Prescribed Sheep Grazing to Suppress Spotted Knapweed on Foothill Rangeland

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Abstract

Spotted knapweed (*Centaurea biebersteinii* DC.) is a perennial, invasive forb that infests millions of hectares of private and public rangelands in western North America. Previous research indicates that domestic sheep (*Ovis aries*) readily graze spotted knapweed, but landscape-scale prescriptive grazing of spotted knapweed has not been studied. We quantified the diets and forage utilization of a ewe–lamb band (about 800 ewes and 1 120 lambs) that prescriptively grazed spotted knapweed–infested foothill rangeland in western Montana in the summers of 2003 and 2004. In mid-June or mid-July, sheep grazed light and moderate infestations of spotted knapweed (13% and 36% of vegetative composition, respectively). Nutritive quality of sheep diets was similar to sheep grazing uninfested rangeland, and sheep exhibited few forage preferences or avoidances. Sheep diets averaged 64% spotted knapweed in the moderate infestation and 26% in the light infestation. Sheep in the light infestation ate fewer graminoids in June than July (17% vs. 55% of their diet, respectively; $P = 0.04$), whereas sheep in the moderate infestation ate fewer graminoids in July (45% in June vs. 20% in July; $P = 0.09$). In the moderate infestation, relative utilization of spotted knapweed was greater in July than June (50% vs. 35%, respectively; $P = 0.04$), but averaged 46% in the light infestation. Previous research suggests that these levels of relative utilization may make herbicide application uneconomical. Relative utilization of graminoids was light in both infestations (15% in June or 31% in July). Our results indicate that sheep can prescriptively graze light or moderate spotted knapweed infestations in either June or July. Sheep consumption and relative utilization of graminoids will be less if light infestations are grazed in June rather than July. In moderate infestations, sheep will eat fewer graminoids and utilize spotted knapweed more heavily when grazed in July rather than June.

Resumen

El "Spotted knapweed" (*Centaurea biebersteinii* DC.) es una hierba perenne invasora que infesta millones de hectáreas de pastizales públicos y privados del oeste de Norte América. Investigación previa indica que los ovinos domésticos (*Ovis aries*) apacientan fácilmente el "Spotted knapweed", pero el apacentamiento prescrito de esta especie a nivel de paisaje no ha sido estudiado. Cuantificamos las dietas y utilización del forraje de un hato de ovejas y corderos (800 ovejas y 1 200 corderos) que apacentaron en forma prescrita, durante los veranos del 2003 y 2004, un pastizal de piedemonte infestado de "Spotted knapweed" en del oeste de Montana. A mediados de junio y mediados de julio los ovinos apacentaron infestaciones ligeras y moderadamente de "Spotted knapweed" (13% y 36% de la composición botánica, respectivamente). La calidad nutritiva de dieta de los ovinos fue similar apacentando pastizales infestados y no infestados, y los animales presentaron pocas preferencias de forrajes o rechazos. Las dietas promediaron 64% de "Spotted knapweed" en la infestación moderada y 26% en la infestación ligera. Los ovinos en la infestación ligera comieron menos gramíneas en junio que en julio (17 vs. 55% de su dieta, respectivamente; $P = 0.04$), mientras que los ovinos en la infestación moderada consumieron menos gramíneas en julio (45% en junio vs. 20% julio; $P = 0.09$). En la infestación moderada, la utilización relativa del "Spotted knapweed" fue mayor en julio que en junio (50% vs. 35%, respectivamente; $P = 0.04$), pero promedio 46% en la infestación ligera. La investigación previa sugiere que estos niveles de utilización relativa pueden hacer que la aplicación de herbicidas no sea económica. La utilización relativa de las gramíneas fue ligera en ambos niveles de infestación (15% en junio o 31% en julio). Nuestros resultados indican que los ovinos pueden apacentar en forma prescrita infestaciones ligeras o moderadas de "Spotted knapweed" tanto en junio como en julio. El consumo de los ovinos y la utilización relativa de las gramíneas será menor si las infestaciones ligeras se apacientan en junio en lugar de julio. En infestaciones moderadas, los ovinos comerán menos gramíneas y utilizaran más el "Spotted knapweed" si se apacientan en julio que en junio.

Key Words: *Centaurea*, Montana, *Ovis aries*, prescribed livestock grazing, targeted livestock grazing, weeds

INTRODUCTION

Spotted knapweed (*Centaurea biebersteinii* DC.) is an invasive, perennial forb introduced to the Pacific Northwest from Eurasia during the late 1800s (Watson and Renney 1974). Spotted knapweed is an aggressive competitor that can form large monocultures, not only in disturbed areas, but also on pristine rangeland (Tyser and Key 1988; Lacey et al. 1990). These monocultures reduce species richness (Tyser and Key

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1988) and available forage for livestock and wildlife (Watson and Renney 1974), and increase surface-water runoff and soil erosion (Lacey et al. 1989). Once restricted to the Pacific Northwest, spotted knapweed now infests every county in Montana, Idaho, Wyoming, and Washington (Sheley et al. 1998), and inhabits every state, except Alaska, Georgia, Mississippi, Oklahoma, and Texas (United States Department of Agriculture 2004). In Montana alone, spotted knapweed infests more than 1.5 million ha (Montana Weed Summit Steering Committee 2005), and knapweeds (including spotted knapweed, diffuse knapweed [*Centaurea diffusa* Lam.], and Russian knapweed [*Acroptilon repens* (L.) DC.]) cause annual losses of greater than $42 million to Montana's economy in direct and indirect costs (Hirsch and Leitch 1996).

Greenhouse clipping studies indicate that four defoliations of 50% relative utilization during the growing season effectively reduce carbohydrate concentrations and pools in spotted knapweed stems, crowns, and roots (Lacey et al. 1994) and negatively affect root growth, crown size, and total aboveground production (Kennett et al. 1992). A single 75% relative utilization clipping treatment during the bolting stage also reduces vigor and standing crop of spotted knapweed (Kennett et al. 1992; Lacey et al. 1994; Walling and Zabinski 2006). A field study by Newingham and Callaway (2006) found that two defoliations (early June + early July) of 50% relative utilization each did not decrease total aboveground production of spotted knapweed, although this clipping regime more than doubled the rate of spotted knapweed mortality during one hot, dry summer. When only a single treatment is possible, mowing during the flowering or seed-producing stage may suppress spotted knapweed (Rinella et al. 2001). Grazing spotted knapweed with domestic livestock offers another means of defoliation that may provide a cost-effective alternative for landowners and an economic return for livestock producers (Lacey 1987). Prescribed livestock grazing may be more cost effective than herbicides when spotted knapweed utilization by livestock reaches 30% on high-producing sites (herbage yield = 680 $kg \cdot ha^{-1}$) and 15% on low-producing sites (herbage yield = 318 $kg \cdot ha^{-1}$; Griffith and Lacey 1991).

Spotted knapweed is a nutritious livestock and wildlife forage, particularly early in the growing season (Kelsey and Mihalovich 1987; Wright and Kelsey 1997; Olson and Wallander 2001; Hale 2002). Domestic sheep (*Ovis aries*) graze spotted knapweed, even in the presence of other high-quality forage (Olson et al. 1997; Olson and Wallander 2001; Hale 2002) and it is also eaten by cervids (Wright and Kelsey 1997). Preliminary results from Launchbaugh and Hendrickson (2001) indicate that grazing spotted knapweed during its rosette stage reduces flower production, and grazing during its flowering stage reduces seed-head production.

These results are encouraging, but prescriptive grazing of spotted knapweed has not been studied on a landscape scale. Further, some land managers have expressed concerns about the quantity of graminoids that sheep may consume while grazing in spotted knapweed infestations. Our objective was to evaluate sheep diets and forage utilization when prescriptive grazing was applied in mid-June or mid-July to light and moderate infestations of spotted knapweed on foothill rangeland in western Montana. We hypothesized that sheep would eat more spotted knapweed in July when other forbs and graminoids are typically less green and moist than in June.

METHODS

Study Area

We conducted our study on two foothill grassland sites in western Montana, one with a light infestation of spotted knapweed and one with a moderate infestation. The two study areas were located 5 km east of Helmville, Montana (lat 46°98′N, long 113°05′W) at about 1 400-m elevation. Both study areas are a rough fescue (*Festuca campestris* Rydb.)/ bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve subsp. *spicata*) habitat type (Mueggler and Stewart 1980). Soils are very deep, well-drained, and include Shawmut cobbly loam (loamy–skeletal, mixed, superactive, frigid Typic Argiustolls), Danvers clay loam (fine, smectitic, frigid Vertic Argiustolls), and Roy gravelly loam (clayey–skeletal, mixed, superactive, frigid Typic Argiustolls) on an alluvial fan (United States Department of Agriculture 2003). The 28-yr average annual precipitation is 317 mm, with 56% occurring as rain between May and September, as reported at the nearest weather station, 5.9 km SSE of Ovando, Montana (lat 46°53′N, long 113°03′W; Western Regional Climate Center 2004). Average maximum and minimum temperatures are 21.9° and 3.7°C in June and 26.4° and 5.3°C in July, respectively. The study was conducted during a 7-yr drought. In June 2003 and 2004, average daily temperatures were normal (13°C), but precipitation was 25% below normal. Average daily temperature was 3°C above normal in July 2003, whereas precipitation was 84% below normal. In July 2004, average daily temperature was 1°C above normal with 41% of normal precipitation (National Climate Data Center 2004a, 2004b; Western Regional Climate Center 2004).

Vegetation was similar at both study areas except for the level of spotted knapweed infestation. The light infestation yielded 122 $kg \cdot ha^{-1}$ of spotted knapweed, whereas the moderate infestation yielded 295 $kg \cdot ha^{-1}$ (13% and 36% of vegetative composition, respectively), as quantified by clipping (see data-collection methods below) immediately before the grazing treatments were applied in mid-June 2003. The light infestation was located within a 65-ha pasture and the moderate infestation was located in an adjacent 115-ha pasture. Spotted knapweed was the dominant forb on both study areas. Common dandelion (*Taraxacum officinale* G.H. Weber ex Wiggers), western yarrow (*Achillea millefolium* L.), yellow salsify (*Tragopogon dubius* Scop.), lupine (*Lupinus* spp. L.), and wild onion (*Allium* spp. L.) were also present. Dominant graminoids included bluebunch wheatgrass, Idaho fescue (*Festuca idahoensis* Elmer), green needlegrass (*Nassella viridula* [Trin.] Barkworth), and Sandberg bluegrass (*Poa secunda* J. Presl). Mountain big sagebrush (*Artemisia tridentata* Nutt. subsp. *vaseyana* [Rydb.] Beetle) was the principal shrub in the area.

Treatments

A commercial Targhee ewe–lamb band (about 800 ewes and 1 120 lambs) prescriptively grazed the spotted knapweed infestations. The grazing prescription was for sheep to graze specific sites within the infestations until perennial graminoids were reduced to a 5–8-cm residual stubble height. Grazing to the prescribed residual stubble height was intended to average about 55% utilization across the dominant graminoid species (Taylor and Lacey 1999). This prescription was intended to attain maximum use of spotted knapweed while limiting adverse impacts to perennial graminoids. Sheep grazed the light and moderate spotted knapweed infestations in June or July for 2 yr (2003, 2004). Ewes weighed 70–80 kg and were accompanied by their lambs that had been born in early to mid-April of each year.

When prescriptive grazing was applied in mid-June, perennial grasses were at the five–six-leaf stage and spotted knapweed was bolting. When prescriptive grazing was applied in mid-July, perennial grasses were in the soft dough stage and spotted knapweed was in the late bud/early flowering stage. Six 15 × 25 m sites (i.e., experimental units) were identified per level of infestation (light, moderate). To ensure that sites were independent, a minimum distance of 20 m was maintained between all 12 sites. Month of sheep grazing (June, July) was randomly assigned to each of the six sites per level of infestation (three sites per month × infestation combination). The three sites in each infestation that were prescriptively grazed in June were temporarily fenced to exclude sheep during the July treatment, and the three sites in each infestation that were prescriptively grazed in July were temporarily fenced to exclude sheep during the June treatment. During the grazing treatments, sheep were herded within the infestations to achieve the desired stubble height in each 15 × 25 m site. In all months and years, the light infestation was grazed first, followed immediately by the moderate infestation. Each infestation was grazed for 1 or 2 d, so that all six sites per month × infestation combination were treated within 2–4 d each year. Cattle grazed both infestations in late May each year; the June sheep grazing treatment began 21 d later. Each year before entering the study areas, the sheep were acclimated for 7 d on adjacent spotted-knapweed–infested rangeland to become familiar with the topography and forage in the study areas.

Data Collection and Laboratory Analyses

Immediately before and after the sheep grazing treatments, current year's plant standing crop was clipped within five 1-m^2 quadrats per site. According to Mueggler (1976), five quadrats of 0.45-m^2 are adequate for measuring total plant standing crop in rough fescue/bluebunch wheatgrass habitat types in Montana. Quadrats were spaced at 4-m intervals along a 20-m transect in each site. Postgrazing transects were located 3 m away, parallel to pregrazing transects. To ensure that the same quadrat locations were not clipped more than once, stakes remained in place until new transects were established. All clipped samples were separated by life form (perennial graminoids, forbs, shrubs), except spotted knapweed was separated from other forbs. Spotted knapweed leaves were manually removed from the stems, resulting in six vegetation classes (perennial graminoids, shrubs, spotted knapweed leaves, spotted knapweed stems, total spotted knapweed, and other forbs). Each vegetation class was weighed and analyzed separately. All clipped samples were dried in a forced-air oven at 55°C for 48 h prior to weighing. Differences in standing crop between the pre- and postgrazing clipped samples were attributed to sheep grazing. Botanical composition of sheep diets was estimated from the clipped samples (Holechek et al. 1982). The percentage of the diet comprised by each vegetation class was calculated by dividing the pre- and postgrazing difference in weight of each vegetation class by the total pre- and postgrazing difference in plant standing crop. Relative utilization (Frost et al. 1994) was estimated from clipped samples using the actual weight (or difference) method (Smith et al. 1963). Relative utilization was calculated for each vegetation class by dividing the pre- and postgrazing difference in weight by the pregrazing weight of the vegetation class. Our methods for quantifying the botanical composition of sheep diets and forage utilization were well-suited for sites like ours, where grazing periods were brief, utilization was relatively uniform, utilization was primarily by one herbivore, and regrowth was not important (Smith et al. 1963; Holechek et al. 1982).

Pregrazing samples were ground in a Wiley mill to pass a 1-mm screen. Ground samples were analyzed for crude protein (CP = %N × 6.25; Association of Official Analytical Chemists 2003), neutral detergent fiber (NDF), and acid detergent fiber (ADF; Van Soest et al. 1991) to estimate nutritive value of sheep diets and available forage. Dietary CP, dietary NDF, and dietary ADF were calculated following Urness and McCulloch (1973), whereby percent diet composition of each vegetation class was multiplied by its percent nutritive value, and these products were then summed for each nutritive variable (CP, NDF, ADF).

Relative preference indices (RPI) were used to evaluate sheep diet selection for each vegetation class. Preference or avoidance for each vegetation class was determined by dividing the percent composition in sheep diets by its presheep grazing percent composition in each site's plant standing crop (Krueger 1972).

Statistical Analyses

Data from the light infestation and moderate infestation were analyzed separately. The 15 × 25 m sites were the experimental units to which prescribed sheep grazing was applied. Experimental design was a split-plot in time, with prescribed sheep grazing applied in two different months (June, July) in 2 yr (2003, 2004). Month was the whole-plot factor and year was the subplot factor. Within each infestation, the grazing treatments were replicated in time (2003, 2004), but the band of sheep ($n = 1\,920$ sheep) was not replicated in space. That is, the three experimental units in each month × infestation combination were grazed simultaneously by one band of sheep, rather than grazed by three separate bands of sheep. Unreplicated studies are appropriate if the statistical inferences drawn are limited to the particular study areas (Wester 1992).

With the use of the Generalized Linear Model procedure of SAS (SAS Institute 2004), analysis of variance was used to examine the main effects of month, year, and their interaction on botanical composition and nutritional content of sheep diets, as well as the relative utilization of the plant standing crop. Differences were considered significant at $P \leq 0.10$ or $P \leq 0.05$. Sheep did not eat any shrubs, thus the percent browse in sheep diets and the relative utilization of shrubs were not

Table 1. Botanical composition of sheep diets (± SE) within light and moderate levels of spotted knapweed infestation on foothill rangeland in western Montana.[1]

Infestation level	Vegetation class	2003 June	2003 July	2004 June	2004 July	Mean June	Mean July
		(%)					
Light	Graminoids	25 (12.4)	62 (3.0)*	9 (5.7)	47 (2.5)**	17 (7.1)	55 (3.9)**
	Forbs	50 (28.9)	15 (3.4)	52 (27.0)	38 (2.2)	51 (17.7)	27 (5.5)
	Knapweed stems	7 (5.6)	12 (0.8)	5 (4.4)	4 (1.9)	6 (3.2)	8 (2.0)
	Knapweed leaves	18 (14.8)	11 (1.4)	35 (26.1)	11 (2.1)	27 (13.9)	11 (1.1)
	Total knapweed	25 (20.3)	23 (0.7)	40 (30.5)	15 (1.2)	32 (16.7)	19 (1.8)
Moderate	Graminoids	49 (24.7)	28 (10.8)	41 (9.8)	13 (10.2)	45 (12.0)	20 (7.5)*
	Forbs	0 (0.0)	10 (4.1)**	3 (2.2)	0 (0.1)	2 (1.2)	5 (2.8)[2]
	Knapweed stems	10 (9.9)	20 (13.1)	3 (2.4)	38 (6.7)**	7 (4.8)	29 (7.6)*
	Knapweed leaves	41 (30.3)	42 (6.2)	52 (8.7)	49 (3.7)	47 (14.3)	46 (3.6)
	Total knapweed	51 (24.7)	62 (10.9)	56 (9.1)	87 (10.1)*	53 (11.8)	75 (8.7)

[1]Means within rows, within main headings, differ if followed by * ($P \leq 0.10$) or ** ($P \leq 0.05$).
[2]Month × year interaction ($P \leq 0.10$).

included in the analyses. Percent data were arcsine transformed to better approximate normal distributions of residuals (Kuehl 2000). The UNIVARIATE procedure of SAS (SAS Institute 2004) was used to test residuals for deviation from normality with the use of the Shapiro-Wilkes test. For those variables whose normality was not improved ($P > 0.10$), the formula $\log(\sigma_i) = \log(\alpha) + \beta \log(\mu_i)$ was used to estimate empirically the appropriate power transformation, equal to $1 - \beta$ (Kuehl 2000). Diet composition of forbs had zero values for several observations; therefore, a small constant, $c = 0.16$, was added to all observations to prevent evaluating a logarithm for 0 (Mosteller and Tukey 1977). Means and standard errors presented in text and tables are from untransformed data.

Relative preference indices were evaluated with confidence intervals calculated per Hobbs and Bowden (1982) to determine whether forage preference or avoidance was significant at $\alpha = 0.10$ or $\alpha = 0.05$. When confidence intervals did not include 1.0, RPI > 1.0 indicated preference, whereas RPI < 1.0 indicated avoidance.

RESULTS

Botanical Composition of Sheep Diets

In the light infestation, grazing in June versus July did not affect the amount of spotted knapweed in sheep diets ($P > 0.10$), with total spotted knapweed averaging 26% of their diet (Table 1). Other forbs were a major component of sheep diets in the light infestation, averaging 39% across June and July. Sheep in the light infestation ate more graminoids in July rather than June (55% vs. 17% of sheep diets, respectively; $P = 0.04$).

In the moderate infestation, sheep ate more spotted knapweed stems in July than June (29% vs. 7% of sheep diets, respectively; $P = 0.09$), and in 2004 total spotted knapweed comprised 87% of sheep diets in July versus 56% in June ($P = 0.08$; Table 1). Overall, in the moderate infestation, sheep diets in June and July averaged 64% total spotted knapweed. Other forbs were a minor component of sheep diets in the moderate infestation, never comprising more than 10%. Sheep in the moderate infestation ate fewer graminoids in July than in June (20% vs. 45% of sheep diets, respectively; $P = 0.09$).

Relative Forage Preferences

Sheep exhibited very few forage preferences or avoidances. In the light infestation, sheep avoided graminoids ($\alpha = 0.10$) in both June and July 2004 (RPI = 0.2 and RPI = 0.7, respectively), and in the moderate infestation sheep avoided forbs ($\alpha = 0.10$) in June 2003 and July 2004 (RPI = 0.0 and RPI = 0.1, respectively). The magnitude of these few avoidances was small, given how near the RPI values were to 1.0. Sheep did not prefer or avoid any other vegetation classes in June or July in either the light or moderate infestation.

Nutritive Quality of Sheep Diets

As expected, nutritive quality of sheep diets was greater in June than July (Table 2). This seasonal decline occurred in both light and moderate infestations. Diet CP averaged 14%–15% in June versus 9% in July. Diet NDF was generally < 40% in June and > 40% in July. Diet ADF was generally < 25% in June and ≥ 25% in July.

Relative Utilization of Available Forage

In the light infestation, relative utilization of total spotted knapweed did not differ between June and July ($P > 0.10$), averaging 46% (Table 3). Relative utilization of other forbs in the light infestation was higher in July than in June (63% vs. 14%, respectively; $P < 0.01$). Relative utilization of graminoids in the light infestation was higher in July than June in both years ($P \leq 0.05$), but relative utilization was very light to light, averaging 5% in June and 39% in July.

In the moderate infestation, relative utilization of total spotted knapweed was greater in July than June (50% vs. 35%, respectively; $P = 0.05$). In 2003, relative utilization of other forbs in the moderate infestation was higher in July ($P \leq 0.01$), but there was no difference between months in 2004 ($P = 0.30$). In 2004, relative utilization of graminoids in the

Table 2. Nutritive quality of sheep diets (± SE) within light and moderate levels of spotted knapweed infestation on foothill rangeland in western Montana.[1]

Infestation level	Nutritive variable	2003		2004		Mean	
		June	July	June	July	June	July
		(%)					
Light	Diet CP	14 (0.5)	9 (0.4)**	17 (2.4)	10 (0.2)**	15 (1.3)	9 (0.3)**
	Diet NDF	37 (3.1)	50 (0.6)**	32 (5.5)	45 (0.6)*	35 (3.0)	48 (1.1)**
	Diet ADF	25 (1.3)	28 (0.1)*	22 (3.6)	25 (0.6)	23 (1.8)	27 (0.8)
Moderate	Diet CP	15 (1.3)	8 (0.5)**	13 (1.1)	10 (0.6)**	14 (0.8)	9 (0.5)[2]
	Diet NDF	41 (7.1)	41 (0.8)	37 (2.6)	43 (0.7)	39 (3.5)	42 (0.6)
	Diet ADF	24 (2.3)	26 (1.7)	21 (0.9)	25 (0.5)**	22 (1.3)	26 (0.8)**

[1]Means within rows, within main headings, differ if followed by * ($P \leq 0.10$) or ** ($P \leq 0.05$). CP indicates crude protein; NDF, neutral detergent fiber; and ADF, acid detergent fiber.
[2]Month × year interaction ($P \leq 0.10$).

moderate infestation was higher in June than July ($P = 0.09$), but there was no difference between months in 2003 ($P = 0.16$). Relative utilization of graminoids in the moderate infestation never exceeded 37%.

DISCUSSION

Sheep Diets

Botanical composition of sheep diets largely reflected forage availability, as indicated by few RPI values greater than or less than 1.0. For example, in the light infestation in July, where graminoids comprised a large proportion of the standing crop and when most forbs had desiccated and were no longer available, sheep diets were 55% graminoids (Table 1). But in the moderate infestation, where graminoids comprised less of the standing crop, sheep ate 20% graminoids during July (Table 1). Grazing to the prescribed residual stubble height in the light infestation may have further encouraged or forced sheep to consume more graminoids during July. A taller stubble height guideline in light infestations may be appropriate to reduce graminoid consumption.

The amount of total spotted knapweed (leaves and stems combined) in sheep diets also reflected forage availability. Sheep diets in the moderate infestation contained 2.5 times more total spotted knapweed than sheep diets in the light infestation (64% and 26%, respectively; Table 1), reflecting the relative amounts of spotted knapweed in the two infestation levels (36% and 13% of the standing crop, respectively).

The amount of graminoids in sheep diets from the moderate infestation (45% in June, 20% in July; Table 1) followed a trend similar to sheep diets from a spotted knapweed infestation in southeastern Idaho (Hale 2002) where the proportion of graminoids in sheep diets was lower in July than June. However, sheep in our study ate fewer forbs and more total spotted knapweed. We suspect the spotted knapweed may have been more palatable on our foothill grassland sites in western Montana than on the sagebrush steppe site in southeastern Idaho.

Table 3. Relative utilization of herbaceous standing crop (± SE) within light and moderate levels of spotted knapweed infestation on foothill rangeland in western Montana.[1]

Infestation level	Vegetation class	2003		2004		Mean	
		June	July	June	July	June	July
		(%)					
Light	Graminoids	6 (4.4)	55 (4.8)**	4 (2.8)	22 (7.1)*	5 (2.4)	39 (8.2)[2]
	Forbs	12 (6.5)	75 (1.8)**	17 (16.7)	51 (9.0)	14 (8.1)	63 (6.8)**
	Knapweed stems	31 (27.1)	57 (12.4)	35 (20.8)	20 (9.9)	33 (15.3)	38 (10.9)
	Knapweed leaves	30 (26.6)	87 (2.9)*	49 (22.3)	62 (3.2)	40 (16.1)	74 (5.9)
	Total knapweed	30 (26.7)	68 (8.7)	46 (23.9)	40 (4.6)	38 (16.4)	54 (7.6)
Moderate	Graminoids	14 (6.9)	37 (10.4)	36 (8.5)	10 (6.1)*	25 (7.0)	23 (8.0)[2]
	Forbs	0 (0.0)	88 (1.3)**	39 (23.1)	6 (5.3)	19 (13.5)	47 (18.5)[2]
	Knapweed stems	8 (8.2)	26 (15.0)	23 (16.4)	45 (9.9)	15 (8.8)	36 (9.0)
	Knapweed leaves	10 (7.8)	74 (5.7)**	67 (6.9)	69 (4.2)	39 (13.6)	76 (3.3)[2]
	Total knapweed	10 (4.2)	44 (11.8)**	59 (8.8)	56 (7.8)	35 (11.7)	50 (6.8)**

[1]Means within rows, within main headings, differ if followed by * ($P \leq 0.10$) or ** ($P \leq 0.05$).
[2]Month × year interaction ($P \leq 0.10$).

Sheep in our moderate infestation preferred spotted knapweed leaves in July, which follows general foraging tendencies that indicate sheep prefer leaves to stems (Buchanan et al. 1972) and young plant tissue over more mature plant tissue (Arnold 1981). In a cafeteria trial that offered sheep dried plant material that had been harvested 1 yr earlier, sheep tended to prefer spotted knapweed rosettes to either bolting or flowering spotted knapweed plants, but this preference was not consistent (Hale 2002). Olson and Wallander (2001) observed that when sheep ate spotted knapweed they removed developing flower heads and leaves from stems, avoided consuming stems, and tended to prefer smaller, younger spotted knapweed plants rather than large, mature ones. Our RPI values did not indicate avoidance or preference of spotted knapweed stems by sheep. The nutritive value of stems in our study (Thrift 2005) was much higher than reported by Olson and Wallander (2001), which may explain why our RPI values did not indicate avoidance of spotted knapweed stems.

Dietary CP in June was 14%–15% (Table 2) and satisfied the protein requirement of 70-kg lactating ewes during the first 6–8 wk of lactation suckling singles or twins (National Research Council 2007). Dietary CP in July (8–10%; Table 2) also satisfied the protein requirement of 70-kg lactating ewes during the last six to eight weeks of lactation (National Research Council 2007). On uninfested tall forb range in southwestern Montana, sheep consumed 14% dietary CP in June and 8% dietary CP in July (Buchanan et al. 1972). Our dietary NDF values for sheep in July compare favorably with Hale (2002), but sheep diets in June were much less fibrous in our study. We suspect the forage in June was more advanced phenologically on the sagebrush steppe site of Hale (2002) than on our foothill grassland sites. Dietary ADF in our study averaged 25%, but generally increased from June to July (Table 2). Buchanan et al. (1972) reported similar sheep dietary ADF values (i.e., 22% in June and 26% in July) on tall forb rangeland in southwestern Montana that was not infested with spotted knapweed.

Forage Utilization

Our sheep grazing prescription averaged very light to light relative utilization of graminoids (4%–37% relative utilization), except in the light infestation under very hot and dry conditions in July 2003 when relative utilization of graminoids reached 55% (Table 3). Graminoid utilization levels of 40%–60% annually are sustainable on foothill rangelands in western Montana (Lacey and Volk 1993; Lee-Campbell 1999).

Relative utilization of total spotted knapweed plants (stems and leaves combined) averaged 45%. This level exceeds the 30% utilization level predicted by Griffith and Lacey (1991) as a threshold whereby herbicide application would not be cost-effective on productive sites (i.e., sites where herbage yield $\geq$ 680 $kg \cdot ha^{-1}$). In 2003, relative utilization of spotted knapweed leaves was less in June than July (30% vs. 87% in the light infestation and 10% vs. 74% in the moderate infestation, respectively), but averaged 62% in June and July 2004. Although the sheep were acclimated to the site for 7 d each year, June 2003 was their first exposure to spotted knapweed, which may account for the lower relative utilization of spotted knapweed leaves in June 2003. It is unknown whether the levels of spotted knapweed defoliation achieved in our study (i.e., 43% relative utilization in the light infestation and 35%–50% in the moderate infestation) during mid-June (bolting stage) or mid-July (late bud/early flowering stage) were sufficient to reduce the vigor, yield, or viable seed production of spotted knapweed. In a greenhouse, a single 75% relative utilization clipping during the bolting stage reduced the vigor and standing crop of spotted knapweed, but a single 25% relative utilization clipping during the bolting stage did not (Kennett et al. 1992; Lacey et al. 1994).

Relative utilization of total spotted knapweed plants in our study (35%–50%) was generally less than the levels reported by Hale (2002), which ranged from 36% to 85%. However, the high levels of spotted knapweed utilization in Hale (2002) were accompanied by heavy to severe utilization of native forbs (73%–87% relative utilization) and moderate to heavy utilization of native grasses (48%–71% relative utilization), which may have at least partially offset the benefits of sheep defoliating spotted knapweed.

MANAGEMENT IMPLICATIONS

Domestic sheep can be used to defoliate spotted knapweed when prescription grazing is applied on a landscape scale. Although sheep did not preferentially select spotted knapweed, they readily included it in their diets, even when other desirable forage was available. Ewes were able to meet their CP requirements throughout summer and consumed a diet similar in nutritive quality to sheep grazing uninfested rangeland. Relative utilization of spotted knapweed averaged 43% in the light infestation and 35%–50% in the moderate infestation. Previous research by Griffith and Lacey (1991) indicates that these levels of relative utilization may make the use of herbicides uneconomical.

In moderate infestations, where forbs other than spotted knapweed are less available, the presence of graminoids is more important to enable sheep to balance their diets. If graminoids are limiting in moderate infestations, managers may need to graze sheep in light spotted knapweed infestations or uninfested areas before moving into moderate or heavy infestations to allow sheep to vary their diet and buffer any toxic effects, as described by Freeland and Janzen (1974) and Provenza et al. (2007).

Relative utilization of graminoids was very light to light in either June or July, except in the light infestation under exceptionally hot and dry conditions. Based on our results, light and moderate spotted knapweed infestations can be prescriptively grazed in either June or July. When consumption of graminoids is a concern, light infestations could be grazed in June when sheep consume fewer graminoids. In moderate infestations, sheep will utilize spotted knapweed more heavily and will eat fewer graminoids when prescriptively grazed in July rather than June. Further research is needed to examine other management alternatives to reduce graminoid consumption by sheep in spotted knapweed infestations. Possible alternatives include 1) reducing available graminoids by grazing cattle immediately before or simultaneously with sheep, 2) allowing more than 3 wk between when cattle and sheep grazing occurs to allow graminoids to mature further and decline in palatability, 3) delaying sheep grazing until after graminoids reach the mature seed stage (late July), 4) using a taller residual stubble height guideline for graminoids in the grazing prescription, or 5) using a grazing prescription guideline based on removal of spotted knapweed flowers rather than residual stubble height of graminoids.

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