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Bison Grazing Ecology at the Rocky Mountain Arsenal National Wildlife Refuge, Colorado

Open-File Report 2013–1112

U.S. Department of the Interior
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Cover photographs: Close-up profile of buffalo bull, courtesy of Ryan Hagerty, U.S. Fish and Wildlife Service; Grazing bison, courtesy of Steve Hillebrand, U.S. Fish and Wildlife Service.

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U.S. Geological Survey
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Contents

Figures

Tables

Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square kilometer (km^2)	247.1	acre
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

NOTE TO USGS USERS: Use of hectare (ha) as an alternative name for square hectometer (hm^2) is restricted to the measurement of small land or water areas.

Abbreviations Used in This Report

FWS	U.S. Fish and Wildlife Service
GIS	geographic information system
GPS	global positioning system
LSD	least significant difference
NCSG	native cool season graminoids
NNCSG	non-native cool season graminoids
NWR	National Wildlife Refuge
NWSG	native warm season graminoids
RMA	Rocky Mountain Arsenal
USGS	U.S. Geological Survey

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Abstract

The Rocky Mountain Arsenal (RMA) National Wildlife Refuge reintroduced bison to a small pasture in 2007. Refuge managers needed information on the effects of bison grazing on vegetation communities in the bison pasture as well as information on how bison might affect other management priorities at RMA. In particular, RMA managers were interested in bison grazing effects on vegetation productivity, amount of vegetation utilization by bison, and habitat selection by bison to inform RMA herd managers and for potential expansion of bison range on the refuge. In 2007, U.S. Geological Survey (USGS) designed a study to investigate bison grazing effects through measurement of vegetation in the 600-hectare enclosure where the bison are currently pastured. This research was a collaborative effort between USGS and RMA refuge staff and had active field components in 2007 and 2010. We found that the effects and intensity of bison grazing on vegetation in the RMA bison pasture is linked to prairie dog presence. Where both species were present, they were removing a significant amount of biomass compared to areas where only bison were present. Also, prairie dogs appeared to enhance the greater production of native forbs, but we were not able to identify the mechanism for this increased production. We were not able, however, to generate an accurate vegetation map for the bison pasture, and this limited our ability to achieve the level of statistical precision necessary to identify grazing impacts and habitat selection of bison.

Introduction

The Rocky Mountain Arsenal (RMA) National Wildlife Refuge (NWR) encompasses 6,070 hectare (ha) of shortgrass prairie approximately 16 kilometers (km) northeast of the center of Denver, Colorado. Historically, RMA was native shortgrass prairie; however, between 1880 and 1942, these lands were grazed by domestic cattle and converted to croplands and non-native grasses. The former farmland was bought in 1942 by the U.S. Army to establish the Rocky Mountain Arsenal, a chemical weapons factory. During World War II and the Cold War of the 1950s, the U.S. Army produced chemical weapons at the site and leased portions of the facility to private companies that produced agricultural pesticides. Years of chemical production left the industrial core of the site contaminated, but deer (*Odocoileus virginianus*), prairie dogs (*Cynomys ludovicianus*), coyotes (*Canis latrans*), eagles, and many species of hawks, owls, and other birds thrived in the surrounding fields, grasslands, and woodlots that had been protected from 40 years of urban sprawl and development. Extensive cleanup of the site began in the 1980s under an Environmental Protection Agency Superfund designation.

In 1992, Congress designated the site as a future national wildlife refuge. Under the National Wildlife Refuge System Improvement Act of 1997, national wildlife refuges were tasked with maintaining biological integrity, diversity, and environmental health of the areas they protected. Under these mandates, RMA identified restoration of native shortgrass prairie vegetation as a primary management objective. Removal of contaminated soils was begun, followed by restoration of native vegetation; both activities continued until completion in 2010. Between 2004 and 2006, 5,059 ha of RMA land was transferred from the U.S. Army to the U.S. Fish and Wildlife Service (FWS) to establish the Rocky Mountain Arsenal National Wildlife Refuge (RMA NWR). Cleanup activities by the Army and private companies were completed in 2010 and at that time an additional 1,012 ha was transferred to FWS making the RMA NWR the largest urban wildlife refuge in the United States (see U.S. Army Rocky Mountain Arsenal Web site at http://www.rma.army.mil/site/sitefrm.html).

In 2007, the U.S. Fish and Wildlife Service translocated 16 American bison (*Bison bison*) from the National Bison Range, in Montana, to the RMA NWR, and later that year three calves were born. The next year, two yearling bulls from Sully's Hill National Game Preserve in North Dakota were introduced to the herd. Seven bison calves were born at RMA during spring and summer 2008, bringing herd size to 28 bison. Through additional translocations and on-site reproduction, herd size increased to 45 by July 2010. All bison are individually identified with microchips. They are currently pastured in a 607-ha enclosure in the northwestern portion of RMA. The refuge is planning to develop facilities to conduct annual roundups in an effort to manage the population within carrying capacity and complete herd-health monitoring in future years (Dratch and Gogan, 2010).

Bison can influence the composition and ecological function of prairie vegetation (Knapp and others, 1999), and it is not yet clear how they may affect vegetation restoration efforts at RMA. Therefore, monitoring the effects of bison on native shortgrass prairie restoration efforts became a necessary component of refuge management at RMA. The influence of bison on grassland bird species diversity and abundance is also unclear because breeding bird densities may either decrease or increase in the presence of large grazers, depending on the bird species (Fontaine and others, 2004; Smith and Lomolino, 2004; Lueders and others, 2006). To help gather relevant information, the U.S. Geological Survey (USGS) and RMA staff developed a plan (K. Schoenecker, L. Zeigenfuss, T. Wright, and S. Skipper, written commun., January 7, 2008) to identify the effects of bison grazing on the vegetation of the RMA bison pasture in order to assess potential conflicts with other refuge management objectives. Of particular interest were the potential impacts of bison herbivory on nesting grassland bird habitat including plant species diversity; shrub-habitat structure and extent; vegetation productivity; and invasion of exotic species such as cheatgrass (*Bromus tectorum*) and crested wheatgrass (*Agropyron cristatum*) into native grasslands, particularly those recently restored to a mix of native sand prairie grasses.

RMA managers asked USGS researchers to address three specific objectives at the outset of this study in 2007: (1) identification of the vegetation communities used most by bison in the pasture, (2) measurement of vegetation utilization by bison in each community, and (3) interpretation of how these changes might affect the breeding songbird community. These objectives were further refined to include measurement of changes to vegetation composition and quantification of productivity as well as utilization rates among vegetation cover types (S. Germaine, USGS, unpub. data, June 3, 2009). In early 2010, refuge managers requested that the study objectives be again changed to: (1) determining annual net-pasture-forage productivity and (2) measurement of vegetation functional-group responses to grazing (S. Berendzen, U.S. Fish and Wildlife Service, oral commun., January 28, 2010). This report details the methods and data collected during the 4-year effort (2007–2010) and identifies additional data and materials that RMA NWR staff will need if they wish to quantify bison herbivory effects at RMA in the future.

Study Area

RMA comprises 6,070 ha on the plains of eastern Colorado in the Denver suburb of Commerce City. Approximately 3,845 ha of the refuge are currently suitable for bison grazing with the potential to support 250 animals (T. Ronning, U.S. Fish and Wildlife Service, oral commun., March 15, 2009). Since translocation to RMA, the bison have been pastured in a 607-ha enclosure in sections 27, 28, 33, and 34, T. 25 N., R. 67 W. in the west-central part of the refuge. At the time bison were reintroduced, vegetation in the pasture was believed to be composed of the following: approximately 227 ha of restored sand prairie (a mix of blue grama [*Bouteloua gracilis*], sand dropseed [*Sporobolus cryptandrus*], sandreed [*Calamovilfa longifolia*], and switchgrass [*Panicum virgatum*]); 157 ha of sand dropseed; 48 ha of needle-and-thread (*Stipa* spp.); 23.5 ha of blue grama; 21 ha of western wheatgrass (*Pascopyrum smithii*); 36 ha dominated by weedy forbs (*Kochia* spp. and Russian thistle [*Salsola* spp.]) associated with black-tailed prairie dog (*C. ludovicianus*) towns; 44 ha of yucca (*Yucca glauca*); 10 ha of mixed shrub (rubber rabbitbrush [*Ericameria nauseosa*], winterfat [*Krascheninnikovia lanata*], fringed sage [*Artemisia frigida*], and green sagebrush [*Artemisia dracunculus*]); and 23.5 ha of crested wheatgrass (*Agropyron cristatum*). Tree groves and roadways covered 1.2 ha, and 15.8 ha and were not accounted for. Areas of non-native vegetation in the pasture were being restored to native-dominated communities.

Methods

Mapping Pasture Vegetation

We generated a pasture vegetation map in 2007 using color-infrared aerial-photographic imagery collected on July 11, 2003. This map was developed to provide quantitative baseline vegetation data in support of project objectives. From the remote imagery, we interpreted pasture vegetation into nominal cover types based on dominant grass/herb species present and then mapped patches of each cover type into a geographic information system (GIS). We then ground-truthed section 34 of the pasture vegetation map by visually identifying the dominant vegetation species present at each of 20 randomly located points. Error rates indicated that the initial mapping effort did a poor job of classifying vegetation cover in section 34 (T. Wright, U.S. Fish and Wildlife Service, oral commun., February 2008).

We conducted a second round of in-field vegetation mapping in section 34 during summer 2008 and reclassified vegetation as native shortgrass, native midgrass, or exotic species-dominated and further defined each of these as cool-season or warm-season dominated. During this exercise, cover-type assignments were made on hardcopy maps while traversing parallel transects separated by approximately 30 m. Assignments were not tied to global positioning system (GPS) coordinates, no additional error checking was conducted within section 34, and the vegetation map of the pasture outside of section 34 was not error-checked in either this or the initial (2007) mapping effort.

Recognizing that a vegetation map containing known levels of error (that is, an error-checked map) was necessary for accurately estimating vegetation productivity and utilization in the pasture, in February 2010, we began a pilot effort to map pasture vegetation using software designed to aid the process of interpreting features present on remotely sensed imagery. Using Envi Feature Extraction software (ITT Visual Information Solutions, 2008), USGS staff performed a computer-aided segmentation of sections 27 and 28 of the pasture from a color-infrared aerial photograph dated June 27, 2009. The segmentation identified six distinct vegetation types and identified boundaries of all patches that exceeded 0.40 ha. Immediately following the segmentation, we conducted site visits to identify the dominant plant species present at 260 points that were systematically located throughout each of the six vegetation types. This data was then transferred to RMA personnel to be used to produce a revised pasture vegetation map.

Vegetation Productivity, Utilization, and Species Composition

In 2007, we used two methods to evaluate the impacts of bison on pasture vegetation: exclosure cages and vegetation transects. First, based on the priorities identified by RMA biologists and using the 2007 pasture vegetation maps, five vegetation types were identified: restored sand prairie, blue grama grasslands, needle-and-thread grasslands, western wheatgrass grasslands, and sand dropseed grasslands. These vegetation types were (1) considered to be representative of the majority of forage types in the bison pasture, (2) specifically informative for grassland birds that may experience habitat impacts from the reintroduction of bison, (3) found on both the pasture and other areas of the refuge outside of the pasture fence for potential control-impact comparison, and (4) important types for shortgrass prairie in general or had been restored to shortgrass prairie. However, we sampled only three of the vegetation types (blue grama, sand dropseed, and needle-and-thread) plus crested wheatgrass, which was added as another type during sampling. Sixteen sites were sampled—five in blue grama grasslands, five in needle-and-thread grasslands, four in crested wheatgrass communities, and two in sand dropseed grasslands (these last two sites were not recorded on a GPS and thus not mapped; fig. 1). Within each vegetation type, we randomly located clusters of 3–4 exclosure cages at each site. Each cage protected a 1-m^2 area from bison grazing allowing us to estimate annual aboveground herbaceous productivity and compare bison forage utilization among vegetation types. Cages were installed in early spring, and vegetation was sampled in June. Cages were then randomly relocated and sampled again in September 2007.

During March and Sept. 2007, we also sampled vegetation using a 50-m fixed-point line-transect methodology to determine plant species composition, density, and diversity at the 16 study sites. At each 1-m increment along transects, we tallied frequency of occurrence of bare soil, litter, rock, and each grass, forb, shrub, and tree species at points 1 m to each side of the transect centerline. These data were entered into an RMA database and transformed into percent cover for comparisons among vegetation types and years. From this data, a variety of comparisons are made possible including mean-percent cover of each species or functional group; relative live-percent cover; frequency that each species, cover type, or functional group occurs at each site; percent total cover that is live vegetation; and percent total cover composed of native vegetation. This method had been used historically at RMA NWR, so results should have been directly comparable with previously collected data.

After 2007, we recognized that prairie dogs occupied roughly half of the pasture area making necessary a second type of cage that would exclude both prairie dogs and bison. Therefore, in May 2010, we identified all areas potentially occupied by prairie dogs by buffering the 2009 GIS pasture prairie dog map outward by 100 m to account for expansion that might have occurred since then. We then deployed one cage of each type at 41 randomly located prairie dog sites and one bison exclosure cage at each of 39 randomly located non-prairie dog sites. Eighty new random plot locations were generated after the first sampling, and cages were moved to those locations in preparation for the late summer sampling session. Concurrent with vegetation sampling during both sessions, we tallied the number of active prairie dog burrows within 10 m and 25 m of each site center to determine whether prairie dogs were actually present or not. In instances where prairie dogs were present at plots that had been misclassified as bison-only plots, the data were discarded because no prairie dog exclusion cage was installed at the site, and the full suite of grazing effects could not be represented from these particular sites. In instances where prairie dogs were absent from plots that had been misclassified as having them present, data from the bison-prairie dog exclosure cages were discarded, whereas data from the bison exclosure and the non-exclosed plot were retained and reclassified as a bison-only plot.

Due to the high error rates present in the 2007 pasture vegetation map, sample sites still could not be partitioned accurately by vegetation community in 2010. The study was further confounded by multiple herbicide treatments that had been broadly applied to some areas of the pasture to eliminate invasive forb species in 2010, but personnel associated with sample-site selection and vegetation sampling were not made aware of the herbicide applications until after sampling was well underway. Only general areas treated with herbicide were identified by RMA personnel; based on this information, we had to make a determination as to whether an individual sampling location had likely been subjected to herbicide treatment.

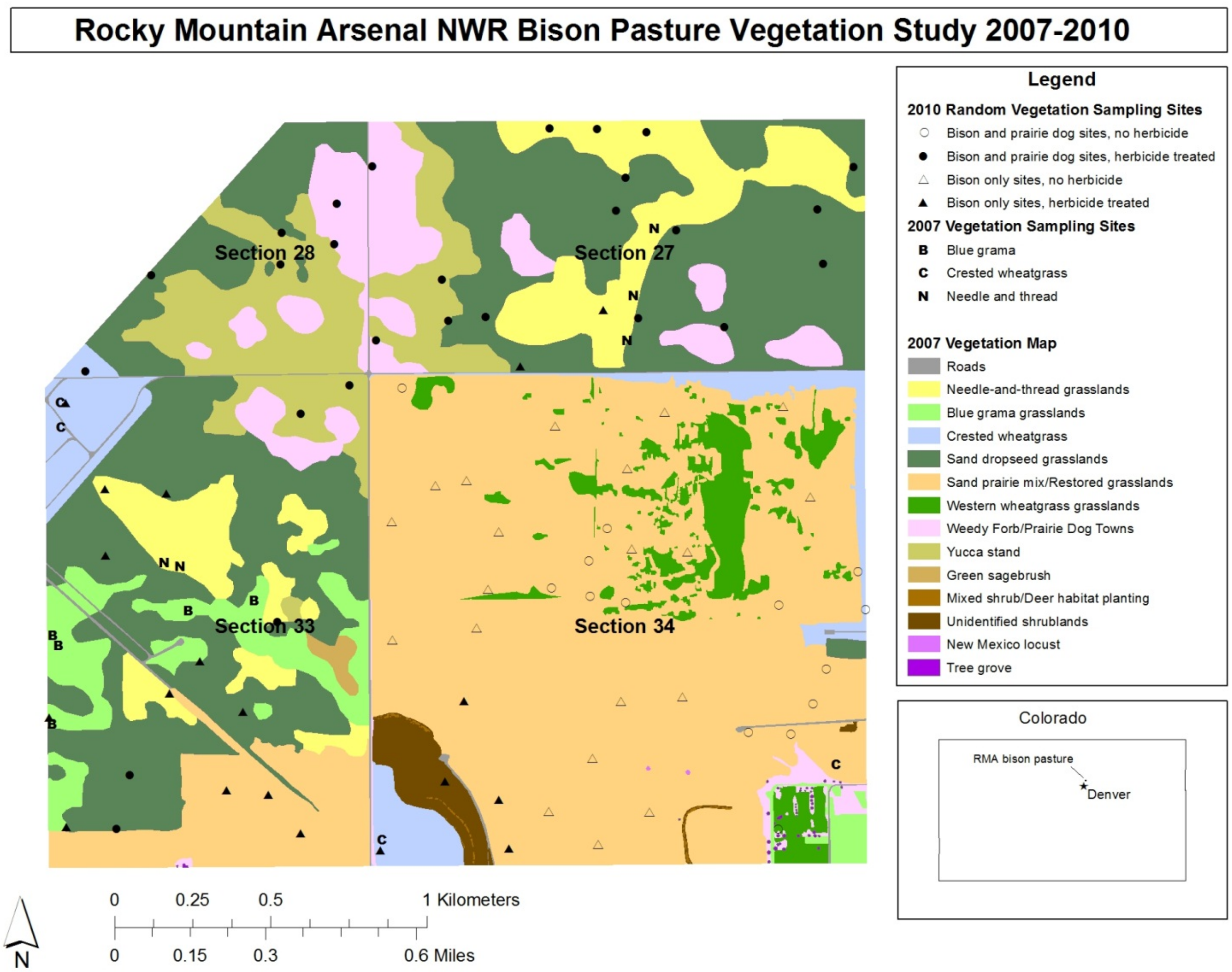

Figure 1. Rocky Mountain Arsenal National Wildlife Refuge (NWR) 2007 vegetation map and locations of 2007 and 2010 U.S. Geological Survey vegetation sampling sites. T. 25 N., R. 67 W. July sampling plots shown; September sampling plots not shown.

In both 2007 and 2010, we clipped all grasses, forbs, and sub-shrubs at ground level in a circular, 0.25-m^2 plot located inside each cage and another plot placed 5 m north of the bison exclosure. Sites were sampled in late June 2007 and mid-July 2010 and again in September in both years. In 2007, we sorted vegetation by species to afford measures of seasonal peak-standing crop (the current year's growth). In 2010, RMA staff revised the nominal plant groupings, and vegetation was sorted into five major plant functional groups—native forbs, non-native forbs, native cool season graminoids (NCSG), non-native cool season graminoids (NNCSG), and native warm season graminoids (NWSG). Vegetation samples were bagged, labeled, oven dried at 55 ^{o}C for ≥48 hours, and then weighed. After each sampling event, we randomly relocated cages for the next sampling visit.

Vegetation productivity (*B*) was calculated as the standing crop inside the most exclusive cage present at each plot (that is, bison and prairie dog exclosures at all prairie dog-occupied sites and bison exclosures at non-prairie dog sites) at the time of sampling. Since the cages were not sampled on a monthly basis throughout the growing season, aboveground net primary productivity could not be estimated. If no biomass was collected for a particular functional group in a clipped quadrat, then a value of zero was entered for that group.

We determined utilization and offtake (see below) of herbaceous forage following Bonham (1989). In areas where only bison were present, utilization of forage by bison was estimated as the difference between standing crop inside the bison exclosure cages versus standing crop outside the exclosure cages (equation 1). In areas where both bison and prairie dogs occurred, utilization of forage by bison was defined as the difference in standing crop inside the bison exclosure cage versus in the unexclosed plot (equation 1), whereas prairie dog utilization was defined as the difference in standing crop inside the bison-prairie dog exclosure versus inside of the bison exclosure cage (equation 2).

$$U_{bison} = P_{bison\ exclosure} - P_{uncaged} \qquad (1)$$

$$U_{prairie\ dogs} = P_{bison\text{-}prairie\ dog\ exclosure} - P_{bison\ exclosure} \qquad (2)$$

Here U_{bison} and $U_{prairie\ dogs}$ are amounts of forage used by bison and prairie dogs, respectively; $P_{bison\ exclosure}$ is the amount of biomass inside the bison exclosure cage; $P_{bison\text{-}prairie\ dog\ exclosure}$ is the amount of biomass inside the bison-prairie dog exclosure cage; and $P_{uncaged}$ is the amount of biomass in paired uncaged plot.

Percent offtake was the preferred variable for comparing utilization between various vegetation types or other groupings because it scales the measure of consumption of forage to the total biomass present in a particular vegetation type or individual sampling site. Percent offtake by bison and prairie dogs for the growing season was calculated as the percentage of production that was consumed (utilized) following equation 3.

$$O_x = (U_x \div B_{ungrazed}) \times 100 \qquad (3)$$

Here O_x = percent offtake of standing crop by ungulate species x; U_x = utilization by ungulate species x; and $B_{ungrazed}$ = ungrazed standing crop within the most exclusive cage.

In cases where no biomass was measured for one of the five major functional groups inside the ungrazed cage, offtake could not be determined (due to division by zero), and this cage was eliminated from offtake calculations.

Bison Habitat Selection

To assess habitat use by bison, we attached a GPS radio collar (one NorthStar Science and Technology, King George, Virginia, and one Habit Research, Victoria, British Columbia, Canada) to each of two adult cow bison in March 2008. A positional fix was collected by each collar every 4 hours with an accuracy of ±5 m. The Habit collar stored data on-board, whereas the NorthStar collar transmitted real time location data over the Globalstar satellite network to NorthStar's Sensorlink Web site.

Statistical Analysis

All statistical analyses were performed using Systat version 11 or SAS version 9.2 statistical analysis software. In 2007, we tested for differences in productivity and offtake among vegetation types using Fisher's least significant difference (LSD) multiple comparison test (SAS, 2008).

Preliminary analysis of the 2010 data using Shapiro-Wilk W tests (Systat, 2007) revealed that the distributions of productivity and offtake data from all five vegetation classes were non-normal ($P < 0.05$). We assumed a priori differences in sites based on the presence of prairie dogs due to site disturbance from burrows and therefore analyzed areas with prairie dogs separately from sites where prairie dogs were absent. We then assessed whether there were differences between areas that received herbicide applications versus those that did not, based on results of the Mann-Whitney tests (table 1). Based on these preliminary investigations, we determined that comparisons of 90-percent confidence intervals around the median (Wilkinson and Engelman, 2007) would be more revealing than rank-based nonparametric analyses as to the nature of differences in productivity and offtake.

Table 1. Mann-Whitney U test statistics for assessing effects of herbicide applications on plant biomass in kilograms per hectare (kg/ha) in each of five vegetation functional groups during July and September 2010 at Rocky Mountain Arsenal National Wildlife Refuge, Colorado.

[NCSG = native cool season graminoids; NNCSG = non-native cool season graminoids; NWSG = native warm season graminoids; n = sample size; *P* = probability of obtaining the observed test value]

Vegetation functional group	Standing crop (kg/ha) — Herbicide treatment: Median (25th–75th percentile)	n	Standing crop (kg/ha) — No herbicide treatment: Median (25th–75th percentile)	n	Mann-Whitney U	*P*
Prairie Dogs Absent						
July						
Native forbs	11 (0–207)	26	12 (0–126)	24	606	0.912
Non-native forbs	11 (0–354)	26	0 (0–1)	24	478	0.004*
NCSG	212 (0–1,040)	26	28 (0–285)	24	545	0.183
NNCSG	73 (0–961)	26	566 (19–1,410)	24	671	0.249
NWSG	115 (15–658)	26	345 (58–608)	24	630	0.726
Total	2,481 (1,573–2,841)	26	1,462 (1,078–2,228)	24	507	0.042*
September						
Native forbs	0 (0–104)	25	3 (0–40)	22	534	0.884
Non-native forbs	0 (0–90)	25	0 (0–0)	22	443	0.025*
NCSG	191 (0–1,086)	25	0 (0–85)	22	451	0.068
NNCSG	8 (0–44)	25	760 (27–960)	22	668	0.003*
NWSG	0 (0–115)	25	329 (117–640)	22	702	0.000*
Total	1,200 (839–1,997)	25	1,558 (1,023–2,009)	22	578	0.286
Prairie Dogs Present						
July						
Native forbs	43 (0–384)	19	311 (113–833)	10	201	0.019*
Non-native forbs	800 (239–1,817)	19	39 (0–124)	10	98	0.018*
NCSG	7 (0–310)	19	130 (0–347)	10	163	0.540
NNCSG	9 (0–112)	19	1 (0–39)	10	156	0.794
NWSG	64 (12–648)	19	41 (13–148)	10	129	0.334
Total	1,738 (1,205–3,127)	19	1,232 (1,020–1,496)	10	111	0.74
September						
Native forbs	0 (0–118)	19	86 (0–422)	8	130	0.311
Non-native forbs	804 (4–3,440)	19	0 (0–1,132)	8	72	0.035*
NCSG	0 (0–410)	19	0 (0–816))	8	110	0.882
NNCSG	0 (0–0)	19	0 (0–60)	8	124	0.389
NWSG	17 (0–146)	19	270 (25–407)	8	142	0.107
Total	1,800 (857–3,479)	19	1,618 (1,147–1,844)	8	99	0.490

*significant at alpha = 0.05.

Results

Vegetation Productivity, Utilization, and Species Composition

2007

During the early growing period (Feb.–June), measured productivity was marginally greater in crested wheatgrass than in needle-and-thread communities (Fisher's LSD = 0.049) and did not differ among any other vegetation cover types (fig. 2). During the late season (June–Sept.), standing crop was greater for crested wheatgrass than for either blue grama (Fisher's LSD = 0.020) or needle-and-thread (Fisher's LSD = 0.003) and did not differ among any other vegetation types.

Offtake data were difficult to interpret due to a number of samples (43 out of 103) where measured productivity was greater outside the grazing cages than inside. When averaged for all samples, offtake estimates were negative for two of the four measured vegetation types in June and all vegetation types in September, suggesting that greater productivity occurred outside the grazing exclosures than inside, despite grazing. Measured offtake did not differ among cover types during either the early or late season (Fisher's LSD >0.05 in all cases; table 2).

Cheatgrass was a large component of the herbaceous vegetation in blue grama and sand dropseed vegetation throughout the growing season (fig. 3). Offtake of cheatgrass ranged from 14 percent in blue grama sites to 80 percent in crested wheatgrass sites. Grazing by bison reduced cheatgrass biomass early in the growing season and reduced cheatgrass biomass 25–57 percent by the end of the growing season in all vegetation types.

Pooling early and late season vegetation transect data, native species composed 64.1 percent of all vegetation cover in 2007. Organic litter composed 28.0 percent of the ground cover, whereas 8.7 percent of the area sampled was bare soil. Species richness was greatest in blue grama communities (24 species observed) and least in sand dropseed communities (7 species observed). Needle-and-thread and crested wheatgrass communities had 14 species each. Cover of non-native species was highest (43-percent mean cover) on the sand dropseed sites with most of this cover contributed by crested wheatgrass (32-percent mean cover). Mean cover of non-natives was 27 percent in blue grama sites, 21 percent in crested wheatgrass sites, and 17 percent in needle-and-thread sites. Cheatgrass composed 9 percent of cover in sand dropseed communities, 14 percent in needle-and-thread, and 17 percent in blue grama communities, but only 1.7 percent in crested wheatgrass communities.

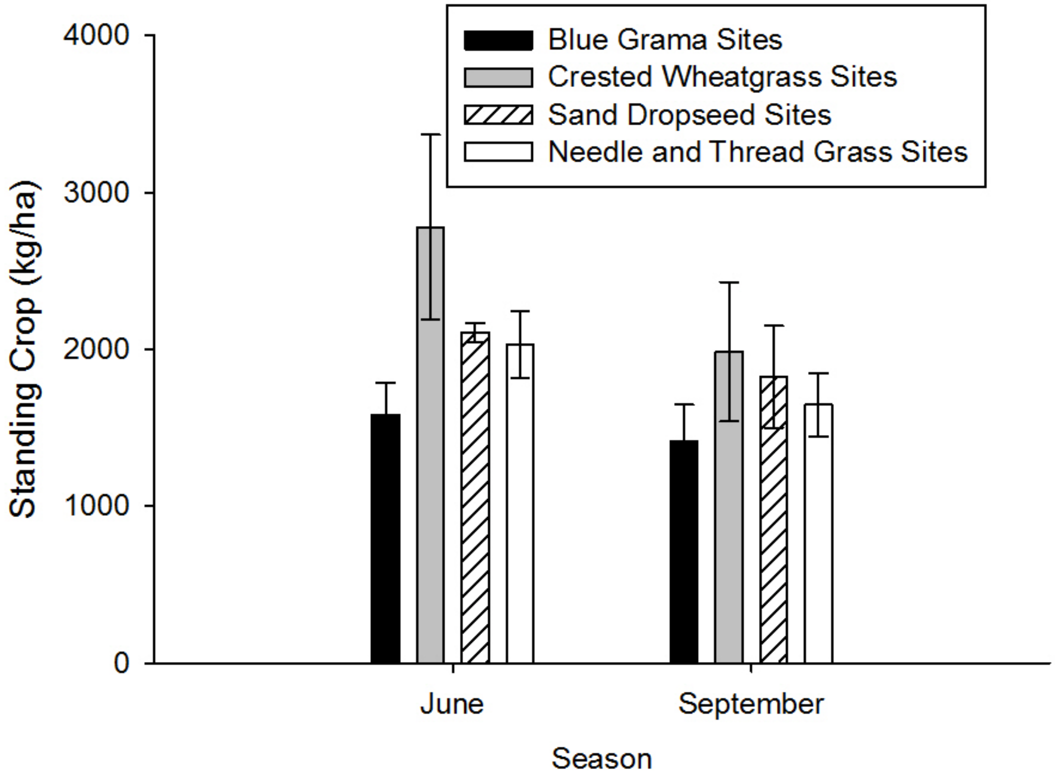

Figure 2. Total herbaceous standing crop (kg/ha [kilograms per hectare]; mean ±1 standard error) estimates for each of four vegetation cover types defined for the June and September 2007 exclosure-cage sampling sessions at Rocky Mountain Arsenal National Wildlife Refuge, Colorado.

Table 2. Consumption (kg/ha [kilograms per hectare]) and offtake (in percent) values for four vegetation cover types defined for June and September 2007 sampling dates at Rocky Mountain Arsenal National Wildlife Refuge, Colorado. Data are mean ±1 standard error (s.e.).

Vegetation type		Consumption (kg/ha)		Offtake (percent)	
		June	September	June	September
	n	mean ± s.e.	mean ± s.e.	mean ± s.e.	mean ± s.e.
Blue grama	5	317.2 ± 129.6	210.7 ± 330.3	13.3 ± 8.5	-16.4 ± 43.4
Crested wheatgrass	4	193.4 ± 173.9	-143.7 ± 585.2	-1,383.4 ± 1,379.8	-97.1 ± 81.3
Sand dropseed	2	-481.5 ± 130.5	175.6 ± 70.8	-15.0 ± 5.1	-6.9 ± 19.4
Needle-and-thread	5	118.7 ± 200.9	-77.5 ± 318.4	1.8 ± 11.5	-0.6 ± 15.1

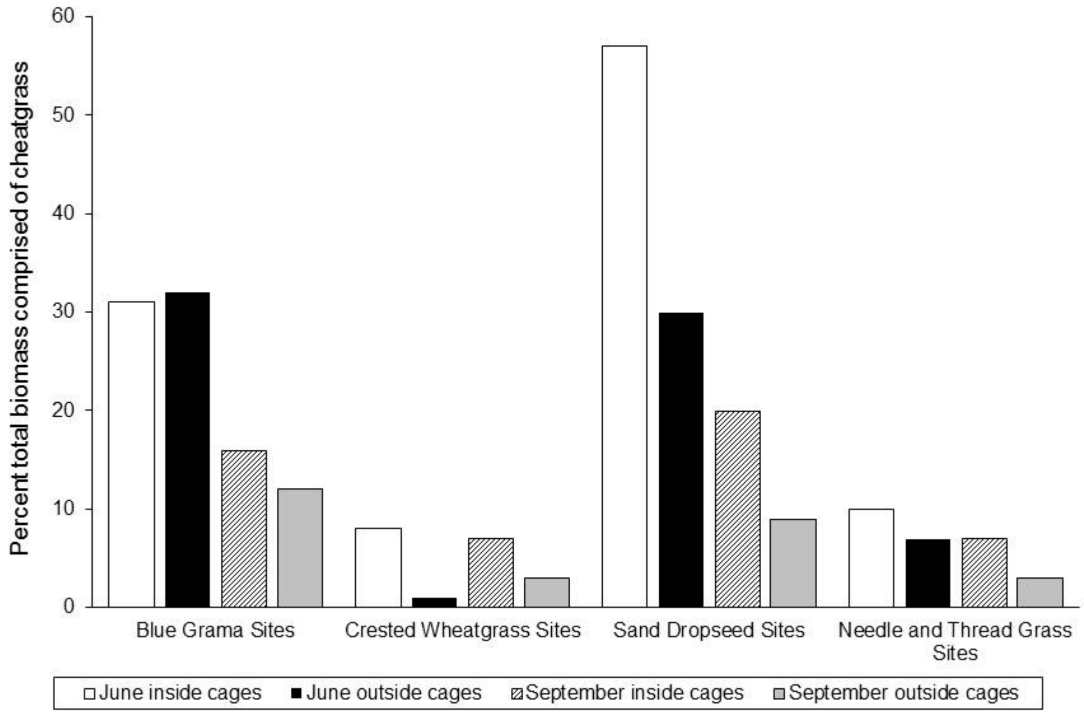

Figure 3. Percent of total herbaceous standing crop comprised of cheatgrass in each of four vegetation cover types on Rocky Mountain Arsenal National Wildlife Refuge bison pasture as defined for sampling in June and September 2007.

2010

Very few differences were found in the 2010 standing crop based on overlap in 90-percent confidence intervals about the median (tables 3 and 4). Median total herbaceous standing crop values were nearly identical inside (July median = 1,462 kg/ha, September median = 1,375 kg/ha) and outside (July median = 1,378 kg/ha, September median = 1,479 kg/ha) of bison-exclusion grazing cages in areas with no prairie dogs in both July and September. Prairie dogs appeared to exhibit little influence on graminoids or total standing crop during the early growing season (July sampling period), but ungrazed plots did appear to have greater biomass of native forbs when prairie dogs were present (median = 312 kg/ha) compared to areas where prairie dogs were absent (median = 12 kg/ha). However, during the late growing season (September sampling period), biomass of non-native cool season graminoids (NNCSG) was greater in areas where prairie dogs were absent (median = 760 kg/ha) than where they were present (median = 0 kg/ha). In areas where prairie dogs were present, total standing crop was greater (as evidenced by non-overlapping 90-percent confidence intervals around the median) in plots inside bison and prairie dog exclusion cages (median = 1,680 kg/ha) compared to plots outside cages (median = 812 kg/ha), indicating that together, bison and prairie dogs were removing a significant amount of biomass (table 3).

Offtake again had a high number of negative values (84 of 216 cages sampled, table 4). In July and September in areas containing only bison, confidence intervals were too wide to discern differences in offtake among most of the plant functional groups. However, in both July and September, offtake of native forbs by bison was greater in areas where prairie dogs were absent (July median = 87-percent biomass consumed, September median = 100-percent biomass consumed) compared with bison offtake in areas where prairie dogs were present (July median = 20-percent biomass consumed, September median = 0-percent biomass consumed, table 4). This is likely because prairie dogs competed with bison for native forbs. In July, prairie dog offtake was much greater on cool season graminoids (both NCSG and NNCSG) than bison offtake in areas where prairie dogs were present. Though bison offtake appeared much higher on these functional groups in areas where prairie dogs were absent, confidence intervals were so wide that such differences could not be conclusively determined. In September total offtake was lower when prairie dogs were absent (median = 5 percent of biomass consumed) than in areas where both prairie dogs and bison grazed (median = 48 percent of biomass consumed). In areas where prairie dogs were present, offtake of total biomass by prairie dogs (median = 40 percent of biomass consumed) was greater than offtake of total biomass by bison (median = 9 percent of biomass consumed).

Despite trends toward differences in certain plant groups based on herbicide treatment, the only significant differences of plant functional groups were found in September standing crop of native warm season graminoids (NWSG) and non-native cool season graminoids (NNCSG) and only in areas where prairie dogs were absent. In these sites herbicide-treated caged plots had lower biomass than untreated caged plots for these two functional groups (table 3). Overlapping confidence intervals were found between all other tested comparisons indicating a small measurable effect of herbicide treatment at these sites.

Table 3. Standing crop (kilograms per hectare [kg/ha]); median and 90-percent confidence interval (CI) of vegetation in the Rocky Mountain Arsenal bison pasture, July and September 2010. Non-overlapping confidence intervals indicate differences between groups.

[(H) denotes herbicide treatment; NCSG = native cool season graminoids; NNCSG = non-native cool season graminoids; NWSG = native warm season graminoids; n = number of samples]

Plant Group	Standing crop (kg/ha)								
	Ungrazed			Grazed only by prairie dogs			Prairie dog and bison grazing		
	n	Median	90 % CI	n	Median	90 % CI	n	Median	90 % CI
July—Prairie dogs absent									
Native forbs	50	12	0–60	.	.	.	50	0	0–16
Non-native forbs	24	0	0–0	.	.	.	24	0	0–0
Non-native forbs (H)	26	11	0–230	.	.	.	26	46	2–328
NCSG	50	116	26–275	.	.	.	50	11	0–304
NNCSG	50	260	59–621	.	.	.	50	79	21–364
NWSG	50	330	106–491	.	.	.	50	281	168–356
Total	24	1,462	1,104–2,006	.	.	.	24	1,378	826–1,879
Total (H)	26	2,481	1,922–2,643	.	.	.	26	1,698	1,268–2,221
July—Prairie dogs present									
Native forbs	10	312	113–1,100	10	139	79–1,620	10	164	91–661
Native forbs (H)	19	43	0–235	19	66	6–357	19	137	8–320
Non-native forbs	10	39	0–1,280	10	0	0–1,760	10	1	0–404
Non-native forbs (H)	19	800	266–1,424	19	740	484–1,055	19	560	221–1300
NCSG	29	20	0–241	29	17	1–55	29	27	0–67
NNCSG	29	1	0–66	29	0	0–16	29	0	0–12
NWSG	29	49	24–200	29	62	9–133	29	55	16–82
Total	29	1,495	1,284–1,890	29	1,419	1,188–2,013	29	1,350	1,102–1,556
September—Prairie dogs absent									
Native forbs	47	1	0–13	.	.	.	47	0	0–9
Non-native forbs	22	0	0–0	.	.	.	22	0	0–2
Non-native forbs (H)	25	0	0–48	.	.	.	25	3	0–84
NCSG	47	0	0–185	.	.	.	47	0	0–236
NNCSG	22	760	35–892	.	.	.	22	202	6–1,120

Table 3. Standing crop (kilograms per hectare [kg/ha]); median and 90-percent confidence interval (CI) of vegetation in the Rocky Mountain Arsenal bison pasture, July and September 2010. Non-overlapping confidence intervals indicate differences between groups.—Continued

[(H) denotes herbicide treatment; NCSG = native cool season graminoids; NNCSG = non-native cool season graminoids; NWSG = native warm season graminoids; n = number of samples]

NNCSG (H)	25	8	1–25	.	.	.	25	15	0–180
NWSG	22	329	158–566	.	.	.	22	298	199–610
NWSG (H)	25	0	0–50	.	.	.	25	0	0–234
Total	47	1,375	1,089–1,832	.	.	.	47	1,479	1,174–1,727
September—Prairie dogs present									
Native forbs	27	16	0–118	27	0	0–40	27	0	0–15
Non-native forbs	8	0	0–1,600	8	76	0–880	8	45	0–130
Non-native forbs (H)	19	804	17–2,115	19	348	73–1,260	19	269	62–812
NCSG	27	0	0–253	27	0	0–263	27	0	0–160
NNCSG	27	0	0–0	27	0	0–1	27	0	0–20
NWSG	27	38	11–217	27	8	0–104	27	33	0–153
Total	27	1,680	1,416–2,384	27	1,260	1,024–1,528	27	812	633–1,386

Table 4. Percent consumption (offtake) of vegetation by bison and prairie dogs (median and 90-percent confidence interval [CI]) in the Rocky Mountain Arsenal bison pasture, July and September 2010. Non-overlapping confidence intervals indicate differences between groups.

[(H) denotes herbicide treatment; NCSG = native cool season graminoids; NNCSG = non-native cool season graminoids; NWSG = native warm season graminoids]

	Offtake (percent)								
	Total offtake			Bison offtake			Prairie dog offtake		
	n	Median	90 % CI	n	Median	90 % CI	n	Median	90% CI
July—Prairie dogs absent									
Native Forb	30	87	53–100	30	87	53–100	.	.	.
Non-native forb	6	-6	-28–100	6	-6	-28–100	.	.	.
Non-native forb (H)	16	27	-105–77	16	27	-105–77	.	.	.
NCSG	32	41	-32–100	32	41	-32–100	.	.	.
NNCSG	39	68	-6–85	39	68	-6–85	.	.	.
NWSG	43	19	-43–53	43	19	-43–53	.	.	.
Total	23	32	-34–40	23	32	-34–40	.	.	.
Total (H)	26	13	-20–43	26	13	-20–43	.	.	.
July—Prairie dogs present									
Native Forb	10	64	-37–93	10	20	-16–54	10	43	-131–88
Native forb (H)	13	30	-277–75	13	0	-34–57	13	-3	-632–76
Non-native forb	5	66	-278–100	5	37	-378–348	5	29	-248–100
Non-native forb (H)	18	29	-7–86	18	17	-13–43	18	6	-20–31
NCSG	18	52	-12–100	18	3	-30–25	18	68	30–95
NNCSG	17	91	35–100	17	1	0–12	17	85	71–100
NWSG	24	44	2.4–72	24	14	-17–34	24	50	-37–73
Total	29	18.2	4.0–43	29	12	-7–24	29	24.2	-18–39
September—Prairie dogs absent									
Native forb	25	100	32–100	25	100	32–100	.	.	.
Non-native forb	3	85	-467–95	3	85	-467–95	.	.	.
Non-native forb (H)	11	83	-48–99	11	83	-48–99	.	.	.
NCSG	20	29	5–100	20	29	5–100	.	.	.
NNCSG	19	28	-54–97	19	28	-54–97	.	.	.
NNCSG (H)	17	55	-17–100	17	55	-17–100	.	.	.
NWSG	20	5	-45–81	20	5	-45–81	.	.	.
NWSG (H)	8	74	-122–100	8	74	-122–100	.	.	.
Total	43	5	-12–15	43	5	-12–15	.	.	.

Table 4. Percent consumption (offtake) of vegetation by bison and prairie dogs (median and 90-percent confidence interval [CI]) in the Rocky Mountain Arsenal bison pasture, July and September 2010. Non-overlapping confidence intervals indicate differences between groups.—Continued

[(H) denotes herbicide treatment; NCSG = native cool season graminoids; NNCSG = non-native cool season graminoids; NWSG = native warm season graminoids]

September—Prairie dogs present									
Native forb	14	99	-52–100	14	0	-151–15	14	82	18–100
Non-native forb	3	94	89–100	3	13	0–25	3	82	65–100
Non-native forb (H)	18	44	-72–72	18	2	-70–50	18	42	19–60
NCSG	11	62	32–84	11	17	0–55	11	20	-86–70
NNCSG	7	19	-84–100	7	0	-180–42	7	80	1–100
NWSG	19	57	-97–91	19	0	-189–45	19	50	-13–91
Total	27	48	30–70	27	9	3–14	27	40	21–60

Bison Habitat Selection

The NorthStar GPS collar failed approximately 1 month after it was successfully launched and secured to a bison. Successful launch was verified prior to deployment. While troubleshooting the problem with the NorthStar technical representative, we learned that the failed collar was one of a cohort of early prototypes having a design flaw that allowed moisture into the transmitter housing, resulting in high failure rates. The Habit Research GPS collar stopped transmitting data when the animal fitted with the collar was fatally struck by lightning. We were unable to recover data from this unit. Available locations from the animal fitted with the NorthStar collar were plotted (fig. 4). These locations were recorded from March 3, 2008, through April 10, 2008. Although we conducted no formal analysis of habitat selection, visual analysis of the location data indicated that this cow used the whole pasture with the majority of the locations in areas initially identified as restored shortgrass prairie, though this type predominates on the 2007 vegetation map.

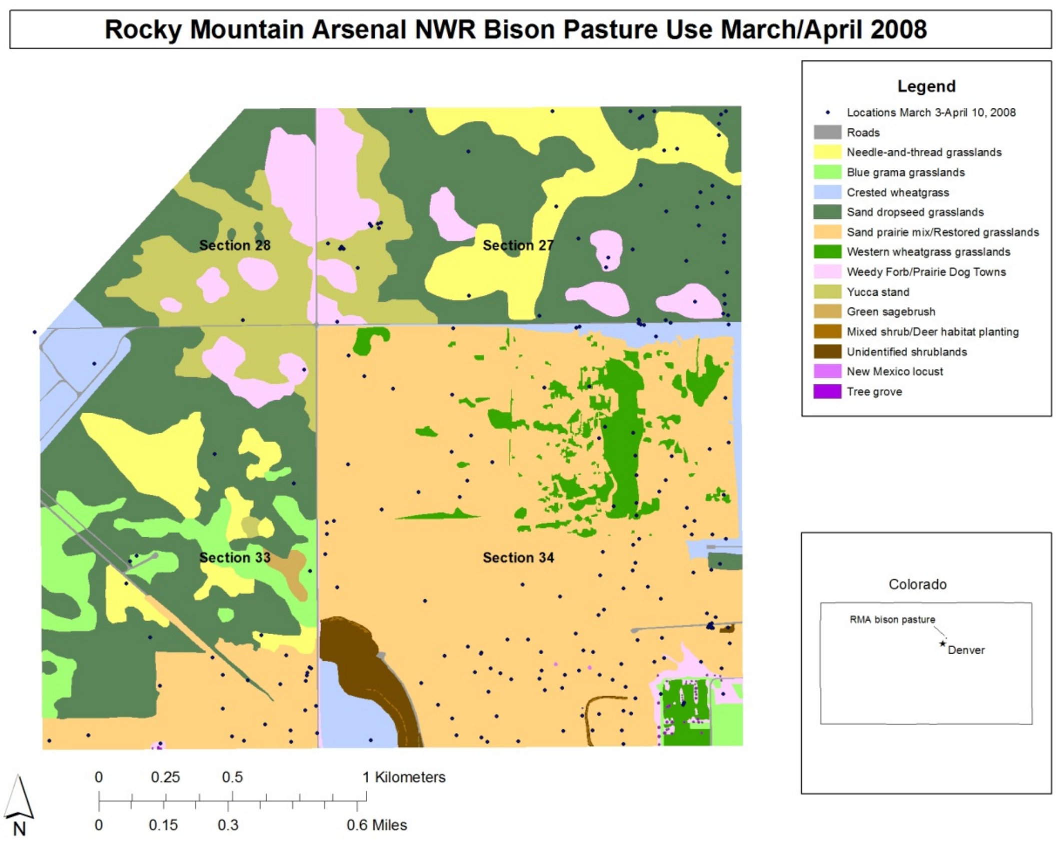

Figure 4. Location data gathered from one cow bison fitted with a GPS radio-collar at Rocky Mountain Arsenal National Wildlife Refuge, Colorado, March 3, 2008, through April 10, 2008.

Discussion

Our study found few significant differences in either productivity or utilization among native vegetation types of the RMA bison pasture in 2007 or 2010 but did find higher productivity in areas identified as crested wheatgrass, an introduced plant type, in 2007. The 2007 data showed low overall offtake rates. The 2010 data indicated that real offtake was occurring and that in the presence of two grazers (prairie dogs and bison) total offtake increased significantly by late in the growing season compared to areas where only bison grazed. We also showed that high levels of prairie dog grazing on native forbs appears to reduce bison offtake of this functional group. Lack of greater observed differences in vegetation offtake in areas containing bison and prairie dogs compared to areas with only bison may have been because bison were not yet influencing pasture vegetation in a measurable manner by 2010. Fahnestock and Detling (2002) found similar results in mixed-grass prairie and attributed it to low stocking rates of bison. However, by 2010 the pasture was at the carrying capacity that RMA NWR personnel deemed appropriate for bison (Tom Ronning, U.S. Fish and Wildlife Service, oral commun., March 15, 2009), and the lack of demonstrated utilization effects by either bison or prairie dogs was most likely due to a loss of statistical precision resulting from our inability to stratify samples by actual vegetation cover types present in the pasture.

Several factors contributed to this study being inconclusive. An accurate vegetation map is critical to collection of accurate, precise, and representative data describing vegetation cover, productivity, and utilization and to interpretation of that data. For a variety of reasons that are beyond the scope of this report, we were unable to complete an accurate and error-free vegetation classification map. This prohibited us from executing a data collection and analysis plan that would have organized data on the vegetation classes present in the pasture. An accurate map of pasture vegetation would have allowed us to constrain our data analysis of any particular plant group to only those areas actually containing that group thus reducing the variation among biomass values for all of the plant group estimates as well as reducing the size of the confidence interval estimates. In many cases the reduction would have been large (based on a review of the number of extremely low values and zeros associated with each class in the data) and would have resulted in more precise estimates of productivity and actual offtake. Bison may have consumed significant amounts of biomass of particular vegetation types, but we were not able to demonstrate this because of the large degree of noise in the data.

Secondarily, additional and incompatible vegetation management actions (herbicide applications, burning, disking, and so forth) were conducted in the pasture while this study was underway. Several rounds of widespread herbicide applications went uncommunicated to USGS staff prior to vegetation sampling in 2010. These activities also contributed to larger confidence intervals about vegetation biomass estimates and hampered our ability to determine causal relations between bison or prairie dog grazing and observed vegetation responses.

In the future, if RMA NWR managers desire to fully understand the effects of bison grazing on pasture vegetation, then other, confounding sources of vegetation change need to be eliminated. Two of the original project goals were to evaluate bison selection among the dominant vegetation types in the pasture and to evaluate bison impacts on pasture vegetation through herbivory. Before either objective can be met, an accurate pasture vegetation map that has known levels of error needs to be completed. During the two rounds of error checking that occurred in section 34, vegetation data were collected at the species level (A. Maes, U.S. Fish and Wildlife Service, oral commun., March 4, 2008). These data and the vegetation data collected during the 2010 ground-truthing effort associated with the USGS pilot vegetation map could help dramatically improve the existing map.

It is also important to ensure that sample sizes (for both transects and exclosures) are adequate to minimize the effects of heterogeneity observed in the 2007 dataset. In both sampling years, a large number of sites had greater recorded vegetation productivity outside of the grazing cages than inside. Although the 16 sites sampled in 2007 was undoubtedly too small a sample, even sampling 80 sites—as was done in 2010—was not enough to overcome our inability to stratify by vegetation classes. An alternate method of locating or sampling cage pairs might also be considered to reduce variability and the number of locations with higher production outside of cages. At a randomly selected site, individual pairs (or trios) of sample plots could be selected based on observer determination of similarity and then randomly assigned to a treatment (caged, uncaged). Another method might be to sample several randomly selected uncaged plots near each caged plot to reduce variation of grazed-plot estimates.

To fully determine the effects of various herbivores on vegetation, then sample size and allocation of samples within vegetation types should include consideration of prairie dogs. Prairie dog towns are distinctly different from other cover types, and bison have been found to use areas around young prairie dog towns preferentially because of the predominance of perennial grasses, enhanced nitrogen content of vegetation, and lower ratios of dead to live plant material near prairie dog towns (Schwartz and Ellis, 1981; Coppock and others 1983a,b; Krueger, 1986; Cid and others, 1991). Therefore, if management goals include discriminating between the effects of prairie dogs and bison, or the effects of prairie dog presence on bison use of the landscape, then prairie dog towns will need to be considered as a separate vegetation cover type. Our limited data showed differences in bison grazing intensity (offtake) on forbs when prairie dogs were present and differences in biomass of native forbs in areas where prairie dogs were present. The increased grazing pressure in areas with bison and prairie dogs should be considered as well in the management of existing and proposed pasture areas.

Allocating samples proportionally among vegetation types will allow within-type sample sizes to represent the proportional distributions of each vegetation type in the pasture. Alternatively, focusing sampling efforts within a restricted number of target vegetation types would provide useful information on those types and is an effective sampling strategy for studies having limited resources. Assigning random sample locations in the project GIS before the field season begins—such as was done in 2010—is the most efficient and error-free way to place sampling locations. Uploading transect coordinates into handheld GPS units is the most precise way to locate them in the field, after which they may be permanently marked on-site. Also, if RMA NWR managers desire to monitor the effects of bison on shrub composition, density, abundance, and structure, then a focused shrub monitoring plan will also need to be developed.

An early objective of this study was to quantify breeding-songbird-community changes associated with bison reintroduction. The refuge collects data on these and other grassland species, but only data collected before the reintroduction of bison to the refuge was available. Continued collection of breeding-bird data both on and off the bison pasture would provide information to help determine the impacts of bison on key avian species. Another objective identified in the early stages of this research was bison habitat selection. Due to failure of one GPS collar and loss of the other, we were not able to meet this objective. This objective may be achievable, but a strong commitment to maintaining active collars on bison will be necessary so that data collection can continue without interruption. An accurate vegetation map will also be necessary before habitat availability and selection estimates can be accurately made.

Ultimately, the success of monitoring programs designed to measure herbivory effects is dependent on following study design and protocols closely and in a timely manner. We encourage RMA bison program managers to carefully consider each element described above as they continue to develop their bison management program to ensure a scientifically sound basis for determining future management actions.

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