

SUMMER DIETS OF SHEEP GRAZING SPOTTED KNAPWEED-INFESTED
FOOTHILL RANGELAND IN WESTERN MONTANA

by

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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 spotted knapweed is nutritious and readily grazed by domestic sheep (*Ovis aries*), but no studies have investigated prescription grazing of spotted knapweed within different levels of infestation or on a landscape scale. This two-year study quantified the diets of a ewe-lamb band ($n \approx 800$ ewes, 1120 lambs) that prescriptively grazed spotted knapweed-infested foothill rangeland in western Montana. Sheep grazed within light and moderate infestations of spotted knapweed (13% and 36% of vegetative composition, respectively) until perennial grasses were reduced to a 5 to 8-cm residual stubble height. Diets were estimated in mid-June and mid-July by clipping current year's standing crop immediately before and after grazing. Clipped samples were analyzed for CP, NDF, and ADF to estimate nutritive quality. Relative preference indices were calculated to evaluate diet selection by sheep. Sheep ate more spotted knapweed in moderate versus light infestations (64 vs. 26% of their diets, respectively; $P < 0.01$), and spotted knapweed averaged 45% of sheep diets between June and July ($P = 0.61$). Within light infestations, sheep ate fewer graminoids in June than July (17 vs. 55% of their diet, respectively; $P < 0.01$). Sheep diets in moderate infestations averaged 33% graminoids regardless of month ($P = 0.18$). Sheep did not select for graminoids in light infestations in June, but did select for spotted knapweed leaves in moderate infestations during July. Nutritive quality of sheep diets was similar to sheep grazing uninfested rangeland. Relative utilization of graminoids averaged 15%, except under exceptionally hot and dry weather conditions. Relative utilization of spotted knapweed averaged 45%. Previous research suggests that this level of spotted knapweed utilization may render herbicide application uneconomical. My results indicate that sheep can prescriptively graze moderate spotted knapweed infestations in either June or July, but to limit graminoid consumption, light infestations should be grazed in June vs. July.

CHAPTER 1

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 extremely aggressive competitor that is capable of forming 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 1988) and available forage for livestock and wildlife (Watson and Renney 1974), and increase surface water runoff, soil erosion, and sediment yield (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 is distributed through every state, except Alaska, Georgia, Mississippi, Oklahoma, and Texas (USDA 2004). In Montana alone, spotted knapweed infests more than 1.5 million ha (MWSSC 2005) causing annual losses of greater than \$42 million to Montana's economy in direct and indirect costs (Hirsch and Leitch 1996).

Attempts to control spotted knapweed typically involve an integrated approach that includes herbicides, biological controls, or both. Eleven species of insects have been released to suppress spotted knapweed (Sheley et al. 1998). The insects reduce seed production and also improve opportunities for infection by fungal and bacterial pathogens (Sheley et al. 1998). Spotted knapweed can be effectively controlled on rangelands by applying picloram, clopyralid, dicamba, or 2,4-D (Sheley et al. 1999), but the high cost of

treating large acreages, need for frequent re-treatment, and increasing environmental concerns often limit the feasibility of treating large infestations.

Greenhouse clipping studies indicate that monthly 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). When only a single treatment is possible, mowing during the flowering or seed producing stage has been recommended to help suppress spotted knapweed (Rinella et al. 2001). Grazing spotted knapweed with domestic livestock offers another means of defoliation that may also provide a cost-effective alternative for landowners and an economic return for livestock producers (Lacey 1987). Griffith and Lacey (1991) predicted that prescribed livestock grazing would be more cost-effective than herbicides when spotted knapweed utilization by livestock reached 30% on high-producing sites (herbage yield = 680 kg ha⁻¹) and 15% on low-producing sites (herbage yield = 318 kg ha⁻¹).

Spotted knapweed is a nutritious livestock and wildlife forage, particularly early in the growing season (Kelsey and Mihalovich 1987, 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. 1997b, Olson and Wallander 2001, Hale 2002) and it is also used by wildlife (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 seedhead production.

These results are encouraging, but no studies have investigated prescription grazing of spotted knapweed within different levels of infestation or on a landscape scale. Additionally, some land managers have expressed concerns about the quantity of grass sheep will consume while grazing spotted knapweed. Therefore, the objective of this study was to investigate the influence of month (June vs. July) and level of spotted knapweed infestation (light vs. moderate) on the relative utilization of available vegetation, and the botanical composition and nutritive quality of sheep diets in a commercial ewe-lamb band prescriptively grazing foothill rangeland in western Montana. Sheep dietary preference for each vegetation class was also evaluated.

CHAPTER 2

LITERATURE REVIEW

Spotted Knapweed

Spotted knapweed is a perennial forb introduced to western North America during the late 1800s (Watson and Renney 1974). Spotted knapweed seeds were introduced as contaminants in alfalfa (*Medicago sativa* L.) and in the ballast discarded from ships (Sheley et al. 1998). Morphological features of spotted knapweed include alternate, divided leaves, black-tipped bracts, and purple flowers (Watson and Renney 1974). The scientific name of spotted knapweed, *Centaurea biebersteinii* DC., follows USDA (2004). However, Ochsmann (2001) suggests that spotted knapweed found in North America has been misidentified and that based on morphological and molecular differences, the correct scientific name is *Centaurea stoebe* L. ssp. *micranthos* (Gugler) Hayek.

Several characteristics of spotted knapweed give it a competitive advantage over native and other introduced species. Spotted knapweed seizes available resources by germinating early, growing rapidly, and allocating resources to above ground biomass (Sheley et al. 1993). It reproduces vegetatively and is a prolific seed producer, producing over 400 seeds plant⁻¹ on rangeland sites and up to 40,000 seeds m⁻² (Watson and Renney 1974). Seed production by spotted knapweed plants in northern Idaho averaged up to 29,600 seeds m⁻², which Shirman (1981) noted was 1,000 times the seed required to maintain the stand at the level he observed, although the level of infestation was not

quantified. Seed production is greatly increased in wet years and on irrigated sites (Watson and Renney 1974, Shirman 1981).

Spotted knapweed seeds are capable of germinating under a broad range of environmental conditions (Watson and Renney 1974), but may also remain dormant in the soil seedbank for many years. After 8 years of dormancy, 25% of buried seeds remain viable (Davis et al. 1993). Animals may also contribute to seed dispersal by transporting seeds externally, or by ingesting them. Twenty-two percent of spotted knapweed seeds may remain viable after passing through the digestive tracts of sheep (Wallander et al. 1995). One percent of spotted knapweed seeds recovered from the pellets of great horned owls (*Bubo virginianus*) that had consumed deer mice (*Peromyscus maniculatus*), which ingested seeds while foraging for gall fly larvae on spotted knapweed plants, remain viable (Pearson and Ortega 2001).

Spotted knapweed also synthesizes cnicin, a sesquiterpene lactone, that is bitter tasting to livestock (Kelsey and Locken 1987). Cnicin also has anti-microbial properties that reduce rumen microbial activity when diet composition of spotted knapweed exceeds 70% (Olson and Kelsey 1997), which may inhibit digestion. Cnicin is found in spotted knapweed stems and leaves, and its levels increase to about 1% early in the growing season where they remain through the summer months (Locken and Kelsey 1987). These traits may deter ruminants from grazing spotted knapweed (Kelsey and Locken 1987). Herbivores attempt to reduce the negative effects of secondary compounds by selecting different types of plants in varying proportions which act to buffer their digestive system (Freeland and Janzen 1974). Although some secondary compounds (e.g., tannins,

terpenoids, and cyanogenic glycosides) deter herbivory, administering these secondary compounds to lambs with feed does not always deter grazing and, depending on the protein and energy content of the diet, may actually increase consumption of the feed (Villalba et al. 2002).

Cnicin also has allelopathic potential, but the allelopathic effects depend on environmental and biological conditions (Locken and Kelsey 1987). Another secondary compound secreted from the roots of spotted knapweed, ($\pm$)-catechin, also appears to have phytotoxic and antimicrobial properties at naturally occurring concentrations. The (–)-catechin enantiomer can inhibit germination and root growth of nearby plants (Bais et al. 2003, Weir et al. 2003, Veluri et al. 2004), whereas (+)-catechin negatively affects some root-colonizing fungi (Veluri et al. 2004).

The prolificacy of spotted knapweed, combined with its grazing deterrents and allelopathic potential, enable it to invade disturbed and pristine rangelands. Spotted knapweed is often found along roads, trails, waste areas, and overgrazed rangelands (Watson and Renney 1974). Although a climax rough fescue (*Festuca campestris* Rydb.) community studied by Lacey et al. (1990) was fairly resistant to spotted knapweed invasion, Tyser and Key (1988) reported spotted knapweed invading fescue grasslands within Glacier National Park. While livestock had not grazed these areas, wildlife and rodent burrowing activity likely facilitated the spread of seeds and creation of colonization sites (Tyser and Key 1988).

Once established, dense stands of spotted knapweed reduce species richness and water infiltration and increase soil erosion. As stem densities of spotted knapweed

increase, species richness and the frequency of many other species decline (Tyser and Key 1988). Lacey et al. (1989) observed 56% greater runoff and 192% more sediment yield in spotted knapweed-dominated plots than in bunchgrass-dominated plots. In addition to environmental degradation, spotted knapweed infestations cost Montana's economy more than \$42 million in direct and indirect costs annually (Hirsch and Leitch 1996). Spotted knapweed infestations decrease available livestock and wildlife forage by reducing the yield of more desirable forage species (Watson and Renney 1974, Sheley et al. 1998). Other studies, however, report that spotted knapweed is grazed by sheep (Olson et al. 1997b, Olson and Wallander 2001, Hale 2002), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), and white-tailed deer (*Odocoileus virginianus*) (Wright and Kelsey 1997).

Sheep for Weed Control

A fundamental consideration when designing a prescription grazing plan is selecting the appropriate species of animal to achieve the desired results. Sheep are well-suited for weed control applications because of their morphology and dietary preferences. Large ruminants, such as cattle (*Bos taurus*), are able to digest lower quality forages because they can retain plant material for a longer period of time than smaller ruminants (Allison 1985, Huston and Pinchak 1991). Thus, smaller ruminants (e.g., sheep and goats (*Capra hircus*)) typically select more digestible forages than cattle because they do not have the ability to retain the forage for the length of time necessary to digest all of the nutrients (Hofmann 1993). Forbs are usually higher in crude protein (CP) and lower in

neutral detergent fiber (NDF) and acid detergent fiber (ADF) than grasses (Holechek 1984).

Sheep are selective grazers (Hofmann 1993) and typically consume a mixed diet of forbs, grasses and some shrubs. Their preference for forbs over grasses or shrubs (Hanley 1982) makes sheep ideal for broad-leaved weed control. Sheep also have a smaller body size, relative to cattle, and narrow muzzles and cleft upper lips that enable them to be more discriminating than cattle when selecting plant parts (Arnold and Dudzinski 1978). The decline of the sheep industry in the United States from 1945 to the present may have contributed to the rapid expansion of many rangeland weeds (Olson 1999).

Sheep have been successfully used to prescriptively graze many weedy species. Leafy spurge (*Euphorbia esula* L.) infestations reduce forage use by cattle (Hein and Miller 1992) and affect habitat use patterns by bison (*Bison bison*), deer, and elk (Trammell and Butler 1995). However, sheep can consume up to 50% of their diet as leafy spurge (Lacey et al. 1984, Landgraf et al. 1984) and lambs have higher average daily gains than when grazing uninfested grass pastures (Bartz et al. 1985). Selective grazing by sheep during the growing season for 5 consecutive years decreased the basal area of leafy spurge 98% (Johnston and Peake 1960).

Prior experience grazing leafy spurge results in greater consumption by lambs and yearling ewes, compared with naïve sheep (Walker et al. 1992, Olson et al. 1996), but differences in consumption between experienced and naïve yearlings disappear within 3 weeks of exposure to leafy spurge (Olson et al. 1996). Sheep grazing leafy spurge-

infested pastures for 3 consecutive summers resulted in 65% fewer viable leafy spurge seeds in the seedbank versus a 45% reduction in ungrazed areas (Olson and Wallander 1998). Leafy spurge seedling densities were also lower in grazed versus ungrazed areas (534 vs. 800 seedlings m⁻², respectively) with minimal effects to the cool season native grasses (Olson and Wallander 1998). Similar to spotted knapweed, sheep can pass a small percentage of viable seeds through their digestive systems, possibly spreading leafy spurge to uninfested areas (Lacey et al. 1992, Olson et al. 1997a). Lacey and Sheley (1996) reported that applying picloram in combination with prescribed sheep grazing reduced leafy spurge stem densities more than either treatment individually.

Cattle are extremely susceptible to poisoning by larkspur (*Delphinium* spp. L.), whereas, sheep are less vulnerable. Sheep prescriptively grazing mountain rangelands infested with waxy larkspur (*D. glaucescens* Rydb.) removed or negatively affected 71-100% of the plants, thereby reducing the likelihood that cattle would consume larkspur (Alexander 1989). In a similar study, Ralphs et al. (1991) reported that sheep grazed 14-73% of waxy larkspur flower heads. Duncetop larkspur (*D. occidentale* (S. Wats.) S. Wats. (pro sp.) [*barbeyi* × *glaucum*]) was grazed by sheep throughout the summer and utilization of plants was 85-98% (Ralphs et al. 1991). Utilization of tall larkspur (*D. barbeyi* (Huth) Huth) by sheep varied depending on stage of growth, but was highest during the bud and flowering stages (Ralphs et al. 1991).

Cattle avoid high densities of oxeye daisy (*Leucanthemum vulgare* Lam.), which reduces cattle carrying capacities of infested pastures (Olson and Wallander 1999).

However, sheep graze oxeye daisy under intensively managed rotational grazing and continuous grazing treatments (Norman 1957).

Fringed sagewort (*Artemisia frigida* Willd.) is considered poor to fair forage for cattle and often increases under heavy cattle grazing (Stubbendieck et al. 1997). Spang (1954) reported that sheep grazing winter range in Montana utilized 60% of fringed sagewort (*Artemisia frigida* Willd.), despite it comprising less than 1% of the available vegetation.

Tansy ragwort (*Senecio jacobaea* L.) contains alkaloids that cause liver damage in cattle, horses (*Equus caballus*), and goats, but prescription grazing of tansy ragwort-infested plots simultaneously by sheep and cattle resulted in only 2% of the plants flowering versus 40% in plots grazed only by cattle (Sharrow and Mosher 1982). Additionally, the intense defoliation by sheep resulted in fewer seeds produced per flowering plant. Sutherland et al. (2000) reported that lambs raised in tansy ragwort-infested pastures removed more ragwort than naïve lambs initially, but both groups removed 60% after 12 weeks.

Prescribed sheep grazing has also been examined as a tool for controlling perennial pepperweed (*Lepidium latifolium* L.), dense clubmoss (*Selaginella densa* Rydb.), and yellow starthistle (*Centaurea solstitialis* L.). Allen et al. (2001) found that repeated grazing resulted in a 78% reduction in the number of perennial pepperweed plants without seriously affecting other vegetation. Intensive sheep grazing also reduced basal cover and vigor of dense clubmoss on Montana rangelands (Van Dyne and Vogel

1967), and repeated sheep grazing reduced biomass, canopy size, and seed production of yellow starthistle on California annual grasslands (Thomsen et al. 1993).

Forage Quality of Spotted Knapweed

The forage quality of spotted knapweed throughout the growing season has been documented by several sources. Early in the growing season, perennial plants briefly use carbohydrate reserves from their roots to generate new photosynthetic material (Donart 1969, Menke and Trlica 1981). During this time, spotted knapweed plants are nutritious and highly digestible. Spotted knapweed plants collected in May contained 18% CP, 24% NDF, and 25% total non-structural carbohydrates (TNC) (Kelsey and Mihalovich 1987). In addition to high digestibility and nutrient content of spotted knapweed early in the growing season, cnicin levels may be at their lowest (0.5 to 0.9%) during this stage of development (Kelsey and Mihalovich 1987, Locken and Kelsey 1987), which may not deter herbivory.

Once an adequate amount of photosynthetic material is present, the carbohydrates produced via current photosynthesis are used to support further shoot and root growth and reproduction, and to replenish the plant's reserves (Brown 1984). In June, spotted knapweed forage quality is lower (9% CP, 27% NDF, 25% TNC) than May and cnicin concentrations are slightly higher (1.0 to 1.2%) (Kelsey and Mihalovich 1987, Locken and Kelsey 1987). Analyzed separately during June, forage quality of spotted knapweed leaves (13% CP, 22% NDF, and 21% ADF) was higher than stems (5% CP, 57% NDF, and 46% ADF) (Olson and Wallander 2001). Cnicin concentrations were also higher in

spotted knapweed leaves than stems (3.4 vs. 0.7%, respectively) in June (Olson and Kelsey 1997).

After native grasses enter dormancy, spotted knapweed remains photosynthetically active and is able to absorb water and nutrients through its deep root system (Watson and Renney 1974). The nutritive quality of spotted knapweed plants collected in July averaged 7% CP, 44% NDF, and 12% TNC in Idaho sagebrush steppe (Launchbaugh and Hendrickson 2001), whereas spotted knapweed leaves and stems analyzed in July contained 9% CP, 24% NDF, 23% ADF, and 3% CP, 61% NDF, 47% ADF, respectively, in Montana grassland (Olson and Wallander 2001). In July, cnicin concentrations in spotted knapweed plants remain around 1.0% (Locken and Kelsey 1987), but mature plants have produced cnicin concentrations ranging from 3.9% in leaves to 0.1% in stems (Olson and Kelsey 1997).

In August, spotted knapweed nutritive quality declines slightly further, yielding 6% CP, 47% NDF, and 19% TNC (Kelsey and Mihalovich 1987), while cnicin concentrations may range from 0.7 to 1.0% (Locken and Kelsey 1987).

Prescription Grazing of Spotted Knapweed

An important component of a prescription grazing program is to determine the most suitable time to graze the target species, without seriously impacting desirable species (Gillen and Scifres 1991, Olson 1999). The prospect of using sheep for prescription grazing of spotted knapweed infestations has been evaluated in several

small-scale studies (Olson et al. 1997b, Olson and Wallander 2001, Hale 2002), and these studies have examined sheep diets during early, mid, and late summer.

In southwestern Montana, Olson et al. (1997b) studied 5 yearling ewes grazing within 0.1-ha pastures infested with spotted knapweed. Depending on forage availability, pastures were grazed for 5 to 7 days in June, 2 to 6 days in July, and 1 to 2 days in September for 3 consecutive years. Stocking rates were 0.2 to 1.7 AUM ha⁻¹. These treatments had minimal effect on native grasses, but negatively impacted spotted knapweed in grazed versus ungrazed areas by reducing the proportion of young plants and the number of seeds in the soil. Sheep did not consistently select spotted knapweed over Idaho fescue (*Festuca idahoensis* Elmer.), but appeared to prefer younger (< 3 years old) spotted knapweed plants and rosettes, apparently because of their greater palatability and digestibility (Olson and Wallander 2001).

Hale (2002) measured forage utilization and diet quality of mature, dry ewes grazing in 0.07-ha spotted knapweed-infested pastures at low and high stocking rates (1.2 and 2.0 AUM ha⁻¹, respectively). Sheep utilized greater than 38% of spotted knapweed regardless of season or stocking rate and spotted knapweed comprised about 49% of sheep diets (Hale 2002). Spotted knapweed utilization was highest in July, during the bolting stage (Hale 2002). Preference for spotted knapweed plants at different phenological stages was also evaluated in a cafeteria trial using 12 mature ewes (Hale 2002). Ewes were simultaneously offered dried, chopped spotted knapweed plants in rosette, bolting, and flowering stages. Ewes consumed spotted knapweed plants from

each phenological stage, but generally preferred rosettes to bolting plants, followed by flowering plants (Hale 2002).

CHAPTER 3

MATERIALS AND METHODS

Study Area

The study area was located 5 km east of Helmville, Montana (46°98' N 113°05' W) at about 1400 m elevation. The ecological site is a Silty, 380 to 480-mm Precipitation Zone in the Foothills and Mountains area (USDA 2003), and is classified as a rough fescue (*Festuca campestris* Rydb.)/bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve ssp. *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 (USDA 2003). The 28-year 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 (46°53' N 113°03' W) (WRCC 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.

Dominant grass species included Idaho fescue, bluebunch wheatgrass, green needlegrass (*Nassella viridula* (Trin.) Barkworth), and Sandberg bluegrass (*Poa secunda* J. Presl). The dominant forb was spotted knapweed. 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. Mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle) was the principal shrub present within the study area.

Treatments

This study quantified the diet of a commercial Targhee ewe-lamb band ($n \approx 800$ ewes, 1120 lambs) prescriptively grazing spotted knapweed-infested foothill rangeland. The grazing prescription was for sheep to graze each site until perennial grasses were reduced to a 5 to 8-cm residual stubble height, which took from 1 to 2 days each in June or July. Grazing to the prescribed residual stubble height was intended to average about 55% utilization across the dominant graminoid species (Taylor and Lacey 1999) in the study area. This prescription was intended to attain maximum use of spotted knapweed while limiting adverse impacts to perennial graminoids.

Ewes weighed 70-80 kg and were accompanied by 2-month-old lambs in June of each year. Sheep grazed within 2 different levels of spotted knapweed infestation (light, moderate), during 2 different months (June, July), for 2 years (2003, 2004). Level of infestation was defined by current year's standing crop of spotted knapweed in June 2003. Lightly-infested patches yielded 122 kg ha^{-1} of spotted knapweed in June 2003, while moderately-infested patches yielded 295 kg ha^{-1} (13% and 36% of vegetative composition, respectively; Table 1). Density of spotted knapweed plants did not differ between infestations, averaging 23 plants m^{-2} in June 2003 ($P=0.18$).

Table 1. Current year's standing crop ($\pm$ SEM) of perennial graminoids, forbs, and spotted knapweed within light and moderate infestations, in June and July of 2003 and 2004.

Year	Lifeform	Infestation	June	July
			----- (kg ha ⁻¹) -----	
2003	Graminoids	Light	630 $\pm$ 35 a ¹ A ²	1170 $\pm$ 55 bA
		Moderate	510 $\pm$ 113 aA	505 $\pm$ 50 aB
	Forbs	Light	174 $\pm$ 8 aA	206 $\pm$ 43 aA
		Moderate	24 $\pm$ 10 aB	94 $\pm$ 40 aA
	Spotted knapweed	Light	122 $\pm$ 36 aA	363 $\pm$ 72 bA
		Moderate	295 $\pm$ 48 aB	1179 $\pm$ 169 bB
2004	Graminoids	Light	502 $\pm$ 59 aA	919 $\pm$ 118 bA
		Moderate	494 $\pm$ 60 aA	613 $\pm$ 117 aA
	Forbs	Light	277 $\pm$ 17 aA	307 $\pm$ 41 aA
		Moderate	28 $\pm$ 14 aB	71 $\pm$ 32 aB
	Spotted knapweed	Light	77 $\pm$ 23 aA	162 $\pm$ 52 aA
		Moderate	393 $\pm$ 48 aB	1213 $\pm$ 171 bB

¹Means within rows, within infestations, followed by the same lowercase letter did not differ ($P>0.01$).

²Means within columns, within lifeforms, followed by the same uppercase letter did not differ ($P>0.01$).

The mid-June grazing treatment occurred when perennial grasses were at the 5 to 6-leaf stage and spotted knapweed was bolting. The mid-July grazing treatment occurred during the soft dough stage for perennial grasses and the late bud/early flowering stage for spotted knapweed. Six, 15 x 25-m patches (i.e., experimental units) were identified within each level of infestation (light, moderate). To ensure that patches were independent, a minimum distance of 20 m was maintained between all 12 patches. Month of sheep grazing (June, July) was randomly assigned to each patch (3 patches for each season $\times$ infestation combination). The 6 moderately-infested patches were located in one, 115-ha pasture and the 6 lightly-infested patches were located in an adjacent 65-ha pasture. Cattle grazed each pasture in late May and the June sheep grazing treatment

began 21 days later. Before entering the research pastures, the sheep were provided a 7-day acclimation period in adjacent pastures to become familiar with the topography and forage in the study area each year. During each grazing treatment, sheep were herded to independently achieve the desired stubble height in each 15×25 -m patch.

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 patch. According to Mueggler (1976), 5 quadrats are adequate for measuring 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 patch. Post-grazing transects were located 3 m from, and parallel to, the pre-grazing transects. To ensure that the same quadrat locations were not clipped more than once, stakes were left in place until new transects were established. All clipped samples were separated by vegetation class (perennial graminoids, forbs, and shrubs), with spotted knapweed samples kept separate from other forbs. Spotted knapweed leaves were manually removed from the stems and each component was weighed and analyzed separately. All clipped samples were dried in a forced-air oven at $55\text{ }^{\circ}\text{C}$ for 48 hours prior to weighing. Differences in standing crop between the pre- and post-clipping were attributed to grazing by the sheep and were also used to calculate relative utilization (Frost et al. 1994) of each vegetation class.

Pre-grazing samples were ground in a Wiley mill to pass a 1-mm screen. Ground samples were analyzed for crude protein ($\text{CP} = \%N \times 6.25$) (AOAC 2000), neutral

detergent fiber (NDF), and acid detergent fiber (ADF) (Van Soest et al. 1991) to estimate nutritive value of sheep diets and available forage. Percent CP, NDF, and ADF in sheep diets was calculated following Urness and McCulloch (1973), whereby the percent diet composition of each forage class was multiplied by its nutritive value and these products were then summed.

Relative preference indices (RPI) were used to evaluate sheep diet selection for each lifeform. Preference or avoidance was determined by dividing each lifeform's percent composition in sheep diets by its percent composition in the infestations (Krueger 1972). Values of RPI greater or less than 1 signified preference or avoidance, respectively, whereas RPI values equal to 1 indicated neither preference nor avoidance.

Statistical Analyses

The experiment utilized a 2-factor split-plot in time design with 2 different levels of spotted knapweed infestation (light, moderate), during 2 different months of use (June, July), for 2 years (2003, 2004). Infestation level and month were whole plot factors and year was the sub-plot factor. Using the GLM procedure of SAS (SAS 2002), analysis of variance (ANOVA) was used to examine the main effects of month, level of infestation, year, and their interactions on botanical composition and nutritional content of sheep diets, as well as the nutritional value and relative utilization of the standing crop (Table 2). Differences were considered significant at $P \leq 0.10$.

Percent data were arcsine transformed to stabilize variances and better approximate normal distribution of residuals (Kuehl 2000). The UNIVARIATE

procedure of SAS (SAS 2002) was used to test residuals for deviation from normality using 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 empirically estimate 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).

Table 2. Analysis of variance table with sources of variation and degrees of freedom for the 2-factor split-plot in time.

Source	df
Month	1
Infestation	1
Month $\times$ Infestation	1
Whole plot error	8
Year	1
Year $\times$ Month	1
Year $\times$ Infestation	1
Year $\times$ Month $\times$ Infestation	1
Subplot error	8
Total	23

Confidence intervals for RPI were calculated per Hobbs and Bowden (1982) to determine whether preference or avoidance was statistically significant ($P=0.10$).

The null hypotheses tested were:

1. Botanical composition (graminoids, forbs, shrubs, spotted knapweed stems, spotted knapweed leaves, and total spotted knapweed plants) of sheep diets did not differ between levels of infestation, months, and years.

2. Forage preferences (graminoids, forbs, shrubs, spotted knapweed stems, spotted knapweed leaves, and total spotted knapweed plants) of sheep did not differ between levels of infestation, months, and years.
3. Nutritive quality (CP, NDF, and ADF) of available vegetation did not differ between levels of infestation, months, and years.
4. Nutritive quality (CP, NDF, and ADF) of sheep diets did not differ between levels of infestation, months, and years.
5. Relative utilization of available forage (graminoids, forbs, shrubs, spotted knapweed stems, spotted knapweed leaves, and total spotted knapweed plants) did not differ between levels of infestation, months, and years.

CHAPTER 4

RESULTS

This study occurred during a 7-year drought. Winter and Spring 2003 were characterized by near normal temperatures and precipitation. Winter and Spring 2004 had above-average temperatures with below-normal precipitation. In June 2003 and 2004, average daily temperatures were normal (13°C), but precipitation was 25% below normal. Average daily temperatures were 3°C above normal in July 2003, whereas precipitation was 84% below normal. In July 2004, average daily temperatures were 1°C above normal with 41% of normal precipitation (NCDC 2004ab, WRCC 2004).

Means and standard errors of means (SEM) presented in text and tables are from untransformed data. Statistical comparisons are presented in the tables to the extent permitted by significant ($P \leq 0.10$) interactions. Shrubs did not contribute to sheep diets and were not included in the analyses.

Botanical Composition of Sheep DietsGraminoids

Graminoid composition of sheep diets in the light and moderate infestations varied by month (Month $\times$ Infestation interaction; $P=0.01$). Within light infestations, sheep ate fewer graminoids in June versus July ($P<0.01$; Table 3), whereas graminoid composition of sheep diets within moderate infestations averaged 33% graminoids regardless of month ($P=0.18$). The proportion of graminoids in sheep diets averaged

Table 3. Perennial graminoids in sheep diets ($\pm$ SEM) within light and moderate levels of spotted knapweed infestation in June and July of 2003 and 2004.

Infestation	2003		2004		Mean		Mean
	June	July	June	July	June	July	
	------(%)-----						
Light	25 $\pm$ 12.4 a ¹ A ²	62 $\pm$ 3.0 bA	9 $\pm$ 5.7 aA	47 $\pm$ 2.5 bA	17 $\pm$ 7.1 aA	55 $\pm$ 3.9 bA	36 $\pm$ 6.9
Moderate	49 $\pm$ 24.7 aA	28 $\pm$ 10.8 aB	41 $\pm$ 9.8 aB	13 $\pm$ 10.2 aB	45 $\pm$ 12.0 aA	20 $\pm$ 7.5 aB	33 $\pm$ 7.7
Mean	37 $\pm$ 13.5 a	45 $\pm$ 9.2 a	25 $\pm$ 8.8 a	30 $\pm$ 9.0 a	31 $\pm$ 7.9	38 $\pm$ 6.5	

¹Means within rows, within main headings, followed by the same lowercase letter did not differ ($P>0.10$).

²Means within columns followed by the same uppercase letter did not differ ($P>0.10$).

31% between infestations in June ($P=0.11$), but was considerably greater in light versus moderate infestations in July ($P=0.01$).

Forbs

Sheep ate more forbs in June than in July ($P=0.02$; Table 4). Within light infestations, sheep consumed 39% of their diet in forbs, whereas diets within moderate infestations included only 4% forbs ($P=0.07$).

Spotted Knapweed

The proportion of spotted knapweed stems in sheep diets was lower in June than July ($P=0.03$; Table 5), but was not different between light and moderate infestations ($P=0.18$). Sheep consumed 33% of their diet in spotted knapweed leaves, regardless of month ($P=0.59$; Table 6). Sheep ate more spotted knapweed leaves ($P<0.01$; Table 6) and more total spotted knapweed in moderate versus light infestations ($P=0.02$; Table 7). Between June and July, however, total spotted knapweed averaged 45% of sheep diets ($P=0.61$).

Relative Preference Indices

Relative preference indices (Table 8) compared the botanical composition of sheep diets versus the vegetative composition of the patches. In June 2003 and 2004, sheep avoided graminoids in light infestations (RPI=0.4 and 0.2, respectively). Sheep grazing within moderate infestations preferred forbs in July 2003 (RPI=2.1). In July 2004, sheep grazing within light infestations preferentially selected forbs (RPI=1.8) and

Table 4. Forbs (minus spotted knapweed) in sheep diets ($\pm$ SEM) within light and moderate levels of spotted knapweed infestation in June and July of 2003 and 2004.

Infestation	2003		2004		Mean		Mean
	June	July	June	July	June	July	
	------(%)-----						
Light	50 $\pm$ 28.9 a ¹ A ²	15 $\pm$ 3.4 aA	52 $\pm$ 27.0 aA	38 $\pm$ 2.2 aA	51 $\pm$ 17.7 aA	27 $\pm$ 5.5 aA	39 $\pm$ 9.6 A
Moderate	0 $\pm$ 0.0 aA	10 $\pm$ 4.1 bA	3 $\pm$ 2.2 aA	0 $\pm$ 0.1 aA	2 $\pm$ 1.2 aA	5 $\pm$ 2.8 aA	4 $\pm$ 1.6 B
Mean	25 $\pm$ 17.1 a	13 $\pm$ 2.7 b	28 $\pm$ 16.2 a	19 $\pm$ 8.6 a	27 $\pm$ 11.3 a	16 $\pm$ 4.4 b	

¹Means within rows, within main headings, followed by the same lowercase letter did not differ ($P>0.10$).

²Means within columns followed by the same uppercase letter did not differ ($P>0.10$).

Table 5. Spotted knapweed stems in sheep diets ($\pm$ SEM) within light and moderate levels of spotted knapweed infestation in June and July of 2003 and 2004.

Infestation	2003		2004		Mean		Mean
	June	July	June	July	June	July	
	------(%)-----						
Light	7 $\pm$ 5.6 a ¹ A ²	12 $\pm$ 0.8 aA	5 $\pm$ 4.4 aA	4 $\pm$ 1.9 aA	6 $\pm$ 3.2 aA	8 $\pm$ 2.0 aA	7 $\pm$ 1.8 A
Moderate	10 $\pm$ 9.9 aA	20 $\pm$ 13.1 aA	3 $\pm$ 2.4 aA	38 $\pm$ 6.7 bB	7 $\pm$ 4.8 aA	29 $\pm$ 7.6 bB	18 $\pm$ 5.5 A
Mean	9 $\pm$ 5.1 a	16 $\pm$ 6.2 a	4 $\pm$ 2.3 a	21 $\pm$ 8.2 b	7 $\pm$ 2.8 a	19 $\pm$ 4.9 b	

¹Means within rows, within main headings, followed by the same lowercase letter did not differ ($P>0.10$).

²Means within columns followed by the same uppercase letter did not differ ($P>0.10$).

Table 6. Spotted knapweed leaves in sheep diets ($\pm$ SEM) within light and moderate levels of spotted knapweed infestation in June and July of 2003 and 2004.

Infestation	2003		2004		Mean		Mean
	June	July	June	July	June	July	
	------(%)-----						
Light	18 $\pm$ 14.8 a ¹ A ²	11 $\pm$ 1.4 aA	35 $\pm$ 26.1 aA	11 $\pm$ 2.1 aA	27 $\pm$ 13.9 aA	11 $\pm$ 1.1 aA	19 $\pm$ 7.1 A
Moderate	41 $\pm$ 30.3 aA	42 $\pm$ 6.2 aB	52 $\pm$ 8.7 aA	49 $\pm$ 3.7 aB	47 $\pm$ 14.3 aA	46 $\pm$ 3.6 aB	47 $\pm$ 7.1 B
Mean	30 $\pm$ 15.9 a	27 $\pm$ 7.5 a	44 $\pm$ 12.9 a	30 $\pm$ 8.8 a	37 $\pm$ 10.0 a	29 $\pm$ 5.6 a	

¹Means within rows, within main headings, followed by the same lowercase letter do not differ ($P>0.10$).

²Means within columns followed by the same uppercase letter do not differ ($P>0.10$).

Table 7. Total spotted knapweed in sheep diets ($\pm$ SEM) within light and moderate levels of spotted knapweed infestation in June and July of 2003 and 2004.

Infestation	2003		2004		Mean		Mean
	June	July	June	July	June	July	
	------(%)-----						
Light	25 $\pm$ 20.3 a ¹ A ²	23 $\pm$ 0.7 aA	40 $\pm$ 30.5 aA	15 $\pm$ 1.2 aA	32 $\pm$ 16.7 aA	19 $\pm$ 1.8 aA	26 $\pm$ 8.3 A
Moderate	51 $\pm$ 24.7 aA	62 $\pm$ 10.9 aB	56 $\pm$ 9.1 aA	87 $\pm$ 10.1 bB	53 $\pm$ 11.8 aA	75 $\pm$ 8.7 aB	64 $\pm$ 7.7 B
Mean	38 $\pm$ 15.4 a	43 $\pm$ 10.2 a	48 $\pm$ 14.7 a	51 $\pm$ 16.8 a	43 $\pm$ 10.3 a	47 $\pm$ 9.5 a	

¹Means within rows, within main headings, followed by the same lowercase letter did not differ ($P>0.10$).

²Means within columns followed by the same uppercase letter did not differ ($P>0.10$).

Table 8. Relative preference indices (RPI) with confidence intervals (CI) for sheep grazing perennial graminoids, forbs, spotted knapweed stems, spotted knapweed leaves and total spotted knapweed plants within light and moderate levels of spotted knapweed infestation in June and July of 2003 and 2004.

Year	Infestation	Forage Class	June				July			
			RPI	90% CI ¹			RPI	90% CI		
2003	Light	Graminoids	0.4	-0.1	—	0.9	0.9	0.8	—	1.1
		Forbs	2.7	-1.8	—	7.2	1.3	0.4	—	2.2
		Knapweed Stems	1.4	-3.5	—	6.3	1.0	0.6	—	1.4
		Knapweed Leaves	1.4	-3.0	—	5.7	1.5	0.8	—	2.2
		Total Knapweed	1.4	-3.1	—	5.9	1.2	0.6	—	1.7
	Moderate	Graminoids	0.8	-0.3	—	2.0	0.9	-0.2	—	2.0
		Forbs	0.0	0.0	—	0.0	2.1	1.7	—	2.5
		Knapweed Stems	0.5	-1.8	—	2.9	0.5	-0.4	—	1.4
		Knapweed Leaves	1.7	-1.9	—	5.3	1.7	1.0	—	2.5
		Total Knapweed	1.4	-0.5	—	3.3	0.9	-2.2	—	4.1
2004	Light	Graminoids	0.2	-0.1	—	0.4	0.7	0.5	—	0.9
		Forbs	1.4	-1.0	—	3.7	1.8	1.1	—	2.5
		Knapweed Stems	2.8	-8.9	—	14.5	0.8	0.0	—	1.7
		Knapweed Leaves	3.6	-6.3	—	13.5	2.3	-0.4	—	4.9
		Total Knapweed	3.5	-6.6	—	13.6	1.5	0.1	—	2.9
	Moderate	Graminoids	0.7	0.3	—	1.2	0.3	-0.6	—	1.2
		Forbs	0.7	-1.3	—	2.6	0.1	0.0	—	0.3
		Knapweed Stems	0.4	-0.5	—	1.3	1.1	0.5	—	1.6
		Knapweed Leaves	1.5	0.8	—	2.2	1.8	1.1	—	2.4
		Total Knapweed	1.3	0.7	—	1.9	1.4	0.9	—	1.8
Means	Light	Graminoids	0.3	-0.2	—	0.7	0.8	0.6	—	1.0
		Forbs	2.1	-0.6	—	4.7	1.5	0.2	—	2.8
		Knapweed Stems	2.1	-3.5	—	7.7	0.9	0.1	—	1.7
		Knapweed Leaves	2.5	-4.0	—	9.0	1.9	0.5	—	3.3
		Total Knapweed	2.5	-3.7	—	8.6	1.3	0.4	—	2.2
	Moderate	Graminoids	0.8	0.0	—	1.6	0.6	-0.4	—	1.6
		Forbs	0.3	-1.3	—	2.0	1.1	-1.1	—	3.4
		Knapweed Stems	0.5	-1.5	—	2.4	0.8	0.0	—	1.6
		Knapweed Leaves	1.6	-0.3	—	3.5	1.7	1.2	—	2.3
		Total Knapweed	1.3	0.2	—	2.5	1.2	0.7	—	1.7

¹Confidence intervals calculated per Hobbs and Bowden (1982). When confidence intervals do not include 1.0, RPI>1.0 indicates preference, whereas RPI<1.0 indicates avoidance.

avoided graminoids (RPI=0.7), whereas sheep grazing within moderate infestations avoided forbs (RPI=0.1) and preferred spotted knapweed leaves (RPI=1.8).

When both years' data were pooled, sheep in light infestations avoided graminoids during June (RPI=0.3) and sheep in moderate infestations preferred spotted knapweed leaves during July (RPI=1.7). Preference indices indicated an overall indifference towards the other forages, regardless of month or level of infestation.

Nutritive Quality of Available Forage

Graminoids

Crude protein levels in graminoids depended upon the year, month, and infestation (Year $\times$ Month $\times$ Infestation interaction; $P=0.03$). In 2003, graminoid CP values averaged 13% between infestations in June ($P=0.90$; Table 9) and declined in July, but were higher in light versus moderate infestations ($P=0.07$). In June 2004, graminoid CP content also was higher in light versus moderate infestations ($P<0.01$), but averaged 9% between light and moderate infestations in July 2004 ($P=0.60$).

Graminoid NDF values in June and July varied by year (Year $\times$ Month interaction; $P<0.01$). Within years and infestations, graminoid NDF content increased from June to July in 2003 and 2004 ($P<0.10$; Table 9). Graminoid ADF content in light and moderate infestations depended upon the year and month (Year $\times$ Month $\times$ Infestation interaction; $P=0.05$). Within years and infestations, graminoid ADF values increased from June to July ($P<0.10$; Table 9). In June 2003, graminoid ADF content averaged 27% across infestations ($P=0.60$), but was greater in moderate versus light

Table 9. Crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of perennial graminoids ($\pm$ SEM) within light and moderate spotted knapweed infestations in June and July of 2003 and 2004.

Nutritive Value	Infestation	2003		2004		Mean		Mean
		June	July	June	July	June	July	
------(%)-----								
CP	Light	13 ± 0.4 a ¹ A ²	9 ± 0.5 bA	15 ± 0.7 aA	9 ± 0.1 bA	14 ± 0.5	9 ± 0.3	12 ± 0.8
	Moderate	13 ± 2.0 aA	7 ± 0.2 bB	10 ± 0.3 aB	9 ± 0.8 aA	11 ± 1.1	8 ± 0.5	10 ± 0.8
	Mean	13 ± 0.9	8 ± 0.4	13 ± 1.0	9 ± 0.4	13 ± 0.6	9 ± 0.3	
NDF	Light	54 ± 0.8 aA	58 ± 0.4 bA	49 ± 0.7 aA	58 ± 0.8 bA	52 ± 1.1	58 ± 0.4	55 ± 1.1
	Moderate	56 ± 0.8 aA	58 ± 0.6 bA	52 ± 0.9 aB	56 ± 0.1 bB	54 ± 0.9	57 ± 0.4	56 ± 0.7
	Mean	55 ± 0.7 a	58 ± 0.3 b	51 ± 0.8 a	57 ± 0.6 b	53 ± 0.8	58 ± 0.3	
ADF	Light	27 ± 0.5 aA	29 ± 0.2 bA	24 ± 0.4 aA	28 ± 0.7 bA	25 ± 0.7	29 ± 0.4	27 ± 0.7
	Moderate	27 ± 0.8 aA	31 ± 0.5 bB	25 ± 0.7 aA	27 ± 0.2 bA	26 ± 0.7	29 ± 0.8	28 ± 0.7
	Mean	27 ± 0.5	30 ± 0.4	25 ± 0.4	28 ± 0.4	26 ± 0.5	29 ± 0.4	

¹Means within rows, within main headings, followed by the same lowercase letter did not differ ($P>0.10$).

²Means within columns, within nutritive values, followed by the same uppercase letter did not differ ($P>0.10$).

infestations during July 2003 ($P=0.05$). In 2004, graminoid ADF averaged 25% in June ($P=0.16$) and 28% in July ($P=0.17$).

Forbs

Forb CP content declined from 15% in June to 11% in July ($P<0.01$; Table 10), and averaged 13% between infestations ($P=0.40$). Forb NDF values in June and July varied by year and level of infestation (Year $\times$ Month $\times$ Infestation interaction; $P=0.06$). Forb NDF content averaged 35% in 2003 ($P>0.10$) and 32% in 2004 ($P>0.10$). Within light infestations, forb NDF values did not differ across months, infestations, or years ($P>0.10$). Within moderate infestations in June, forb NDF values were considerably higher in 2003 than in 2004 ($P=0.05$). Within moderate infestations in July, forb NDF values were only slightly higher in 2003 versus 2004 ($P=0.08$). Forb ADF content averaged 25% in 2003 ($P=0.64$) and 21% in 2004 ($P=0.73$).

Spotted Knapweed

Crude protein values of spotted knapweed stems in light and moderate infestations depended upon the year (Year $\times$ Infestation interaction; $P=0.08$). Crude protein content of spotted knapweed stems had similar declines from June to July in 2003 and 2004 ($P<0.01$ and $P<0.01$, respectively; Table 11). Neutral detergent fiber in spotted knapweed stems increased from 33% in June to 52% in July ($P<0.01$), but was slightly less in light versus moderate infestations ($P=0.04$). Spotted knapweed stem ADF values in June and July varied by year (Year $\times$ Month interaction; $P=0.08$). Acid detergent fiber in spotted knapweed stems averaged 24% in June 2003 and 2004 ($P=0.50$). During July,

Table 10. Crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of forbs (minus spotted knapweed) ($\pm$ SEM) within light and moderate spotted knapweed infestations in June and July of 2003 and 2004.

Nutritive Value	Infestation	2003		2004		Mean		Mean
		June	July	June	July	June	July	
------(%)-----								
CP	Light	15 ± 0.5 a ¹ A ²	10 ± 0.7 bA	15 ± 0.8 aA	10 ± 0.3 bA	15 ± 0.4 aA	10 ± 0.4 bA	13 ± 0.8 A
	Moderate	16 ± 1.3 aA	11 ± 0.9 bA	13 ± 0.7 aA	10 ± 0.6 bA	14 ± 0.9 aA	11 ± 0.5 bA	13 ± 0.8 A
	Mean	16 ± 0.7 a	11 ± 0.6 b	14 ± 0.6 a	10 ± 0.3 b	15 ± 0.5 a	11 ± 0.3 b	
NDF	Light	33 ± 1.3 aA	36 ± 1.5 aA	33 ± 4.3 aA	33 ± 1.3 aA	33 ± 2.0	35 ± 1.1	34 ± 1.1
	Moderate	37 ± 2.3 aA	34 ± 0.8 aA	28 ± 0.3 aA	30 ± 1.5 aA	32 ± 2.7	32 ± 1.2	32 ± 1.3
	Mean	35 ± 1.5	35 ± 0.9	31 ± 2.7	32 ± 1.2	33 ± 1.6	34 ± 0.9	
ADF	Light	25 ± 1.0 aA	26 ± 1.0 aA	23 ± 3.0 aA	22 ± 0.6 aA	24 ± 1.4	24 ± 1.0	24 ± 0.8
	Moderate	23 ± 2.4 aA	23 ± 1.1 aA	18 ± 0.2 aA	19 ± 1.1 aB	20 ± 1.8	21 ± 1.2	21 ± 1.0
	Mean	24 ± 1.2 a	25 ± 0.9 a	21 ± 2.1 a	21 ± 0.9 a	22 ± 1.2	23 ± 0.9	

¹Means within rows, within main headings, followed by the same lowercase letter did not differ ($P>0.10$).

²Means within columns, within nutritive values, followed by the same uppercase letter did not differ ($P>0.10$).

Table 11. Crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of spotted knapweed stems ($\pm$ SEM) within light and moderate spotted knapweed infestations in June and July of 2003 and 2004.

Nutritive Value	Infestation	2003		2004		Mean		Mean
		June	July	June	July	June	July	
------(%)-----								
CP	Light	19 ± 0.7 a ¹ A ²	5 ± 0.2 bA	24 ± 4.4 aA	6 ± 0.3 bA	21 ± 2.3	6 ± 0.2	14 ± 2.6
	Moderate	21 ± 1.7 aA	6 ± 0.2 bA	14 ± 1.9 aB	6 ± 0.0 bA	18 ± 1.9	6 ± 0.1	12 ± 2.0
	Mean	20 ± 0.9 a	6 ± 0.2 b	19 ± 3.1 a	6 ± 0.1 b	20 ± 1.5	6 ± 0.1	
NDF	Light	30 ± 1.1 aA	49 ± 0.8 bA	30 ± 4.1 aA	49 ± 7.3 bA	30 ± 1.9 aA	49 ± 3.3 bA	40 ± 3.4 A
	Moderate	31 ± 0.8 aA	52 ± 1.2 bA	40 ± 1.7 aB	55 ± 0.2 bA	35 ± 2.2 aA	54 ± 0.9 bA	45 ± 3.0 B
	Mean	31 ± 0.6 a	51 ± 0.9 b	35 ± 3.0 a	52 ± 3.6 b	33 ± 1.6 a	52 ± 1.8 b	
ADF	Light	23 ± 0.7 aA	36 ± 0.5 bA	21 ± 2.5 aA	31 ± 4.5 aA	22 ± 1.2 A	33 ± 2.3 A	28 ± 2.1 A
	Moderate	23 ± 0.8 aA	38 ± 0.5 bB	27 ± 0.7 aB	34 ± 0.1 bA	25 ± 1.1 B	36 ± 1.0 A	31 ± 1.8 B
	Mean	23 ± 0.5 a	37 ± 0.7 b	24 ± 1.8 a	33 ± 2.1 b	24 ± 0.9	35 ± 1.3	

¹Means within rows, within main headings, followed by the same lowercase letter did not differ ($P>0.10$).

²Means within columns, within nutritive values, followed by the same uppercase letter did not differ ($P>0.10$).

spotted knapweed stem ADF values were higher in 2003 than 2004 ($P=0.07$). Spotted knapweed stem ADF content was only slightly lower in light versus moderate infestations ($P=0.04$).

Spotted knapweed leaf CP values in light and moderate infestations depended upon the year and month (Year $\times$ Month $\times$ Infestation interaction; $P<0.01$). In June 2003, spotted knapweed leaf CP values averaged 15% ($P=0.80$; Table 12), but differed slightly between light and moderate infestations in July ($P=0.04$). Spotted knapweed leaf CP content averaged 17% in June 2004 ($P=0.11$) and declined to 12% during July 2004 ($P=0.50$). In June, light infestations had lower spotted knapweed leaf CP in 2003 than 2004 ($P=0.04$), whereas, within moderate infestations in July, spotted knapweed leaf CP values were lower in 2003 versus 2004 ($P=0.04$).

In June and July, spotted knapweed leaf NDF and ADF values varied by year (Year $\times$ Month interactions; $P<0.01$ and $P<0.01$, respectively). In 2003, NDF content of spotted knapweed leaves decreased slightly from June to July ($P<0.01$; Table 12), but increased from June to July in 2004 ($P<0.01$). Neutral detergent fiber in spotted knapweed leaves was also somewhat higher in moderate versus light infestations ($P=0.03$). Spotted knapweed leaf ADF was higher in June versus July 2003 ($P<0.01$), but averaged 17% in 2004 ($P=0.13$). Spotted knapweed leaf ADF values averaged 17 and 19% in light and moderate infestations, respectively ($P=0.02$).

Crude protein content of total spotted knapweed plants in light and moderate infestations varied by month and year (Year $\times$ Month $\times$ Infestation interaction; $P<0.01$). In 2003, total spotted knapweed plants provided 16% CP in June ($P=0.40$; Table 13)

Table 12. Crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of spotted knapweed leaves ($\pm$ SEM) within light and moderate spotted knapweed infestations in June and July of 2003 and 2004.

Nutritive Value	Infestation	2003		2004		Mean		Mean
		June	July	June	July	June	July	
------(%)-----								
CP	Light	14 ± 0.8 a ¹ A ²	11 ± 0.3 bA	19 ± 1.4 aA	12 ± 0.7 bA	16 ± 1.3	11 ± 0.4	14 ± 1.0
	Moderate	15 ± 1.2 aA	9 ± 0.6 bB	15 ± 1.2 aA	12 ± 0.8 aA	15 ± 0.8	11 ± 0.8	13 ± 0.8
	Mean	15 ± 0.6	10 ± 0.5	17 ± 1.2	12 ± 0.5	16 ± 0.8	11 ± 0.4	
NDF	Light	27 ± 1.3 aA	23 ± 0.9 bA	21 ± 1.4 aA	28 ± 2.0 bA	24 ± 1.5 A	26 ± 1.6 A	25 ± 1.0 A
	Moderate	28 ± 1.2 aA	24 ± 0.3 bA	25 ± 0.8 aB	29 ± 1.1 bA	26 ± 0.9 A	26 ± 1.2 A	26 ± 0.7 B
	Mean	28 ± 0.8 a	24 ± 0.6 b	23 ± 1.1 a	29 ± 1.0 b	25 ± 0.9	26 ± 1.0	
ADF	Light	19 ± 0.7 aA	16 ± 0.2 bA	15 ± 0.7 aA	17 ± 1.4 aA	17 ± 0.9 A	16 ± 0.7 A	17 ± 0.6 A
	Moderate	20 ± 1.1 aA	18 ± 0.1 bB	17 ± 0.4 aB	18 ± 0.7 aA	19 ± 0.9 A	18 ± 0.4 B	19 ± 0.5 B
	Mean	20 ± 0.6 a	17 ± 0.4 b	16 ± 0.5 a	18 ± 0.8 a	18 ± 0.7	17 ± 0.5	

¹Means within rows, within main headings, followed by the same lowercase letter did not differ ($P>0.10$).

²Means within columns, within nutritive values, followed by the same uppercase letter did not differ ($P>0.10$).

Table 13. Crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of total spotted knapweed plants ($\pm$ SEM) within light and moderate spotted knapweed infestations in June and July of 2003 and 2004.

Nutritive Value	Infestation	2003		2004		Mean		Mean
		June	July	June	July	June	July	
------(%)-----								
CP	Light	15 ± 0.5 a ¹ A ²	8 ± 0.2 bA	20 ± 1.7 aA	8 ± 0.2 bA	17 ± 1.2	8 ± 0.2	13 ± 1.5
	Moderate	17 ± 1.2 aA	7 ± 0.1 bA	15 ± 1.3 aB	9 ± 0.3 bA	16 ± 0.9	8 ± 0.4	12 ± 1.3
	Mean	16 ± 0.7	8 ± 0.1	18 ± 1.4	9 ± 0.2	17 ± 0.8	8 ± 0.2	
NDF	Light	27 ± 0.8 aA	40 ± 0.7 bA	22 ± 0.6 aA	39 ± 4.2 bA	25 ± 1.2 aA	39 ± 1.9 bA	32 ± 2.4 A
	Moderate	29 ± 1.1 aA	42 ± 1.4 bA	28 ± 0.3 aB	44 ± 0.1 bA	28 ± 0.6 aB	43 ± 0.7 bA	36 ± 2.2 B
	Mean	28 ± 0.7 a	41 ± 0.8 b	25 ± 1.3 a	42 ± 2.2 b	27 ± 0.8 a	41 ± 1.1 b	
ADF	Light	20 ± 0.3 aA	28 ± 0.4 bA	16 ± 0.2 aA	24 ± 2.7 bA	18 ± 0.9	26 ± 1.5	22 ± 1.5
	Moderate	21 ± 1.1 aA	31 ± 0.7 bB	19 ± 0.2 aB	27 ± 0.3 bA	20 ± 0.7	29 ± 0.9	25 ± 1.4
	Mean	21 ± 0.6 a	30 ± 0.6 b	18 ± 0.7 a	26 ± 1.4 b	19 ± 0.6	28 ± 0.9	

¹Means within rows, within main headings, followed by the same lowercase letter did not differ ($P>0.10$).

²Means within columns, within nutritive values, followed by the same uppercase letter did not differ ($P>0.10$).

versus 8% in July ($P=0.14$). In June 2004, total spotted knapweed plant CP values were higher in light versus moderate infestations ($P=0.09$), but averaged 9% in July 2004 ($P=0.28$). Neutral detergent fiber in total spotted knapweed plants was slightly higher in light versus moderate infestations ($P=0.01$) and increased considerably from June to July ($P<0.01$). Total spotted knapweed plant ADF values were slightly higher in 2003 versus 2004 ($P<0.01$).

Nutritive Quality of Sheep Diets

Dietary Crude Protein

Crude protein in sheep diets depended upon the year, month, and level of infestation (Year $\times$ Month $\times$ Infestation interaction; $P=0.09$). In 2003, dietary CP averaged 15% in June ($P=0.77$; Table 14) and 9% in July ($P=0.24$), whereas in 2004, dietary CP was 15% in June ($P=0.46$) and 10% in July ($P=0.77$). In 2003, dietary CP decreased from June to July within light ($P<0.01$) and moderate infestations ($P<0.01$). A similar decline from June to July was also noted within light ($P=0.05$) and moderate infestations ($P=0.04$) in 2004.

Dietary Neutral and Acid Detergent Fiber

Dietary NDF values in light and moderate infestations varied by month (Month $\times$ Infestation interaction; $P=0.07$). During July, dietary NDF was slightly higher in light versus moderate infestations ($P<0.01$; Table 15). In light infestations, dietary NDF increased from June to July ($P<0.01$), but in moderate infestations, dietary NDF averaged

Table 14. Crude protein (CP) content of sheep diets ($\pm$ SEM) within light and moderate spotted knapweed infestations in June and July of 2003 and 2004.

Infestation	2003		2004		Mean		Mean
	June	July	June	July	June	July	
	------(%)-----						
Light	14 $\pm$ 0.5 a ¹ A ²	9 $\pm$ 0.4 bA	17 $\pm$ 2.4 aA	10 $\pm$ 0.2 bA	15 $\pm$ 1.3	9 $\pm$ 0.3	12 $\pm$ 1.1
Moderate	15 $\pm$ 1.3 aA	8 $\pm$ 0.5 bA	13 $\pm$ 1.1 aA	10 $\pm$ 0.6 bA	14 $\pm$ 0.8	9 $\pm$ 0.5	12 $\pm$ 0.9
Mean	15 $\pm$ 0.6	9 $\pm$ 0.3	15 $\pm$ 1.4	10 $\pm$ 0.3	15 $\pm$ 0.8	9 $\pm$ 0.3	

¹Means within rows, within main headings, followed by the same lowercase letter did not differ ($P>0.10$).

²Means within columns followed by the same uppercase letter did not differ ($P>0.10$).

Table 15. Neutral detergent fiber (NDF) content of sheep diets ($\pm$ SEM) within light and moderate spotted knapweed infestations in June and July of 2003 and 2004.

Infestation	2003		2004		Mean		Mean
	June	July	June	July	June	July	
	------(%)-----						
Light	37 $\pm$ 3.1 a ¹ A ²	50 $\pm$ 0.6 bA	32 $\pm$ 5.5 aA	45 $\pm$ 0.6 bA	35 $\pm$ 3.0 aA	48 $\pm$ 1.1 bA	42 $\pm$ 2.5
Moderate	41 $\pm$ 7.1 aA	41 $\pm$ 0.8 aB	37 $\pm$ 2.6 aA	43 $\pm$ 0.7 aB	39 $\pm$ 3.5 aA	42 $\pm$ 0.6 aB	41 $\pm$ 1.7
Mean	39 $\pm$ 3.6 a	46 $\pm$ 2.1 a	35 $\pm$ 2.9 a	44 $\pm$ 0.7 b	37 $\pm$ 2.3	45 $\pm$ 1.1	

¹Means within rows, within main headings, followed by the same lowercase letter did not differ ($P>0.10$).

²Means within columns followed by the same uppercase letter did not differ ($P>0.10$).

41% between June and July ($P=0.49$). Dietary ADF (Table 16) increased somewhat between June and July ($P=0.02$), but averaged 25% between infestations ($P=0.56$).

Relative Utilization of Available Forage

Graminoids

Relative utilization of graminoids varied by month and year (Year $\times$ Month interaction; $P=0.01$). Relative utilization of graminoids in 2003 was 10% in June versus 46% in July, ($P<0.01$), but averaged 18% between June and July 2004 ($P=0.90$; Table 17). Overall, relative utilization of graminoids in light infestations was lower in June than in July in 2003 and 2004 ($P<0.01$ and $P=0.05$, respectively).

Forbs

Relative utilization of forbs depended upon the year, month, and level of infestation (Year $\times$ Month $\times$ Infestation interaction; $P=0.03$). Relative utilization of forbs averaged 6% in June 2003 ($P=0.12$; Table 17) and 28% in June 2004 ($P=0.48$). In July 2003, relative utilization of forbs was lower in light versus moderate infestations ($P<0.01$), whereas in July 2004, relative utilization of forbs was greater in light infestations versus moderate infestations ($P=0.02$).

In 2003, relative utilization of forbs was considerably less in June versus July within light infestations ($P<0.01$) and within moderate infestations ($P<0.01$). In 2004, relative utilization of forbs averaged 34% in light infestations ($P=0.12$) and 22% in moderate infestations ($P=0.30$).

Table 16. Acid detergent fiber (ADF) content of sheep diets ($\pm$ SEM) within light and moderate spotted knapweed infestations in June and July of 2003 and 2004.

Infestation	2003		2004		Mean		Mean
	June	July	June	July	June	July	
	------(%)-----						
Light	25 $\pm$ 1.3 a ¹ A ²	28 $\pm$ 0.1 bA	22 $\pm$ 3.6 aA	25 $\pm$ 0.6 aA	23 $\pm$ 1.8 aA	27 $\pm$ 0.8 aA	25 $\pm$ 1.1 A
Moderate	24 $\pm$ 2.3 aA	26 $\pm$ 1.7 aA	21 $\pm$ 0.9 aA	25 $\pm$ 0.5 bA	22 $\pm$ 1.3 aA	26 $\pm$ 0.8 bA	24 $\pm$ 0.9 A
Mean	24 $\pm$ 1.2 a	27 $\pm$ 0.9 b	21 $\pm$ 1.7 a	25 $\pm$ 0.4 b	23 $\pm$ 1.1 a	26 $\pm$ 0.5 b	

¹Means within rows, within main headings, followed by the same lowercase letter did not differ ($P>0.10$).

²Means within columns followed by the same uppercase letter did not differ ($P>0.10$).

Table 17. Relative utilization of graminoids, forbs, spotted knapweed stems, spotted knapweed leaves, and total spotted knapweed plants ($\pm$ SEM) within light and moderate spotted knapweed infestations in June and July of 2003 and 2004.

Vegetation Class	Infestation	2003		2004		Mean		Mean
		June	July	June	July	June	July	
		------(%)-----						
Graminoids	Light	6 ± 4.4 a ¹ A ²	55 ± 4.8 bA	4 ± 2.8aA	22 ± 7.1 bA	5 ± 2.4	39 ± 8.2	22 ± 6.5
	Moderate	14 ± 6.9 aA	37 ± 10.4 aA	36 ± 8.5 aB	10 ± 6.1 bA	25 ± 7.0	23 ± 8.0	24 ± 5.1
	Mean	10 ± 4.0 a	46 ± 6.6 b	20 ± 8.2 a	16 ± 5.0 a	15 ± 4.6	31 ± 5.6	
Forbs	Light	12 ± 6.5 aA	75 ± 1.8 bA	17 ± 16.7 aA	51 ± 9.0 aA	14 ± 8.1	63 ± 6.8	39 ± 8.9
	Moderate	0 ± 0.0 aA	88 ± 1.3 bB	39 ± 23.1 aA	6 ± 5.3 aB	19 ± 13.5	47 ± 18.5	33 ± 11.7
	Mean	6 ± 3.9	82 ± 3.0	28 ± 13.6	29 ± 11.2	17 ± 7.5	55 ± 9.7	
Spotted knapweed stems	Light	31 ± 27.1 aA	57 ± 12.4 aA	35 ± 20.8 aA	20 ± 9.9 aA	33 ± 15.3 aA	38 ± 10.9 aA	35 ± 9.0 A
	Moderate	8 ± 8.2 aA	26 ± 15.0 aA	23 ± 16.4 aA	45 ± 9.9 aA	15 ± 8.8 aA	36 ± 9.0 aA	26 ± 6.7 A
	Mean	20 ± 13.6 a	42 ± 11.0 a	29 ± 12.1 a	33 ± 8.4 a	24 ± 8.8 a	37 ± 6.8 a	
Spotted knapweed leaves	Light	30 ± 26.6 aA	87 ± 2.9 bA	49 ± 22.3 aA	62 ± 3.2 aA	40 ± 16.1 A	74 ± 5.9 A	57 ± 9.7 A
	Moderate	10 ± 7.8 aA	74 ± 5.7 bA	67 ± 6.9 aA	69 ± 4.2 aA	39 ± 13.6 A	76 ± 3.3 A	58 ± 8.3 A
	Mean	20 ± 13.2 a	81 ± 4.0 b	58 ± 11.2 a	66 ± 2.9 a	40 ± 10.0	75 ± 3.3	
Total spotted knapweed	Light	30 ± 26.7 aA	68 ± 8.7 aA	46 ± 23.9 aA	40 ± 4.6 aA	38 ± 16.4 aA	54 ± 7.6 aA	46 ± 8.9 A
	Moderate	10 ± 4.2 aA	44 ± 11.8 bA	59 ± 8.8 aA	56 ± 7.8 aA	35 ± 11.7 aA	50 ± 6.8 aA	43 ± 6.9 A
	Mean	20 ± 12.9 a	56 ± 8.4 b	53 ± 11.8 a	48 ± 5.3 a	37 ± 9.6 a	52 ± 4.9 a	

¹Means within rows, within main headings, followed by the same lowercase letter are not different ($P>0.10$).

²Means within columns, within vegetation classes, followed by the same uppercase letter are not different ($P>0.10$).

Spotted Knapweed

Relative utilization of spotted knapweed stems was 31% regardless of month ($P=0.23$; Table 17) or level of infestation ($P=0.43$). Relative utilization of spotted knapweed leaves in June and July varied by year (Year $\times$ Month interaction; $P=0.03$). In 2003, relative utilization of spotted knapweed leaves was lower in June versus July ($P<0.01$), but averaged 62% between June and July 2004 ($P=0.55$). Sheep consumed 58% of spotted knapweed leaves regardless of infestation level ($P=0.84$). Relative utilization of total spotted knapweed was 45% regardless of month ($P=0.12$) or level of infestation ($P=0.17$), but overall trended higher in July in light and moderate infestations.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

Botanical Composition of Sheep Diets

Botanical composition of sheep diets was more influenced by availability of forage than forage quality. While sheep diet composition of graminoids did not differ during June, sheep diets contained a greater proportion of graminoids in light versus moderate infestations during July. This was somewhat surprising given the lower forage quality of graminoids during this time, but corresponded with the relative increase in availability of graminoids within light infestations in July. Additionally, grazing to the prescribed residual stubble height within the light infestations may have forced sheep to consume more graminoids in July. Diet composition of graminoids did not change from June to July within moderate infestations, which also was more closely related to forage availability than forage quality.

Within a moderate spotted knapweed infestation in Idaho, sheep consumed 45% of their diet as graminoids in June versus 25% in July (Hale 2002). These data compare favorably with the moderately infested sites in my study (45% in June, 20% in July). However, results from Hale (2002) do not compare closely with the light infestations of my study. Sheep in my study consumed notably fewer graminoids in June and notably more graminoids in July. I attribute these differences to site characteristics. Within the light infestations, graminoids in my study were more abundant and probably remained more palatable in July than graminoids on the more xeric site in Idaho. Differences in the

amounts of graminoids in sheep diets between Hale (2002) and within the light infestations in my study may also be attributed to differences in the proportions of the standing crop comprised by graminoids and spotted knapweed.

Forb composition of sheep diets in my study reflected availability within the infestations, as well as seasonal changes in forage quality. In light infestations, forbs comprised 39% of diets versus 4% in moderate infestations. Forbs never comprised more than 5% of the vegetative composition in moderate infestations, whereas forbs were 12 to 32% of the standing crop in the light infestations, depending on the month and year. Sheep ate 27% forbs in June versus 16% forbs in July. While standing crop of forbs did not differ between June and July, forbs comprised a smaller proportion of the total standing crop in July. This reduction in relative availability likely resulted in less forb consumption in July.

Sheep grazing within spotted knapweed-infested sagebrush-steppe in Idaho consumed about 16% of their diet as forbs in June and about 14% in July (Hale 2002). Again, differences in forb production and maturity between the 2 study areas in June likely explain the difference in sheep diet composition of forbs between the 2 studies. Forb production within the light infestations of my study was greater than in the moderate infestations studied by Hale (2002).

Sheep consumption of spotted knapweed stems increased from June to July, despite declines in nutritive values for stems. Consumption of spotted knapweed stems did, however, correspond with increased availability in July. The proportion of spotted knapweed leaves in sheep diets was similar in June and July, although the nutritive

quality of spotted knapweed leaves did not appreciably decrease from June to July and spotted knapweed leaves had less NDF and ADF than graminoids, forbs, or spotted knapweed stems. The higher diet composition of spotted knapweed leaves in moderate versus light infestations reflected the greater availability of these leaves and the limited availability of other forbs. Total spotted knapweed in sheep diets was 2.5 times greater in moderate infestations versus light infestations, but was not different between June and July. This corresponded with the relative amounts of spotted knapweed in the 2 levels of infestation, but occurred despite seasonal declines in forage quality of spotted knapweed. In comparison with the moderate infestation studied by Hale (2002) in southeastern Idaho, total spotted knapweed comprised a greater proportion of sheep diets in the moderate infestation of my study (64 vs. 50% of sheep diets). Spotted knapweed was likely less palatable on the more xeric site in Idaho.

Relative Preference Indices

Sheep selected against graminoids within light infestations in June and preferred spotted knapweed leaves within moderate infestations in July. Within light infestations in June, sheep diets averaged 51% forbs and 32% spotted knapweed, although these components only totaled about 36% of the available vegetation. The preference of sheep for spotted knapweed leaves within moderate infestations in July reflected the combined effects of the greater availability of spotted knapweed leaves, their lower NDF and ADF values than graminoids, forbs, or spotted knapweed stems, and the limited availability of other forbs.

These findings also support 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, 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 sheep removed developing flowerheads and leaves from stems, while avoiding consuming stems, and that sheep tended to prefer smaller, younger spotted knapweed plants. My RPI values did not indicate avoidance or preference of spotted knapweed stems by sheep. The nutritive value of stems in my study was notably higher than those reported by Olson and Wallander (2001), which may explain why my RPI values did not indicate avoidance of spotted knapweed stems.

Nutritive Quality of Available Forage

Forage CP content generally declined whereas NDF and ADF content generally increased from June to July. Forage quality did not differ much between light and moderate infestations. The seasonal decline in forage quality was expected and resulted from increased amounts of indigestible structural carbohydrates (e.g., hemicellulose and lignin) and reallocation of soluble carbohydrates within the plants (Coyne et al. 1995). As plants senesce, proteins are converted into amino acids, which are more easily translocated from aboveground tissues for future use (Coyne et al. 1995). Nitrogen may also become bound by structural carbohydrates making it less available (Coyne et al. 1995).

The NDF and ADF content of spotted knapweed stems and leaves reflected effects of the timing and amount of precipitation received. For example, ADF content of spotted knapweed stems increased from 23 to 37% between June and July 2003, but only increased from 24 to 33% between June and July 2004. I attribute the difference between years to the intermittent precipitation received in July 2004 (NCDC 2004b) which delayed maturation of spotted knapweed stems.

Below normal precipitation in Summer 2003 may explain why spotted knapweed NDF and ADF values decreased slightly from June to July. Precipitation was 25% below normal in June 2003 and 84% below normal in July 2003 (NCDC 2004ab, WRCC 2004). A mild water deficit can decrease cell growth and cause a decline in cell wall synthesis (Brown 1995), which may account for the decline in NDF and ADF.

The total spotted knapweed nutritive values from my study generally agreed with those of Hale (2002), except that my nutritive values for June were more similar to his May observations, whereas my July observations fell between his June and July values. A similar relationship exists when my spotted knapweed nutritive values are compared to those of Kelsey and Mihalovich (1987). These results indicate that the spotted knapweed plants in my study were less mature in June and July than were those in the other studies.

Nutritive Quality of Sheep Diets

Dietary CP was higher in June regardless of infestation, averaging about 15%, which met the protein requirement of 70-kg, lactating ewes during the first 6 to 8 weeks of lactation suckling singles or twins (NRC 1985). In July, dietary CP ranged from 8 to

10%. This seasonal decline in diet quality was expected as the quality of the available forage declined.

The dietary CP values in July were marginal for meeting the protein requirements of 70-kg, lactating ewes (i.e., 10.7 to 13.4% of their diet during the last 6 to 8 weeks of lactation), but dietary CP was adequate to meet their maintenance requirement of 9.4% (NRC 1985). Lactation is usually insignificant after 8 to 10 weeks (Kott 1998), so the ewes were likely meeting their dietary protein requirement. Sheep grazing a tall forb range in southwestern Montana consumed 14% dietary CP in June and 8% dietary CP in July (Buchanan et al. 1972).

Dietary NDF was higher in light infestations during July, which probably resulted from the increased consumption of graminoids in light infestations during July. Graminoid NDF content in light infestations was 58% in July and graminoids comprised 55% of sheep diets. In comparison, sheep grazing a spotted knapweed-infested sagebrush steppe community had higher dietary NDF values of 55 and 59% in June and July, respectively (Hale 2002). Higher dietary NDF in that study likely resulted from the vegetation being more mature.

Dietary ADF averaged 25% between infestations, but increased from 23% in June to 26 % in July. Buchanan et al. (1972) reported similar sheep dietary ADF values of 22% in June and 26% in July on tall forb rangeland in southwestern Montana that was not infested with spotted knapweed.

Relative Utilization of Available Forage

The sheep grazing prescription used in this study resulted in an average relative utilization of graminoids of 15%, except under very hot and dry conditions in July 2003 when relative utilization of graminoids averaged 46%. Graminoid utilization levels of 40-60% are sustainable on foothill rangeland in western Montana (Lacey and Volk 1993, Lee-Campbell 1999).

Relative utilization of total spotted knapweed plants averaged 45%. This level exceeds the 30% utilization level predicted by Griffith and Lacey (1991) as the threshold needed to make herbicide application uneconomical on high-producing sites. Relative utilization of spotted knapweed leaves was less in June versus July 2003 (20 vs. 81%, respectively), but averaged 62% in 2004. Although the sheep were provided a 7-day acclimation period each year, June 2003 was their first exposure to spotted knapweed, which may account for the lower relative utilization. It is unknown whether the levels of spotted knapweed defoliation achieved in my study are sufficient to reduce the vigor or viable seed production of spotted knapweed. In greenhouse clipping studies, Kennett et al. (1992) and Lacey et al. (1994) determined that 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.

Average relative utilization of total spotted knapweed plants in my study (45%) was generally less than the levels reported by Hale (2002), which ranged from 36 to 85%. However, the high levels of spotted knapweed utilization achieved by Hale (2002) were accompanied by heavy utilization of native forbs (73-87% relative utilization) and native

grasses (48-71% relative utilization), at least partially offsetting the benefits of sheep eating the spotted knapweed.

Conclusions

My results indicate that sheep in a large ewe-lamb band readily graze spotted knapweed plants when prescription grazing is applied on a landscape-scale. The botanical composition of sheep diets was influenced more by availability than forage quality; however, ewes were able to meet their CP requirements and consumed a diet similar in quality to sheep grazing uninfested rangeland. While sheep may not preferentially select spotted knapweed, it appears that: 1) their consumption of spotted knapweed increases when other forbs are less available, and 2) sheep include spotted knapweed in their diet even when other desirable forage is available. Additionally, relative utilization of spotted knapweed achieved by prescription sheep grazing of infested foothill rangeland averaged 45% which may render the application of herbicides uneconomical.

CHAPTER 6

MANAGEMENT IMPLICATIONS

Domestic sheep can be used to suppress 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, particularly when other desirable forbs were less available, and ewes were able to meet their CP requirements throughout the summer. Relative utilization of spotted knapweed averaged 45% regardless of month or level of infestation and relative utilization of graminoids averaged 15%, except under exceptionally hot and dry conditions. Based on my results, light and moderate spotted knapweed infestations can be prescriptively grazed in either June or July. In moderate infestations, where other forbs are less available, the presence of graminoids is more important to allow 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 infestations to allow sheep to select a more varied diet and buffer any toxic effects (Freeland and Janzen 1974). When consumption of graminoids is a concern, light infestations should be grazed in June when sheep consume more forbs and spotted knapweed. Further research is needed to examine other management alternatives to reduce graminoid consumption by sheep in spotted knapweed infestations. Possible alternatives include reducing available graminoids by grazing cattle immediately before or simultaneously with sheep, allowing more than 3 weeks

between cattle and sheep grazing, or delaying sheep grazing until after graminoids set seed.

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