilizer more efficiently to the point where they can competitively exclude native individuals, addition of this fertilizer is harmful and can degrade grazing sites that contain significant populations of introduced species initially.

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FIGURES

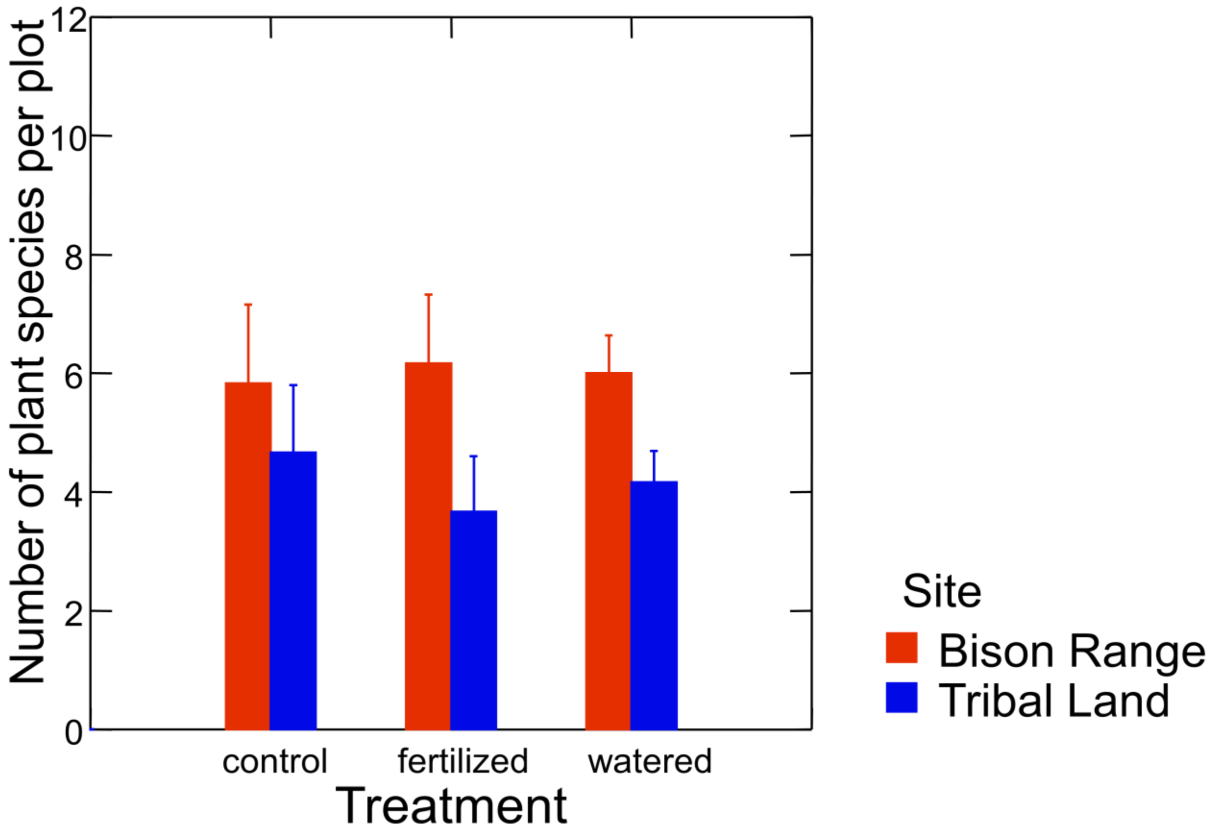


Figure 1. Number of species in $0.1m^2$ plots at the National Bison Range and CSKT Tribal Lands between three treatments.

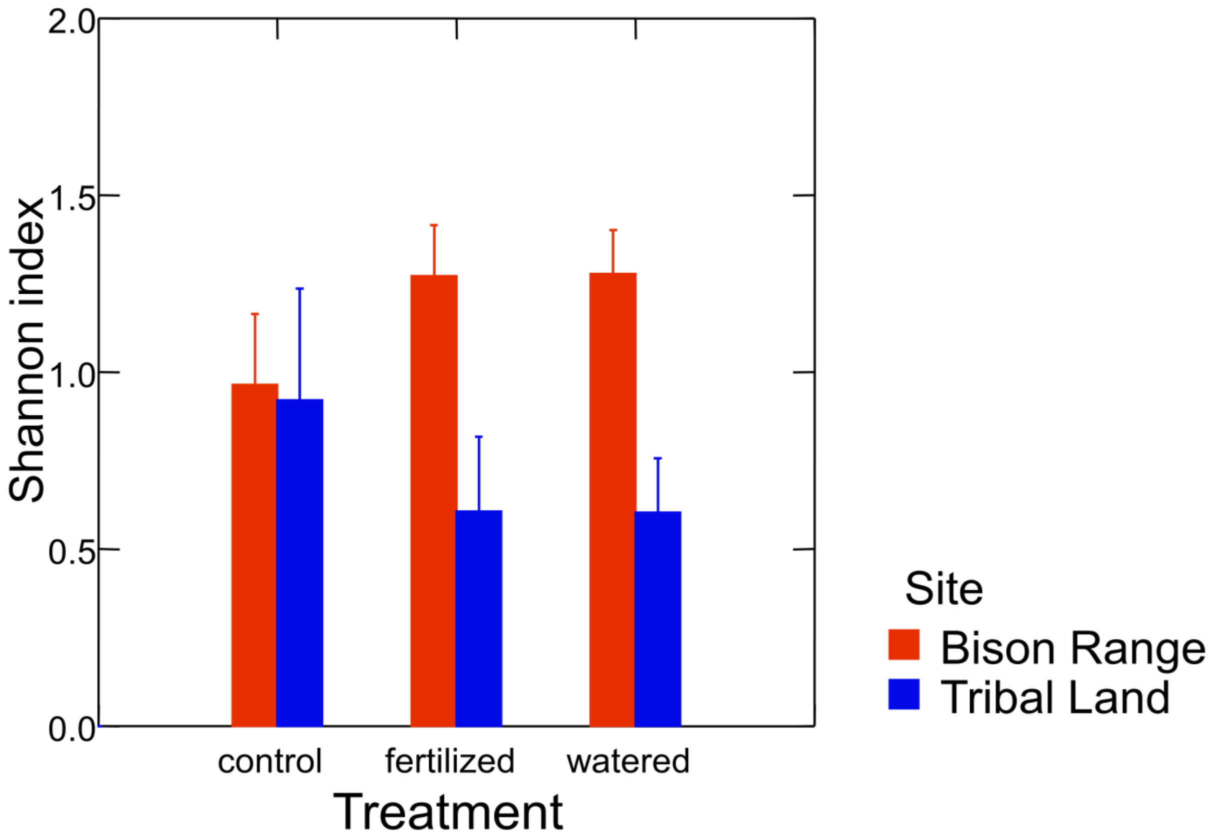


Figure 2. Shannon indeces (± standard error) of all species in 0.1m^2 plots on Tribal land (TL) ($F_{2,18}$ = 0.7051, P=0.5072) versus National Bison Range (BR) sites ($F_{2,15}$ = 1.560, P=0.2423).

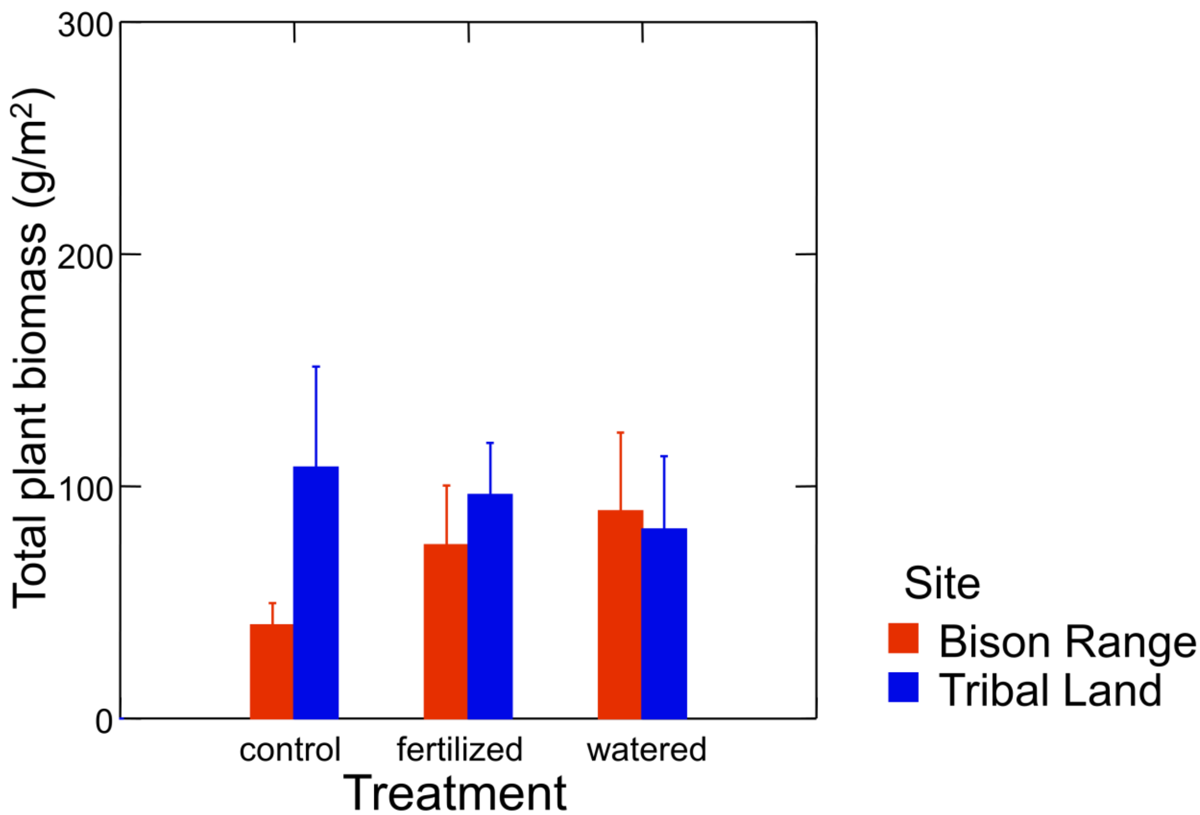
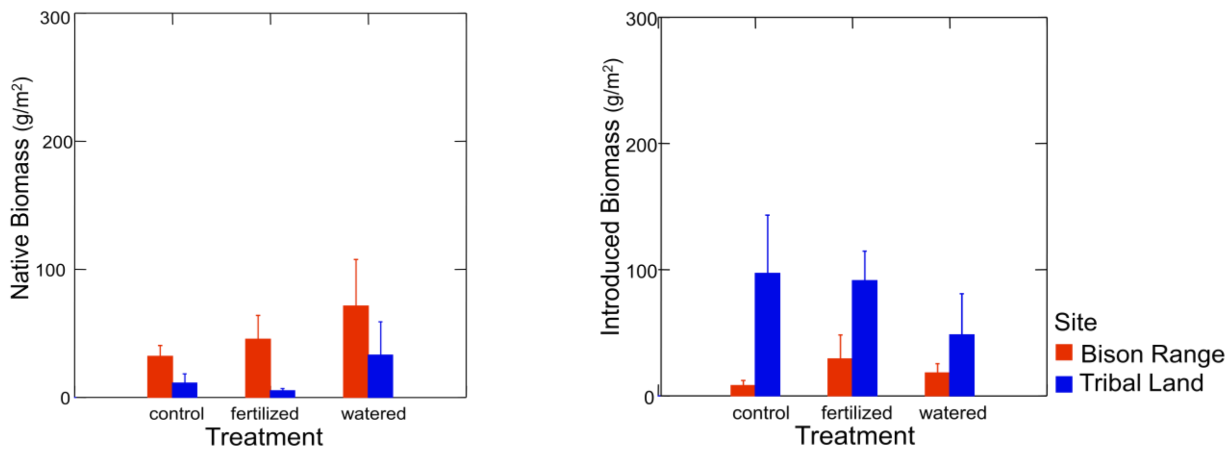


Figure 3. Biomass of plants clipped from $0.1m^2$ plots at the National Bison Range and CSKT Tribal Lands between three treatments.



Figures 4 and 5. Native species (left) and introduced species (right) biomasses of plants clipped from $0.1m^2$ plots at the National Bison Range and CSKT Tribal Lands between three treatments.

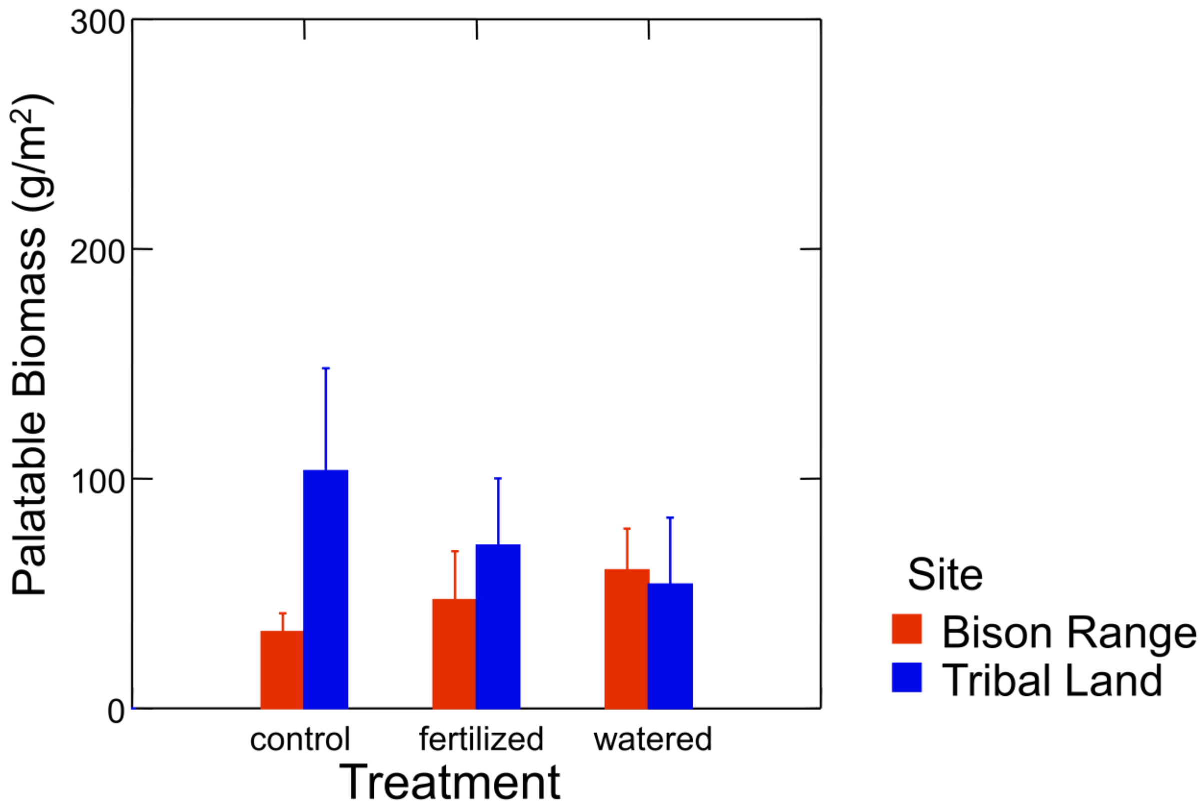


Figure 6. Treatment versus palatable biomass: no significant change in palatable biomass with treatment type.

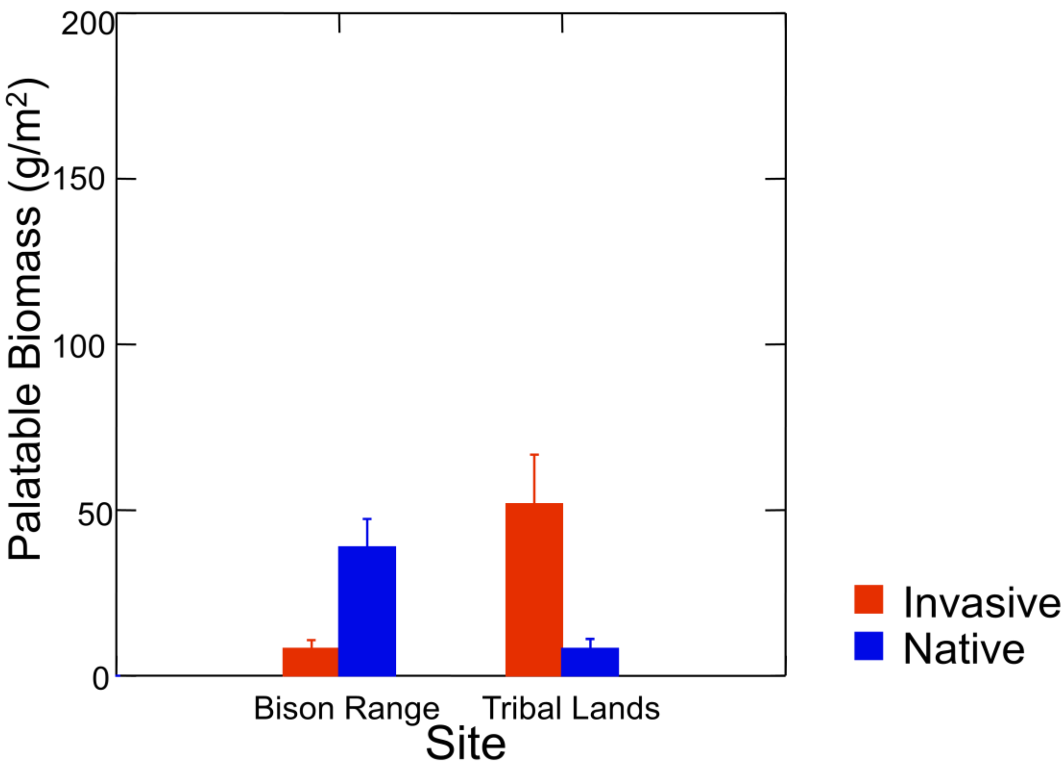
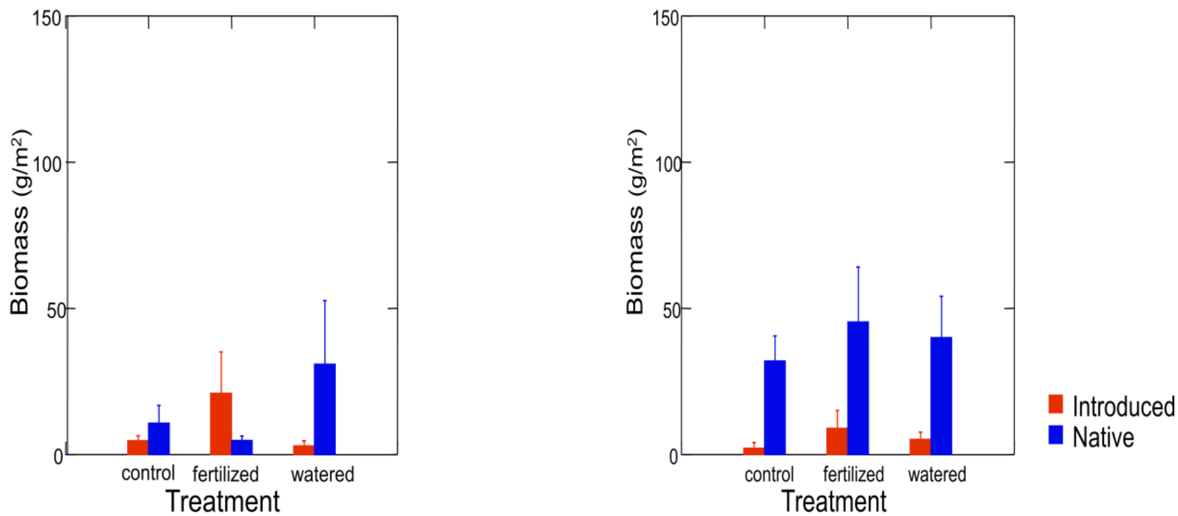


Figure 7. Invasive and native biomasses of palatable species at each site.



Figures 8 and 9. Tribal Land (left) and Bison Range (right) biomasses of plants clipped from $0.1m^2$ plots between three treatments, separated by introduced and native species.