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## EFFECTS OF EXOTIC PLANTS ON NATIVE UNGULATE USE OF HABITAT

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**Abstract:** Leafy spurge (*Euphorbia esula*), smooth brome (*Bromus inermis*), Japanese brome (*B. japonicus*), and downy brome (*B. tectorum*) are exotic plant species that dominate and displace native forage species throughout much of central North America. However, information on how exotic plant infestations affect native ungulate use of habitat is limited. We used pellet-group densities to estimate use of habitat by bison (*Bos bison*), elk (*Cervus elaphus*), and deer (*Odocoileus* spp.) during 1992–93 growing seasons within 4 exotic plant-infested and 4 comparable noninfested grassland habitats in Theodore Roosevelt National Park, North Dakota. We used twig count and twig measurement methods to estimate use of browse during summer (1992) and winter (1992–93), respectively, for both leafy spurge-infested and noninfested woodland habitats. Bison use of 2 leafy spurge-infested grassland habitats averaged 83% less than that for noninfested sites ( $P < 0.001$ ). Deer pellet-group densities, normally highest within creeping juniper (*Juniperus horizontalis*)-little bluestem (*Schizachyrium scoparium*) habitat, were reduced  $\leq 70\%$  by infestations of leafy spurge (1992,  $P = 0.035$ ; 1993,  $P = 0.002$ ). Use of brome-grass-infested grassland by bison, elk, and deer was similar to that for noninfested sites for 1992 and 1993 ( $P > 0.05$ ). Use of browse in green ash (*Fraxinus pennsylvanica*)-chokecherry (*Prunus virginiana*) habitat during summer and winter was reduced an average of 32% by infestations of leafy spurge ( $P < 0.05$ ). The reduction in native ungulate use of leafy spurge-infested sites may be attributed to lower forage production in infested sites as well as simple avoidance.

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**Key words:** bison, *Bos bison*, brome-grass, *Bromus* spp., browse, carrying capacity, *Cervus elaphus*, deer, elk, *Euphorbia esula*, exotics, habitat, leafy spurge, *Odocoileus* spp.

Exotic plant invasions often are characterized by the spread of a particular species over a large area and are usually regarded as ecologically threatening events (Hengeveld 1988). Exotic plants alter community composition and structure by influencing energy, nutrients, or water out of proportion to their biomass or apparent abundance in the community (Vitousek 1982). As exotics become established, native forage species used by ungulates may receive such a small share of available resources that they are

able to persist only at very low population levels (Cody 1986). Degradation of the native community and local extinction of preferred plant species may reduce carrying capacity of the landscape for native wildlife.

An increase in exotic plant species in Theodore Roosevelt National Park, North Dakota, generated concern about its effect on native communities. A survey conducted over 3 growing seasons identified 36 species of exotic plants in the park (Trammell 1994). The majority of the exotics were infrequent and minor components of the landscape. However, 4 species (smooth brome, Japanese brome, downy brome,

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and leafy spurge) tended to dominate and displace many native species. Lym and Messersmith (1987) reported that leafy spurge infestations can reduce carrying capacity of pastures for livestock by 50–75%, with much of this loss attributed to decreased forage production and avoidance of infested sites (Lym and Kirby 1987, Hein and Miller 1992). However, information addressing the role exotics may have on native ungulate use of habitat is limited. In this study, we tested the hypothesis that use of habitat by bison, elk, and deer was not influenced by infestations of 4 exotic plant species.

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## STUDY AREA

The 18,756-ha study area was in the South Unit of Theodore Roosevelt National Park (TRNP), North Dakota. The badlands topography of the region consisted of gullies and ravines separated by relatively large upland plateaus and small erosion-resistant buttes capped by scoria (Norland 1984). The continental climate was characterized by short, arid summers and long, cold winters. Precipitation was irregular in amount and distribution, with a long-term annual mean of 38 cm (Perrich 1992).

Vegetation of TRNP was primarily mixed-grass prairie characterized by prairie sandreed (*Calamovilfa longifolia*), needle-and-thread (*Stipa comata*), threadleaf sedge (*Carex filifolia*), western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*), and little bluestem (Whitman 1979). Cottonwood (*Populus deltoides*) forests occurred along the Little Missouri floodplain and its associated tributaries, while green ash-chokecherry woodlands dominated the upland drainages. Rocky Mountain juniper (*J. scopulorum*) was common on steep north- to northeast-facing slopes. The complex vegetational mosaic of TRNP was classified into several habitats (Whitman 1979, Hansen et al. 1984, Girard 1985, Hirsch 1985).

## METHODS

We selected 5 habitats, as identified by Hansen et al. (1984), to evaluate the effects of 4

exotic plant species on native ungulate use of habitat (Table 1). Leafy spurge infestations occurred as patches, 10–20,000 m<sup>2</sup>, throughout the silver sagebrush (*Artemisia cana*)-western wheatgrass and needle-and-thread-threadleaf sedge grassland habitats. Bromegrass infestations were similar, but more common in the western wheatgrass-threadleaf sedge habitat. We selected 10 infested sites, 100–150 m in diameter with approximately 100% foliar cover of exotic plants, within each habitat. We selected a comparable noninfested site for each infested site. Infested and noninfested sites occupied similar positions on the landscape and differed only in exotic plant infestation.

In May 1992, we established 1 permanent 2 × 100-m pellet transect within each of the 10 infested and corresponding noninfested sites. Because of the relatively small size of the creeping juniper-little bluestem habitat, we used 6 2 × 30-m pellet transects in each infested and noninfested site. We removed and counted all fecal material occurring within each transect in May, June, July, and August 1992–93. We evaluated use collectively for the 3 bromegrass species as they often occupied an infested site as a complex mosaic. Given the semiarid climate of the region, we assumed that our short count interval (approx 30 days) minimized the potential for pellet-group loss because of decomposition between sampling periods and for any differences in pellet-group persistence between infested and noninfested sites (Lehmkuhl et al. 1994).

We randomly selected 4 infested sites and 4 noninfested sites to describe vegetation of each habitat. We established a 25-m transect perpendicular to each pellet-group transect and placed quadrats (20 × 50 cm) at 1-m intervals along each transect for a total of 100 quadrats for each infested and noninfested site. We assigned each species occurring in the quadrat to a cover class: (1) 0–5%, (2) 6–25%, (3) 26–50%, (4) 51–75%, (5) 76–95%, and (6) 96–100% (Daubenmire 1959). We used the midpoint of each cover class to calculate mean foliar cover for each herbaceous species for each transect. We then used mean foliar cover values for each transect (excluding exotic plant species) to (1) calculate a mean Shannon's diversity index for infested and noninfested sites and (2) construct an  $n$  (infested transects) ×  $n$  (noninfested transects) percent similarity matrix (% similarity =  $[2W / (A + B)] \times 100$ , where  $A$  = sum of foliar



Table 1. Means and standard errors for percent similarity in species composition, Shannon's diversity index ( $H'$ ; Bray and Curtis 1957, Ludwig and Reynolds 1988), and species richness within 5 infested (exotic plants were excluded) and noninfested habitats in Theodore Roosevelt National Park, North Dakota, 1992–93. Effects of infestation on mean diversity and richness within each habitat were compared using a 2-sample  $t$ -test.<sup>a</sup>

Habitat	n	% similarity <sup>b</sup>		$H'$			Species richness		
		$\bar{x}$	SE	$\bar{x}$	SE	$P$ ( $\Delta$ )	$\bar{x}$	SE	$P$ ( $\Delta$ )
Leafy spurge infested									
Green ash-chokecherry	98	55	0.3						
Infested	7			2.59	0.04	0.26	26	1.4	0.03
Noninfested	14			2.68	0.06	(0.18)	31	0.9	
Juniper-little bluestem	16	52	0.7						
Infested	4			2.18	0.22	0.77	19	0.3	0.02
Noninfested	4			2.24	0.34	(0.79)	24	1.3	
Needle-and-thread-threadleaf sedge	16	59	0.8						
Infested	4			1.68	0.07	0.69	12	0.6	0.72
Noninfested	4			1.64	0.07	(0.41)	13	1.9	(8)
Silver sagebrush-western wheatgrass	16	62	0.8						
Infested	4			1.96	0.09	0.53	13	0.5	0.07
Noninfested	4			1.89	0.05	(0.41)	15	0.5	(3)
Bromegrass sp. infested									
Western wheatgrass-threadleaf sedge	16	63	0.6						
Infested	4			1.66	0.06	0.18	14	0.9	0.44
Noninfested	4			1.55	0.04	(0.28)	13	0.9	(5)

<sup>a</sup> Effect size ( $\Delta$ ) was estimated when  $P > 0.05$ , where effect size was the minimum detectable difference ( $\alpha = 0.05$ ,  $\beta = 0.10$ ,  $n$  = no. of transects evaluated in infested and noninfested sites; Zar 1984).

<sup>b</sup> Estimates calculated from  $n$  (infested transects)  $\times$   $n$  (noninfested transects) similarity matrix.

cover for the sampled infested site,  $B$  = sum of foliar cover for the sampled noninfested site, and  $W$  = sum of the lesser foliar cover value for those species present in both infested and noninfested sites (Bray and Curtis 1957, Ludwig and Reynolds 1988; Table 1).

In August 1991–93, we estimated peak above-ground biomass from 1 randomly selected infested site, and its corresponding noninfested site, in the needle-and-thread-threadleaf sedge (leafy spurge infested) and western wheatgrass-threadleaf sedge (bromegrass infested) habitats. We randomly placed 10 20-  $\times$  50-cm quadrats in each infested site and noninfested site within each habitat. To estimate the effect of moderate levels of infestation, we subjectively placed 10 quadrats around the periphery of each infested site so that the exotic covered approximately 50% of the quadrat. We sampled each bromegrass species separately in the western wheatgrass-threadleaf sedge habitat. We clipped biomass to ground level and separated harvested material into 3 categories: (1) exotic, (2) key forage, which included western wheatgrass, needle-and-thread, and blue grama, and (3) other. We oven-dried samples at 105 C until completely dry and then weighed them to the nearest 0.1 g.

We evaluated use of the green ash-chokecherry woodland habitat, common in upland

drainages, within 2 leafy spurge-infested and 2 noninfested drainages. We placed variable length transects (23–115 m) perpendicular to the direction of the drainage from footslope to summit at 10-m intervals (Butler et al. 1986). The number of transects (7–14) was determined by the length of the drainage. We evaluated composition of herbaceous vegetation as previously described from quadrats placed at 1-m intervals along each transect (621 quadrats for noninfested sites, 314 for infested sites). We selected the chokecherry plant nearest to the transect line at 3-m intervals, placed it into 1 of 2 height classes (1 = 30–100 cm, 2 = 101–200 cm), and then tagged it with a numbered metal tag. We chose chokecherry because it represents a major seasonal diet component of elk and deer within TRNP (Irby, L. R., C. B. Marlow, H. D. Picton, and M. G. Sullivan, Montana State Univ., Bozeman, unpubl. data). We estimated ungulate use of browse plants during summer 1992 by counting all twigs of current year's growth occurring below 2 m on each tagged plant in May 1992 (Moore and Johnson 1967). We recounted the number of browsed and unbrowsed twigs on each plant at the end of summer (late Aug) and calculated percent use by dividing the total of browsed and unbrowsed twigs. We estimated chokecherry densities by height class from 100-  $\times$  100-cm quadrats placed at 2-m intervals along



each transect (233 quadrats for noninfested sites, 131 for infested sites).

During September 1992–May 1993, we estimated use of tagged browse plants in fall and winter by measuring current year's growth at the end of the growing season (Aldous 1945, Smith and Urness 1962). In spring, we remeasured previous year's growth on each tagged plant and estimated percent use by dividing the total length of browsed twigs by the total length of browsed and unbrowsed twigs.

We used a 2-sample *t*-test to compare the effect of exotic infestation on mean diversity ( $H'$ ), species richness, and chokecherry density (PROC TTEST; SAS Inst. Inc. 1988). Because of the small sample sizes used to estimate mean  $H'$  and species richness ( $n = 4$ ), we estimated effect size ( $\Delta$ ) when  $P > 0.05$ , where effect size was the minimum detectable difference between the 2 means ( $\alpha = 0.05$ ,  $\beta = 0.10$ ; Zar 1984). We used a 2-way analysis of variance (ANOVA) procedure (PROC GLM; SAS Inst. Inc. 1988) to compare the effect of exotic infestation, year, and their interaction on pellet-group means for each species of ungulate. Because the distribution of pellet-group values resembled a Poisson distribution, we performed a square root transformation prior to analysis (Zar 1984). Monthly values between June, July, and August were similar ( $n = 10$  for each month;  $P > 0.05$ ); thus, we pooled them by year. We used ANOVA procedures (PROC GLM; SAS Inst. Inc. 1988) to compare the main effect of infestation on key forage biomass, total (native + exotic) biomass, and chokecherry density. When treatment differences ( $P < 0.05$ ) were identified, we separated means with Bonferroni *t*-tests (SAS Inst. Inc. 1988) to control the level of experimental error. We compared ungulate summer and winter use of browse between leafy spurge-infested and noninfested green ash-chokecherry sites with a Wilcoxon rank sums test.

## RESULTS

Species composition and diversity between exotic plant-infested and noninfested sites were similar (Table 1). However, native species biomass was reduced an average of 56 and 84% by moderate (50% cover of selected exotic) and heavy (100% foliar cover of selected exotic) infestations of exotic plants, respectively (Fig. 1). Biomass of key forage species averaged 77% (range 69–88%) of total biomass on noninfested sites while composing only 4% (range 1–8%) of

total biomass on heavily infested sites. With the exception of downy brome in 1991 and leafy spurge in 1993, key forage species biomass was reduced by moderate infestations of exotic plants (smooth brome,  $F = 22.80$ , 35.29, and 13.96 for 1991–93, respectively; 2, 27 df;  $P < 0.001$ ; Japanese brome,  $F = 19.67$  and 61.19 for 1991–92, respectively; 1, 18 df;  $P < 0.001$ ;  $F = 4.25$  for 1993; 1, 18 df;  $P = 0.054$ ; downy brome,  $F = 28.14$  and 23.33 for 1991–92, respectively; 1, 18 df;  $P < 0.001$ ;  $F = 7.93$  for 1993; 1, 18 df;  $P = 0.011$ ; leafy spurge,  $F = 41.77$  and 44.58 for 1991–92, respectively; 2, 27 df;  $P < 0.001$ ;  $F = 33.95$  for 1993; 2, 26 df;  $P < 0.001$ ). Total above-ground biomass (native + exotic) was higher on sites heavily infested with smooth brome ( $F = 20.13$ , 26.99, and 18.34 for 1991–93, respectively; 2, 27 df;  $P < 0.001$ ), Japanese brome ( $F = 18.29$  and 18.34 for 1991 and 1993, respectively; 2, 27 df;  $P < 0.001$ ;  $F = 7.73$  for 1992; 2, 27 df;  $P = 0.002$ ), leafy spurge ( $F = 43.20$  and 51.95 for 1991–92, respectively; 2, 27 df;  $P < 0.001$ ;  $F = 2.01$  for 1993; 2, 27 df;  $P = 0.147$ ), and downy brome ( $F = 9.74$  and 20.59 for 1991 and 1993, respectively; 2, 27 df;  $P < 0.001$ ;  $F = 3.44$  for 1992; 2, 27 df;  $P = 0.047$ ) than on noninfested sites.

Bison pellet-group densities in the leafy spurge-infested silver sagebrush-western wheatgrass habitat were 69 and 89% less than in noninfested sites for 1992 and 1993 ( $F = 51.99$ ; 1, 116 df;  $P < 0.001$ ), respectively (Table 2). Similarly, use of infested needle-and-thread-threadleaf sedge habitat averaged 86% less than that of noninfested sites for both years ( $F = 44.67$ ; 1, 116 df;  $P < 0.001$ ). Use of these 2 habitats was similar between years in infested sites ( $F = 8.43$  for silver sagebrush-western wheatgrass habitat; 1, 116 df;  $P = 0.94$ ;  $F = 3.42$  for needle-and-thread-threadleaf sedge habitat; 1, 116 df;  $P = 0.86$ ); however, pellet-group densities in noninfested sites were 100–197% greater in 1993 than 1992 ( $P = 0.001$  for silver sagebrush-western wheatgrass habitat;  $P < 0.016$  for needle-and-thread-threadleaf sedge habitat). Bison pellet-group densities between brome-grass-infested and noninfested western wheatgrass-threadleaf sedge habitat varied by year (yr  $\times$  infestation interaction,  $F = 5.73$ ; 1, 116 df;  $P = 0.018$ ); however, pellet-group densities in infested sites were similar to those in noninfested sites for 1992 ( $P = 0.119$ ) and 1993 ( $P = 0.072$ ).

Deer pellet-group densities within infested creeping juniper-little bluestem sites were 69



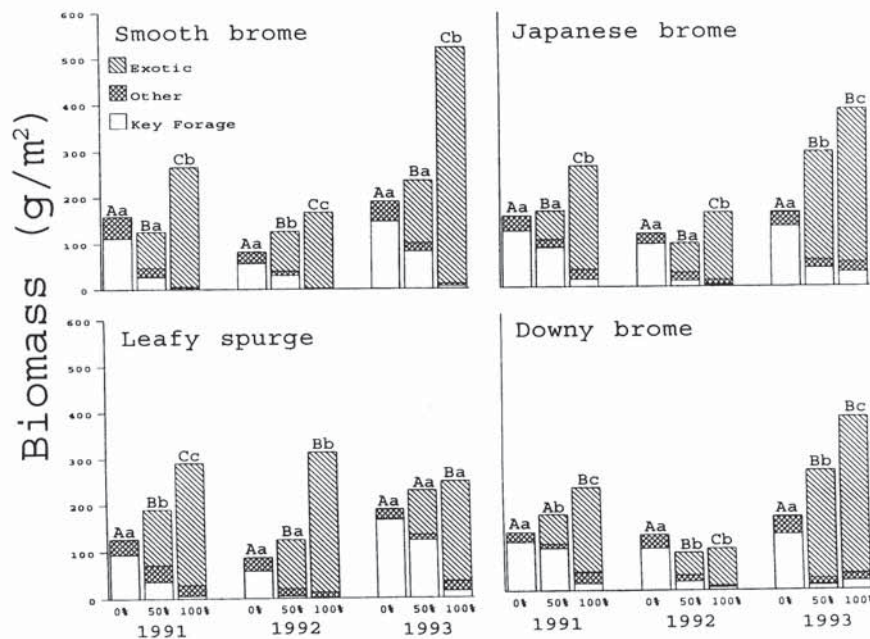


Fig. 1. Mean aboveground biomass ( $\text{g}/\text{m}^2$ ) for exotic species, key forage species (western wheatgrass, needle-and-thread, and threadleaf sedge), and other species (native species minus key forage species) at 3 levels of exotic plant infestation (0% foliar cover of exotic, 50% foliar cover of exotic, and 100% foliar cover of exotic) in a leafy spurge-infested needle-and-thread-threadleaf sedge habitat and a western wheatgrass-threadleaf sedge habitat infested with smooth brome, Japanese brome, and downy brome in Theodore Roosevelt National Park, North Dakota, 1991–93. Bars within years with different uppercase letters indicate differences in mean biomass of key forage species among levels of infestation ( $n = 10$ ,  $P < 0.05$ ). Bars within years with different lowercase letters indicate differences in total mean biomass among levels of infestation ( $n = 10$ ,  $P < 0.05$ ).

and 70% less than those in noninfested sites for 1992 and 1993, respectively ( $F = 14.60$ ; 1, 68 df;  $P < 0.001$ ). Elk pellet-group densities between infested and noninfested creeping juniper-little bluestem sites were similar ( $F = 0.25$ ; 1, 68 df;  $P = 0.615$ ). Elk pellet-group densities averaged 81% lower in infested than noninfested sites within the needle-and-thread-threadleaf sedge habitat ( $F = 7.39$ ; 1, 116 df) for 1992 ( $P = 0.059$ ) and 1993 ( $P = 0.067$ ). A similar pattern was recorded between infested and noninfested sites for 1993 in the silver sagebrush-western wheatgrass habitat ( $F = 11.09$ ; 1, 116 df;  $P < 0.001$ ).

There were differences in use of summer and winter chokecherry browse between leafy spurge-infested and noninfested sites within the green ash-chokecherry habitat (Table 3). The exception occurred within the 30–100-cm height class during summer 1992 ( $\Delta = 11.8\%$ ,  $n = 22$ ,  $\alpha = 0.05$ ,  $\beta = 0.10$ ; Zar 1984). Use of chokecherry browse (101–200 cm height class) in summer within the leafy spurge-infested sites was 33% less ( $\chi^2 = 7.77$ , 1 df,  $P = 0.005$ ) than within the noninfested site (Table 3). Similarly, use of chokecherry in winter was lower for both height

classes (30–100 cm,  $\chi^2 = 11.83$ , 1 df,  $P = 0.008$ ; 101–200 cm,  $\chi^2 = 8.80$ , 1 df,  $P = 0.004$ ) within infested sites than noninfested sites. Density of chokecherry shrubs in infested sites was 43 and 27% less than in noninfested sites for the 30–100 ( $t = 13.19$ , 362 df,  $P < 0.001$ ) and 101–200 cm ( $t = 7.69$ , 362 df,  $P < 0.001$ ) height classes, respectively.

## DISCUSSION

Ungulate use, as determined from pellet-group densities, of noninfested habitats was similar to previous research conducted within TRNP (Norland 1984; Irby et al., unpubl. data). We found no published literature that addressed potential effects of exotic plants such as leafy spurge on large, native ungulates. Previous studies focused on domestic livestock; however, we anticipated similar responses for bison, elk, and deer. Leafy spurge infestations can reduce carrying capacity of pastures for livestock 50–75% (Lym and Messersmith 1987). Much of this loss is attributed to decreased forage production of native vegetation and avoidance of infested grazing sites by cattle (Lym and Kirby 1987, Hein and Miller 1992). Leafy spurge also con-



tains a toxic substance that acts as an irritant, emetic, and purgative when taken internally (Messersmith and Lym 1983). Kronberg et al. (1993) suggested that cattle avoid leafy spurge because they develop a conditioned aversion to it after initially ingesting some threshold amount. Leafy spurge has been reported to cause scours in cattle that may result in death (Selleck et al. 1962). The toxin also has produced inflammation and loss of hair on the feet of horses who walked in freshly mowed stubble in leafy spurge-infested areas (Kingsbury 1964).

Western wheatgrass, needle-and-thread, and blue grama, which normally compose 43% of the yearly diets of bison within TRNP (Norland 1984), were reduced by moderate and heavy infestations of leafy spurge. These 3 species also contribute 18% to the annual diets of elk in TRNP (Irby et al., unpubl. data). Although less pronounced than in bison, reduced biomass and avoidance may also explain patterns in elk use.

Deer pellet-group densities, normally highest within the creeping juniper-little bluestem habitat were reduced by leafy spurge infestations. This habitat generally occurs on relatively steep (25% slope) north-facing slopes throughout the badlands. Creeping juniper is a low-growing shrub that often forms a dense mat of vegetation <30 cm high (Miller 1978). Although little bluestem and threadleaf sedge were the dominant herbaceous species on infested and noninfested sites (Trammell 1994), they compose a small percentage of deer diets in the region (McKean 1954; Irby et al., unpubl. data). Therefore, this habitat likely serves as a lounging area for deer during summer, and avoidance of leafy spurge-infested sites may be due to toxins.

In general, bison pellet-group densities between brome-grass-infested and noninfested sites were similar despite higher biomass in infested than noninfested sites. Further, peak above-ground biomass of brome-grass was higher in 1993 than 1992. However, Norland (1984) and Irby et al. (unpubl. data) found that, collectively, Japanese brome, downy brome, and smooth brome compose only 3% of the yearly diets of bison and elk within TRNP. Bison often decrease use of cool season brome-grasses late in the growing season as they become less palatable (Reid 1942, Stewart and Hull 1949, Klemmedson and Smith 1964). Thus, bison use of brome-grass infestations appears to be dependent upon seasonal quality, rather than quantity, of forage production.

Table 2. Mean number of pellet groups (no./ha) and standard errors by ungulate species sampled during the 1992–93 growing seasons within 4 habitats infested and noninfested with exotic plant species in Theodore Roosevelt National Park, North Dakota.

Species	Habitat <sup>a</sup>											
	JU			AR			ST			AG		
	1992 (n = 16)	1993 (n = 18)	1993 (n = 30)	1992 (n = 30)	1993 (n = 30)	1993 (n = 30)	1992 (n = 30)	1993 (n = 30)	1993 (n = 30)	1992 (n = 30)	1993 (n = 30)	1993 (n = 30)
Bison												
Infested	9 <sup>b</sup>	9	9.3	27A	8.2	28A	8.5	10A	4.4	6.3	62	10.1
Noninfested	0	18	12.7	87B	11.2	258C	46.9	60B	11.1	25.0	92	12.0
Elk												
Infested	46	28	15.1	0A	0.0	2A	1.7	3	2.3	2.3	2A	1.7
Noninfested	37	65	30.5	2A	1.7	20B	5.7	15	4.9	7.3	3A	2.3
Deer												
Infested	46A	65A	19.7	7	3.1	7	3.1	0A	0.0	1.7	10	3.7
Noninfested	148B	222B	42.6	17	4.3	20	7.8	2A	1.7	9.2	17	4.9

<sup>a</sup> JU = leafy spurge-infested creeping juniper-little bluestem habitat, AR = leafy spurge-infested silver sagebrush-western wheatgrass habitat, ST = leafy spurge-infested needle-and-thread-threadleaf sedge habitat, AG = brome-grass sp.-infested western wheatgrass-threadleaf sedge habitat.

<sup>b</sup> Means within an ungulate species and habitat followed by the same letter or no letter are not different (Bonferroni *t*-test,  $P > 0.05$ ), using ANOVA on transformed data (model:  $\sqrt{x + 3/8}$  = infestation/yr; Zar 1984).



Table 3. Means and standard errors for density (no./m<sup>2</sup>) and percent ungulate use by height class of chokecherry shrubs during summer 1992 (twig-count method) and winter 1992–93 (twig-measurement method) in leafy spurge-infested and noninfested green ash-chokecherry habitats, Theodore Roosevelt National Park, North Dakota.

Height	Density (no./m <sup>2</sup> )			% use					
				Summer			Winter		
	n	$\bar{x}$	SE	n	$\bar{x}$	SE	n	$\bar{x}$	SE
30–100 cm									
Infested	131	0.7	0.03	32	21.8	1.93	32	19.1	1.25
Noninfested	233	1.3 <sup>a</sup>	0.03	16	26.2	3.06	16	32.5 <sup>a</sup>	2.50
100–200 cm									
Infested	133	0.7	0.03	25	22.6	1.37	25	22.0	2.62
Noninfested	131	1.0 <sup>a</sup>	0.03	32	34.0 <sup>a</sup>	1.62	32	34.7 <sup>a</sup>	1.47

<sup>a</sup> Indicates differences ( $P < 0.05$ ) between infested and noninfested sites within like height classes and seasons.

We found differences in use in leafy spurge-infested and noninfested sites for 1 height class of chokecherry shrubs in summer 1992 and for both height classes during winter 1992–93 within green ash-chokecherry habitat. McKean (1954) and Irby et al. (unpubl. data) listed chokecherry as a major seasonal diet component for elk and mule deer in the area. High use of chokecherry compared with other selected species is probably a result of its abundance and nutritional qualities (Aipperspach 1980). A reduction in use of leafy spurge-infested green ash-chokecherry habitats can probably be attributed to combined effects of avoidance and reduced density of chokecherry shrubs.

Ungulate use increased in most noninfested sites from 1992 to 1993. Peak aboveground production of native plant species was higher in 1993, a period of above average precipitation and below average temperatures, than in 1992 when temperature and precipitation were below average (Trammell 1994). The increase in forage production may be responsible for the concentration of ungulates within noninfested sites during the 1993 growing season. Frank and McNaughton (1992) reported that forage consumption by large herbivores in Yellowstone National Park was positively correlated with site aboveground production. Their results also indicated that as production of a landscape patch increases, so too does consumption at a constant rate per unit area of productivity. In addition, ungulate fecal deposition was positively and linearly correlated to production and consumption (Frank and McNaughton 1992).

If the number of sites infested with leafy spurge and brome grass increase and become less productive for ungulates, the overall carrying capacity of TRNP may be reduced. Lym and Kirby (1987) reported that leafy spurge infes-

tations caused cattle to increase use of noninfested sites, which decreased preferred herbage species, decreased species diversity, and improved conditions for invasion of undesirable plant species, such as leafy spurge. Thus, a reduction in carrying capacity because of exotic plant infestation may result in overgrazing and overbrowsing of many sites considered exotic free, thereby creating a possible invasion point from surrounding infested sites and accelerating the invasion process.

## MANAGEMENT IMPLICATIONS

Exotic plants could influence wildlife habitat by displacing forage species, modifying habitat structure, or changing species interactions within the ecosystem (Belcher and Wilson 1989, Bedunah 1992). Consequently, managers should be aware of the exotic plant species that might occur in their area and recognize potential interactions. An inventory of exotic plant species occurring in an area will assist in making decisions concerning their possible effects on wildlife or wildlife habitat. Adjustments in wildlife population densities may be needed to reduce habitat degradation of habitats free of exotic plants because of the reduction in forage or avoidance of exotic plant-infested habitats. This may reduce the effect of exotic plant species that rely on disturbance such as overgrazing or overbrowsing as a mechanism for spreading (Bazzaz 1986).

Attempts at controlling leafy spurge with herbicides have produced mixed results. The plant is difficult and expensive to control with conventional methods, which has limited the approach to areas of high productivity. Alternative approaches have centered on biological insect control (Pecora et al. 1989, Gagne 1990, Gassman and Shorthouse 1990) and behaviorally en-



couraging lambs and goats to preferentially graze on leafy spurge (Walker et al. 1992). Heavy infestations of brome grass can be reduced, at least temporarily, with burning in spring (Whisenant and Uresk 1990, Masters et al. 1992).

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## FECAL MEASURES OF DIET QUALITY IN WILD AND DOMESTIC RUMINANTS

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**Abstract:** Fecal indices of diet quality are often used to assess diet quality in free-ranging ungulates, but the nutritional attribute fecal indices measure, the mechanism by which it is measured, and the assumptions involved are seldom considered. I developed an algebraic model relating apparent digestibility (DIG) of diets to endogenous and dietary sources of fecal components. This model predicted that if the ratio of metabolic fecal products to dry matter intake (MFP : DMI) is constant, and a fecal measure indexes MFP, then (1) the fecal index will measure DIG, (2) the relationship between DIG and the fecal index will be curvilinear and asymptotic, and (3) other nutritional characteristics of the diet will be indexed only to the extent that they are correlated with DIG. I used published data from domestic sheep and cattle to test the model assumption that MFP : DMI was constant and to test model predictions for percent fecal nitrogen (FN). Variation in MFP : DMI was partitioned into random variation and that related to apparent indigestibility (INDIG;  $r^2 = 0.46$ ,  $P < 0.001$ ). Variation in MFP : DMI related to INDIG slightly altered the expected curvature of the relationship between DIG and fecal measures, whereas remaining random variation influenced the resolution of that relationship. Domestic sheep and cattle on grass diets had the predicted curvilinear relationship between DIG and FN. Also, curvilinear relationships between DIG and FN were similar between domestic sheep fed grass and alfalfa diets, despite different ( $P < 0.001$ ) intercepts. In contrast, slopes of the relationships between dietary N and FN for domestic sheep differed ( $P < 0.001$ ) between grass and alfalfa diets, with little overlap between the 2 forage groups, supporting the prediction that dietary N is not indexed directly by FN. Reduced protein digestibility from dietary tannins will confound the relationship between DIG and FN because increased forage N in FN reduces the ability of FN to index MFP. Other potential fecal indices may be less influenced by tannins. I recommend using a natural log transformation of fecal measures that index MFP to linearize their relationship with DIG. The model provides a conceptual framework for additional research relative to fecal measures of diet quality.

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**Key words:** diet quality, digestibility, fecal indices, fecal nitrogen, ruminant nutrition.

Diet quality is fundamentally important to the population ecology of free-ranging wild ruminants, but its measure has been problematic. Fecal indices of diet quality are particularly

attractive because they are easy to sample and inexpensive, but their interpretation remains uncertain. Investigations of fecal indices of diet quality began in the late 1940s, when FN was