# SEQUENTIAL CATTLE AND SHEEP GRAZING

# FOR SPOTTED KNAPWEED CONTROL

by

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# TABLE OF CONTENTS

## LIST OF TABLES

# ABSTRACT

Spotted knapweed (*Centaurea stoebe* L.) infests millions of hectares of native rangeland in North America. Spotted knapweed creates large monocultures, which decreases biodiversity, reduces livestock and wildlife forage, and increases surface water runoff and soil erosion. Sheep are an effective tool for controlling spotted knapweed and have been widely used on cattle ranches for weed control. However, cattle producers are concerned that sheep will over-utilize desirable graminoids. Therefore, research is needed to determine an effective grazing strategy using cattle and sheep that will adversely affect spotted knapweed, while minimizing over-use of desirable graminoids across the landscape. This 2-year study quantified graminoid and spotted knapweed utilization and diet composition and foraging behavior of cattle and sheep sequentially grazing spotted knapweed-infested rangeland in western Montana. Twenty-one Targhee yearling wethers and 9 Black Angus yearling cattle were used. Animals were randomly assigned to one of 3, 0.81-ha pastures that were grazed in either mid-June or mid-July (n=6 pastures). Cattle grazed each pasture for 7 days, immediately followed by sheep grazing for 7 days in each month. Analysis of covariance was used to determine differences in diets, relative preference indices, foraging behavior, and utilization between June and July for cattle and sheep to determine the optimal month for implementing prescribed sheep grazing. Relative utilization of spotted knapweed did not differ between June and July and averaged 61.5%. Graminoid utilization was moderate (<45%). Cattle preferred forbs in June, spotted knapweed and forbs in July, and avoided graminoids in July. Sheep avoided graminoids in June and July, preferred forbs in June, and showed no preference or avoidance of spotted knapweed. Cattle ranches with large spotted knapweed infestations can effectively use prescribed sheep grazing immediately following cattle grazing in June or July to achieve high levels of use on spotted knapweed, thus reducing viable seeds incorporated into the soil, while maintaining optimal utilization levels on desirable graminoids.

# CHAPTER 1

## INTRODUCTION

Spotted knapweed (*Centaurea stoebe* L. ssp. *micranthos* (Gugler) Hayek) is an invasive perennial forb introduced to North America from Eurasia in the late 1800s (Watson and Renney 1974). Spotted knapweed is an aggressive invader capable of creating large monocultures in disturbed and pristine rangeland (Tyser and Key 1988; Lacey et al. 1990). Large infestations reduce available forage for cattle and wildlife (Watson and Renney 1974) and reduce biodiversity (Tyser and Key 1988). Spotted knapweed plants produce over 1,000 seeds plant$^{-1}$ annually (Story 1976; Schirman 1981) and up to 40,000 seeds m$^{-2}$ year$^{-1}$ (Watson and Renney 1974), which can remain viable in the soil for at least eight years (Davis et al. 1993). Seeds germinate in a variety of environmental conditions (Watson and Renney 1974), germinate early, and grow quickly (Sheley 1998). Spotted knapweed currently infests every state in the U.S. except Alaska, Texas, Oklahoma, and Mississippi (USDA-NRCS 2007). Concern in Montana is growing because spotted knapweed infests over 1.5 million hectares of native rangeland (MWSSC 2005) and costs the state over $42 million in losses per year (Hirsch and Leitch 1996).

Common approaches for spotted knapweed control have been chemical, mechanical, biological, prescription grazing, or a combination of methods. Herbicides most commonly used to control spotted knapweed are picloram, 2,4-D, clopyralid and dicamba (Sheley et al. 1998). These herbicides are selective for broad-leaf plants and most grasses are resistant to their effects. If applied incorrectly, herbicides can potentially contaminate water sources, and human health issues may be of concern. Herbicide application alone costs a minimum of $61.75 per hectare (MWSSC 2005). Picloram needs to be applied every three to five years after residuals dissipate, and 2,4-D and dicamba need to be applied annually for effective control (Lacey et al. 1986). The high cost and frequent application of herbicides (Sheley 1999) make their use uneconomical for treating large-scale infestations. A single annual mowing at the flowering or seed production stage can achieve partial control of spotted knapweed (Rinella et al. 2001). The number of seed producing plants and percent germination were reduced when mowing occurred during the flowering stage, in the Ukraine (Watson and Renney 1974). Burning adult spotted knapweed infestations 3 consecutive years reduced plant densities, seedling densities, and juvenile densities on grasslands in Michigan (MacDonald et al. 2007). While these methods may suppress spotted knapweed, they may not be suited for diverse topography and are labor intensive. The goal of biological control is to stress the target weed and reduce its dominance within a plant community (Wilson and McCaffrey 1999). Insects can achieve this by boring into roots, defoliation, and seed predation. Eleven species of insects have been used to control spotted knapweed, and nine of those have been established in Montana (Sheley et al. 1998). *Agapeta zoegana* (knapweed root boring moth) intermediate herbivory didn’t reduce shoot biomass, shoot number, or seed yield of spotted knapweed, but did reduce plant height and reproduction mass in Basel, Switzerland (Müller-Schärer 1991; Steinger and Müller-Schärer 1992). There are also fungal and bacterial pathogens, which infect spotted knapweed, and are often associated with insect injury (Sheley et al. 1998).

Prescribed sheep grazing may be an effective alternative for spotted knapweed control. Sheep are selective grazers (Hofmann 1988), prefer forbs over grasses (Hanley 1982), adapt well to diverse topography (Olsen and Lacey 1994), and their narrow muzzles and cleft upper lips enable them to select plant parts (Arnold and Dudzinski 1978). These are all desirable characteristics that make sheep ideal for broad-leaf weed control. Sheep will readily graze spotted knapweed (Olsen et al. 1997b; Launchbaugh and Hendricks 2001; Thrift et al. 2008) in all growth stages, even when other palatable forage is available (Olson and Wallander 2001; Hale 2002). Prescribed sheep grazing during either the bolting stage (June) or flowering stage (July) reduces spotted knapweed density and number of flowering stems (Launchbaugh and Hendrickson 2001). Effective noxious weed control depends on the ability to prevent seed production and seed bank development (DiTomaso 2000). Sheep select spotted knapweed flower heads (Olson and Wallander 2001), and defoliation during the growing season reduces seed production (Olson et al. 1997c; Benzel 2008). Defoliating spotted knapweed during the late-bud/early flower stages also effectively suppresses spotted knapweed seed viability (Benzel 2008). Frequent defoliations throughout the growing season reduce spotted knapweed carbohydrate concentrations and pools (Lacey et al. 1994), root and crown growth, and total biomass production (Kennet et al. 1992). Prescribed sheep grazing for weed control has multiple benefits. Integrating the use of sheep into ranch operations provides both weed control and revenue (wool and meat) for the livestock producer.

Prescribed sheep grazing on light infestations achieved 46% utilization on spotted knapweed and 37% utilization on desirable graminoids in either June or July (Thrift et al.

2008) suggesting that sheep grazing in either month can achieve adequate use on spotted knapweed while minimizing use on desirable graminoids. Defoliation of spotted knapweed reduced seed viability by 90% in June and 100% in July (Benzel 2008). Therefore, grazing in those two months would be the most effective in reducing seeds, if animals graze before the plants set seed. Prescribed grazing in June or July generally coincides with summer grazing management strategies on cattle operations.

Prescribed sheep grazing can effectively suppress spotted knapweed, but cattle producers are concerned that sheep may over-utilize the graminoids in spotted knapweed-infested pastures and reduce forage available to cattle. The amount of graminoids and forbs sheep consume parallels graminoids and forb availability on spotted knapweed-infested foothill rangeland (Thrift et al. 2008). Since cattle prefer grasses, grazing cattle prior to sheep may reduce graminoid availability and increase forb availability, suggesting sheep may increase spotted knapweed use if grazed after cattle. For prescribed sheep grazing to be more widely applied on cattle ranches with spotted knapweed infestations, prescribed sheep grazing needs to be refined to maximize use of spotted knapweed and minimize use of desirable graminoids. The objective of this 2-year study was to quantify graminoid and spotted knapweed utilization by cattle and sheep when grazed sequentially in June vs. July.

# CHAPTER 2

# LITERATURE REVIEW

## Spotted Knapweed Distribution and Ecology

Spotted knapweed infests millions of hectares of native rangeland throughout North America. Spotted knapweed was introduced as seed contaminants in alfalfa (*Medicago sativa* L.) and ballast water discharge from ships (Sheley et al. 1998). Spotted knapweed is found in every U.S. state except for Alaska, Texas, Oklahoma, and Mississippi (USDA-NRCS 2007), and inhabits every county in Idaho, Montana, Washington, and Wyoming (Sheley et al. 1998). In Montana, spotted knapweed infests 1.5 million ha of rangeland (MWSSC 2005), and spreads at a rate of 10-27% per year (Griffith and Lacey 1991; MWSSC 2005). These large infestations cost Montana's economy over $42 million annually (Hirsch and Leitch 1996).

Spotted knapweed can be identified by its alternate divided leaves, black tipped bracts, and bright purple flowers (Watson and Renney 1974). Other characteristics of spotted knapweed include early germination, growing quickly and early in the season, and a deep taproot for efficient water use and added competitive ability over native plants (Sheley et al. 1998). Spotted knapweed reproduces largely by seed. Spotted knapweed plants are prolific seed producers, producing 1,000 seeds plant$^{-1}$ annually (Story 1976; Schirman 1981) and up to 40,000 seeds m$^{-2}$ year$^{-1}$ (Watson and Renney 1974), and are capable of forming large monocultures (Tyser and Key 1988; Lacey et al. 1990). Spotted knapweed infestations reduce available forage for cattle and wildlife (Watson and

Renney 1974) and reduce biodiversity (Tyser and Key 1988). Other environmental impacts of spotted knapweed include increased surface water runoff and soil erosion (Lacey et al. 1989). Spotted knapweed grows along roadsides, waste areas, and on overgrazed rangelands (Watson and Renney 1974). As disturbance increases, spotted knapweed densities increase (Watson and Renney 1974), however, spotted knapweed is also capable of growing in undisturbed and pristine rangelands (Tyser and Key 1988; Lacey et al. 1990). Therefore, effective, economical, and environmentally sound methods to control and/or eliminate spotted knapweed should be investigated.

Spotted knapweed seeds can germinate in a variety of environmental conditions (Watson and Renney 1974). Spotted knapweed seeds can remain dormant in the seedbank for extended periods, and after 8 years, 25% of buried seeds remain viable (Davis et al. 1993). Spotted knapweed plants, in northern Idaho, produced up to 29,600 seeds $m^{-2}$ (Schirman 1981). Seeds germinate in the fall and early spring and under a broad range of temperatures (7- 34 ºC) (Watson and Renney 1974) and seed production increases during wet years and on irrigated sites (Watson and Renney 1974; Schirman 1981). Animals and insects can aide in the dispersal of spotted knapweed seeds. Twenty-two percent of spotted knapweed seeds can remain viable after passing through sheep, with seeds remaining viable for up to 7 days (Wallander et al. 1995). Twenty-five percent of spotted knapweed seeds can remain viable after passing through mule deer, with seeds remaining viable for up to 10 days (Wallander et al. 1995). Myrmecochorous ants show preference for dispersing spotted knapweed seeds with elaiosomes over native plant seeds that lack elaiosomes (Jensen and Six 2006).

Spotted knapweed synthesizes a sesquiterpene lactone called cnicin. Cnicin is in the stems and leaves of spotted knapweed, and cnicin levels increase early in the growing season and remain at the higher level through the summer (Locken and Kelsey 1987). Cnicin can enter the soil through decomposing plant material (Picman 1987), and though it is not a strong inhibitor, cnicin can inhibit germination of some plants (Locken and Kelsey 1987) and retard root development and seedling growth (Fletcher and Renney 1963; Kelsey and Locken 1987). Cnicin is bitter tasting to livestock (Kelsey and Locken 1987) and has anti-microbial properties, which may reduce rumen microbial activity and inhibit digestion (Olson and Kelsey 1997). These properties may deter livestock from grazing spotted knapweed (Kelsey and Locken 1987). However, studies have shown that sheep will readily eat spotted knapweed (Olson et al. 1997c; Launchbaugh and Hendrickson 2001; Olson and Wallander 2001; Thrift et al. 2008), despite the presence of cnicin.

Another secondary compound found in spotted knapweed is (±) catechin. Spotted knapweed exudes (±) catechin from its roots and this chemical compound appears to have phytotoxic and anti-microbial properties at naturally occurring concentrations (Bias et al. 2003). The (-)-catechin enantiomer may inhibit root growth and germination of neighboring plants (Bias et al. 2003; Veluri et al. 2004). (+)-Catechin has antibacterial and antifungal properties that act against root-colonizing fungi (Veluri et al. 2004). At high concentrations, (±)-catechin is phytotoxic, while low concentrations increase pathogen resistance (Prithiviraj et al. 2007). Blair et al. (2006) argued that although (±)-catechin may be toxic at high concentrations, it is unlikely that the chemical could build up in the soil. (±)-Catechin rapidly degrades in moist soils from low to trace amounts and therefore adequate rainfall would keep (±)-catechin from reaching toxic levels (Blair et al. 2006). Native plants silky lupine (*Lupinus sericeus* Pursh) and blanket flower (*Gaillardia grandiflora* Van Houtte) excrete oxalate in response to (±)-catechin, which minimizes damage due to oxidative stress caused by (±)-catechin (Weir et al. 2006). This suggests that some native plants may have a defense mechanism against spotted knapweed invasions.

## Nutritive Quality of Spotted Knapweed

Early in the growing season, spotted knapweed is highly digestible and nutritious. Spotted knapweed collected in May in western Montana consisted of 18% crude protein (CP), 24% neutral- detergent fiber (NDF), and 25% total non-structural carbohydrates (TNC) (Kelsey and Mihalovich 1987). Cnicin levels of spotted knapweed in May are relatively low and range from 0.5-0.9% (Kelsey and Mihalovich 1987; Locken and Kelsey 1987).

Spotted knapweed nutrient values start to decline as the summer progresses. Spotted knapweed plants collected in June in western Montana consist of 9% CP, 27% NDF, and 25% TNC. Cnicin levels average 1.0-1.2% in June (Kelsey and Mihalovich 1987). Leaves and stems of spotted knapweed consist of 11% CP, 21% NDF and 6% CP, 41% NDF, respectively (Olson and Kelsey 1997). Cnicin levels are also higher in spotted knapweed leaves (3.4%) compared to spotted knapweed stems (0.7%) (Olson and Kelsey 1997). In July, spotted knapweed plants consisted of 9% CP, 44% NDF, and 12% TNC

(Launchbaugh and Hendrickson 2001). The nutritive quality of spotted knapweed declines slightly from June to July. Leaves and stems of spotted knapweed consisted of 9% CP, 24% NDF and 3% CP, 61% NDF, respectively (Olson and Wallander 2001). Cnicin levels remained at approximately 1.0% (Locken and Kelsey 1987). On foothill rangeland in western Montana, spotted knapweed plants contained 17%CP and 27% NDF in June and 8% CP and 41% NDF in July. In June, leaves and stems of spotted knapweed consisted of 16% CP, 25% NDF and 20% CP, 33% NDF, respectively. In July, leaves and stems of spotted knapweed consisted of 11% CP, 26% NDF and 6% CP, 52% NDF, respectively (Thrift 2008).

Spotted knapweed can be nutritious forage. Spotted knapweed's deep taproot allows the plant to absorb water and nutrients and continue photosynthetic activity after native grasses go dormant and senesce (Watson and Renney 1974). In western Montana, the nutrient content of spotted knapweed in the spring (Kelsey and Mihalovich 1987) or summer (Thrift et al. 2008) was adequate to meet livestock requirements. In southwestern Montana, the nutrient values of spotted knapweed leaves and flowerheads was consistently greater than Idaho fescue (Olson and Wallander 2001). Thrift et al. (2008) reported that nutrient quality of sheep diets grazing spotted knapweed infested rangeland in June and July was similar to sheep grazing uninfested rangeland.

## Prescribed Livestock Grazing for Weed Management

Sheep are an effective tool for controlling weeds (Williams et al. 1996) and have been used to control leafy spurge (Johnston and Peake 1960; Olson and Wallander 1998), tansy ragwort (Sharrow and Mosher 1982), yellow starthistle (Thomsen et al. 1993), and spotted knapweed (Olson et al. 1997c). In Montana and other western states, sheep have been used effectively to control weeds on cattle ranches with large weed infestations (Montana Sheep Institute 2008). Sheep morphology and diet preferences are conducive for consuming spotted knapweed and other weeds. Sheep efficiently graze broad-leaf weeds with their narrow muzzles and cleft upper lips, allowing them to select plant parts more effectively (Arnold and Dudzinski 1978). Animals select food by sight, smell, taste, touch (Arnold 1966; Krueger et al. 1974), and previous experience (Olson et al. 1996). Sheep will consume grasses, but they generally prefer forbs and browse (Cook 1954). Sheep have a smaller rumen with less capacity, and therefore select more digestible forages that are retained for a shorter length of time (Hofmann 1988). In contrast, cattle are able to consume lower quality forages because their rumens are larger and they can retain plant material for longer periods of time, which promotes further digestion of plant material (Allison 1985).

Leafy spurge infestations reduce forage available for cattle (Hein and Miller 1992), and cattle will not generally utilize leafy spurge in their diets (Landgraf et al. 1984). Sheep will consume up to 50% leafy spurge in their diets and select all phenological growth stages (Landgraf et al. 1984). Previous experience increases leafy spurge consumption by lambs and yearling ewes compared to sheep with no experience (Walker et al. 1992). Long-term continuous sheep grazing reduced the seed bank from >3,500 to 15 seeds $m^{-2}$ in Saskatchewan, Canada (Bowes and Thomas 1978). Economical feasibility of sheep grazing leafy spurge increases as the size of the infestation within the pasture increases (Williams et al. 1996). However, twenty-four percent of leafy spurge seeds can remain viable after passing through sheep (Olson et al. 1997b), with seeds remaining viable for up to 5 days (Lacey et al. 1992), which warrants proper animal husbandry techniques to limit the spread of leafy spurge seed through feces.

Tansy ragwort contains pyrrolizidine alkaloids, which are highly toxic to cattle (Kingsbury 1964) and cause liver damage in most other livestock, but sheep appear to be immune to these alkaloids (Sharrow and Mosher 1982). Sheep and cattle grazing together reduced the number of flowering plants in southwestern Oregon with only 2% of the plants flowering compared to 40% of plants flowering with cattle grazing only (Sharrow and Mosher 1982). Sheep suppress tansy ragwort populations by reducing the plant's ability to flower and produce seeds (Sharrow and Mosher 1982).

Diterpenoid alkaloids present in larkspur (*Delphinium* spp. L.) are also highly toxic to cattle, while sheep are relatively resistant to larkspur toxicity (Ralphs et al. 1988). Ralphs and Olsen (1992) reported that sequential sheep and cattle grazing of waxy larkspur infested-pasture (*Delphinium glaucescens* Wats) reduced the threat of cattle poisoning. Sheep grazing in southwestern Montana consumed 70% of waxy larkspur flower heads. Cattle consumed 43-49% less larkspur after sheep grazed the pastures, thus reducing the cattle's risk of poisoning (Ralphs and Olsen 1992).

Prescribed sheep grazing has been used to suppress yellow starthistle (*Centaurea solstitialis* L.). Yellow starthistle provides livestock with green, nutritious foliage in late spring and early summer after most annual plants have senesced (Thomsen et al. 1993). On annual grasslands in California, sheep grazing in late May-June (bolting, pre-spiny stage), with 1-3 repeated grazing periods, reduced yellow starthistle flowerhead and seed production, plant densities, and canopy size (Thomsen et al. 1996). The number of grazing periods required to impact yellow starthistle increases with spring rain and replenished soil moisture (Thomsen et al. 1993). In grasslands of Idaho, sheep readily graze yellow starthistle during the late bud stage, which limits bud development (Wallace et al. 2008). Grazing yellow starthistle during the late bud stage, when soil moisture may be limited, also reduces seed yields (Wallace et al. 2008).

Sheep can consume noxious plants that are typically poisonous to cattle (Sharrow and Mosher 1982; Ralphs et al. 1991) and plants that contain secondary compounds (Locken and Kelsey 1987; Olson and Kelsey 1997), such as cnicin found in spotted knapweed. However, sheep rumen microbes are negatively affected when sheep diets contain between 30% and 70% spotted knapweed (Olson and Kelsey 1997); the exact threshold is unknown. Ruminants may experience post-ingestive feedback when secondary compounds found in some plants (Freeland and Janzen 1974) negatively affect rumen microbes. If ruminants experience post-ingestive feedback, they will avoid or reduce their use of those plants (Provenza 1995). Depending on feed nutritional content (e.g., protein and energy), plant secondary compounds (e.g., terpenoids, cyanogenic glycosides, and tannins) may increase consumption rather than deter grazing (Villalba et al. 2002). Rumen microbial activity may actually detoxify secondary compounds (Freeland and Janzen 1974; Smith 1992). Grazing animals cope with toxins by avoiding or reducing toxin intake through diet selection, selecting mixed diets to dilute toxins, or consume toxins in a cyclic approach (Pfister 1999).

Sheep will readily graze spotted knapweed (Olsen et al. 1997b; Launchbaugh and Hendricks2001; Thrift et al. 2008) in all growth stages; however, sheep prefer rosette and bolting foliage compared to flowering foliage (Launchbaugh and Hendrickson 2001; Hale 2002). Sheep select younger (<3 years), smaller, more palatable spotted knapweed plants (Olson and Wallander 2001). Repeated sheep grazing can reduce the number of spotted knapweed plants and recruitment of younger plants into the community (Olson et al. 1997c; Olson and Wallander 1998). Sheep increase their use of spotted knapweed when other forbs are less available, however, sheep also consume spotted knapweed even when desirable forage is present (Thrift et al. 2008). Long-term repeated sheep grazing may slow the rate of increase of spotted knapweed spread (Olson et al. 1997c). Prescribed sheep grazing during the bolting and flowering stages will reduce spotted knapweed density and number of flowering stems (Launchbaugh and Hendrickson 2001). Sheep select flower heads (Olson and Wallander 2001), which reduces seed production (Olson et al. 1997c). Defoliating spotted knapweed during the late-bud/early flower stages effectively suppresses spotted knapweed seed viability (Benzel 2008).

In southwestern Montana, Olson et al. (1997c) reported that three consecutive summers of sheep grazing negatively impacted spotted knapweed while minimally affecting native desirable grasses. They grazed 5 Targhee yearling ewes, with no previous spotted knapweed exposure, on 0.1-ha spotted knapweed-infested pastures. Pastures were grazed for 5-7 days in mid-June, 2-6 days in July, and 1-2 days in early September, depending on forage availability. During the first year, pastures were dominated by spotted knapweed (25%) and Idaho fescue (41%). Sheep grazing reduced spotted knapweed seedling densities, rosettes, and mature plants. Sheep reduced spotted knapweed recruitment into the population by preferring younger age classes and reducing viable seed production from older pants. Grazed pastures had fewer spotted knapweed seeds in the soil (12 seeds $m^{-2}$) compared with ungrazed pastures (49 seeds $m^{-2}$). Idaho fescue densities increased 40% in grazed pastures (Olson et al. 1997c).

Cattle are not widely used for weed control because of their morphology and diet preferences; however, cattle have contributed to weed management programs for some species. On California annual grasslands, when cattle grazed 3 consecutive years during the bolting stage, yellow starthistle flowerhead densities were reduced and canopy densities were reduced more than 90% in 2 of the 3 years (Thomas et al. 1993). In southwestern Montana, intensive cattle grazing reduce densities of oxeye daisy (*Chrysanthemum leucanthemu*) seedlings and rosettes, and reduce the number of seeds incorporated into the soil (Olson et al. 1997a). Intensive grazing pressure in the summer by cattle reduces the number of seedlings and juvenile plants of broom snakeweed (*Gutierrezia sarothrae*) (Ralphs and Banks 2008). Cattle have also been successfully used to control pampas grass (*Cortaderia* spp.) in New Zealand forests (Dale and Todd 1988; West and Dean 1990). In radiata pine (*Pinus radiata* D. Don) forests of New Zealand, cattle have been used for controlling bracken fern (*Pteridium* spp.) and gorse (*Ulex europaeus* L.) (West and Dean 1990).

## Microhistological Analysis for Determining Diet Composition

Microhistological analysis is a widely accepted method for determining diet botanical composition of ruminants (Sparks and Malechek 1968; Dearden et al. 1975; Vavra and Holechek 1980; Holechek and Gross 1982b; Alipayo et al. 1992). Microhistological analysis is based on several assumptions. These assumptions include: 1) fragments of every plant species ingested and all its plant parts are recoverable and identifiable in fecal samples (Storr 1961), 2) results are repeatable among technicians (Sparks and Malechek 1968), 3) recovery and identification rates are proportional to ingested rates or correction factors can be developed for differential digestibility (Dearden et al. 1975), and 4) frequency of occurrence of ingested material in the sample and the weight or density of that material has a predictable relationship (Sparks and Malechek 1968; Gill et al. 1983). Some advantages of this analysis are the ability to collect large numbers of fecal samples with limited observation of animals, no need to harvest animals or disrupt their foraging behavior, and topography or vegetation does not affect the ability to collect fecal samples (Smith and Shandruk 1979). Disadvantages of this analysis include variation in accuracy between technicians (Holechek and Gross 1982a), differences in diet estimates between fecal and rumen samples due to differential digestibility (Vavra et al. 1978; McInnis et al. 1983), and the extensive time required in the laboratory. When forbs, shrubs, or both are a major component of the diet, microhistological analysis can be inaccurate (Voth and Black 1973; Westoby et al. 1976; McInnis et al. 1983; Gill et al. 1983). Forbs tend to be underestimated because they are highly digestible (Vavra and Holechek 1980; McInnis et al. 1983). Grass and browse species can either be under- or over-estimated in fecal analyses depending on the species (Dearden et al. 1975; Vavra and Holechek 1980). Phenology can also affect digestibility and cause over- or under-estimation of forages (Leslie et al. 1983). Differential digestibility may bias potential estimates of herbivore diets (Smith and Shandruk 1979) therefore; fecal sample analysis can be adjusted for differential digestion by creating correction factors through in vitro digestibility of selected forage (Dearden et al. 1975, Vavra and Holecheck 1980; Leslie et al. 1983; McInnis et al. 1983). The effect of correction factors on fecal analysis results depends on the relative proportions of each forage species in the diet (Leslie et al. 1983).

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# CHAPTER 3

# SEQUENTIAL CATTLE AND SHEEP GRAZING FOR SPOTTED KNAPWEED CONTROL

## Introduction

Spotted knapweed (*Centaurea stoebe* L. ssp. *micranthos* (Gugler) Hayek) is a perennial forb investing millions of hectares of native rangeland in the United States and has become an environmental concern in Montana. Spotted knapweed invests over 1.5 million hectares of rangeland in Montana (MWSSC 2005) and is currently in every Montana county (USDA-NRCS 2007). These large infestations reduce cattle and wildlife forage (Watson and Renney 1974), reduce biodiversity (Tyser and Key 1988), and cost Montana's economy over $42 million in losses annually (Hirsch and Leitch 1996). Spotted knapweed is becoming an increasing threat in Montana because the rate of spread for this invasive plant ranges between 10 and 27% per year (Griffith and Lacey 1991; MWSSC 2005). The high cost of using herbicide to control large-scale infestations have land managers and some cattle producers looking for more economical methods to control spotted knapweed.

Prescribed sheep grazing of spotted knapweed during its bolting stage occurring in June and its flowering stage occurring in July reduces spotted knapweed density, number of flowering stems, and the number of viable seeds contributed to the seedbank (Olson et. al. 1997; Launchbaugh and Hendrickson 2001; Benzel 2008). However, when prescribed sheep grazing is used for spotted knapweed control, cattle producers may be concerned that sheep will over-use graminoids in spotted knapweed infested-pastures and reduce available cattle forage. The amount of graminoids and forbs sheep consume parallels the amounts available on spotted knapweed-infested foothill rangeland (Thrift et al. 2008). Since cattle prefer grasses, grazing cattle prior to sheep may reduce graminoid availability and increase forb availability, which suggests sheep may increase their use of spotted knapweed if grazed immediately after cattle. Prescribed sheep grazing on light infestations achieved 46% utilization on spotted knapweed and 37% utilization on desirable graminoids in either June or July (Thrift et al. 2008), suggesting that prescribed sheep grazing in either month can achieve adequate use on spotted knapweed while minimizing use on desirable graminoids. Defoliation of spotted knapweed reduced seed viability by 90% in June and 100% in July (Benzel 2008). Therefore, grazing in those two months would be the most effective in reducing seeds, if animals graze before the plants set seed. Additionally, administering prescribed sheep grazing in June or July generally coincides with summer grazing management strategies on cattle operations. Therefore, the objectives of this study were to: 1) compare graminoid and spotted knapweed utilization by cattle and sheep grazed sequentially in June vs. July, and 2) compare diet composition, dietary preference, and foraging behavior of cattle and sheep grazed sequentially in June vs. July. My hypothesis was that graminoid and spotted knapweed utilization and cattle and sheep diet composition, dietary preference, and foraging behavior would not differ between June and July when cattle and sheep graze sequentially.

## Materials and Methods

### Study Area

The study area for this 2-year study was located on the Paws Up Ranch near Greenough, MT (46.9028ºN, 113.4230ºW) at approximately 1,100 m in elevation. The ecological site is Silty, in the 381 to 483-mm precipitation zone (USDA-NRCS 2003), and is classified as a mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle)/rough fescue (*Festuca campestris* Rydb.) habitat type (Mueggler and Stewart 1980). The 41-year average precipitation is 375-mm (Potomac, Montana 46.881N, 113.578W), with 38% falling as rain between April and July (WRCC 2006). The average minimum and maximum temperatures are 4 and 22ºC in June and 5 and 28ºC in July, respectively. Soils are very deep, somewhat excessively drained, Perma gravelly and stony loams (Loamy-skeletal, mixed Typic Haploborolls), which formed in alluvium (USDA-NRCS 2003).

Dominant graminoid species on the site include Idaho fescue (*Festuca idahoensis* Elmer), rough fescue, bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve), threadleaf sedge (*Carex filifolia* Nutt.), prairie junegrass (*Koeleria macrantha* (Ledeb.) J.A. Schultes), and Sandberg bluegrass (*Poa secunda* J. Presl). Dominant forb species include spotted knapweed, lupine (*Lupinus sericeus* Pursh), rose pussytoes (*Antennaria rosea* Greene), and western yarrow (*Achillea millefolium* L.). The primary shrub on the site is mountain big sagebrush.

Grazing Trial

Twenty-one Targhee yearling wethers and 9 Black Angus yearling cattle were used for the grazing trial. Animals were randomly assigned to 0.81-ha pastures composed of rangeland vegetation, approximately 15% spotted knapweed, and a small component of mountain big sagebrush (6%). The phenological stages of spotted knapweed plants were the bolting stage (June) and the late bud/early flower stage (July). Pastures were grazed in either mid-June or mid-July [n=6 pastures (experimental units), 3 pastures (replicates) per month] for 2 summers (2006 and 2007). Treatments included: 1) cattle grazing immediately followed by sheep grazing in mid-June, and 2) cattle grazing immediately followed by sheep grazing in mid-July. Cattle (n=3 per pasture) grazed three pastures in mid-June and three pastures in mid-July for seven days, followed immediately by sheep (n=7 per pasture) grazing for seven days each month. All pastures were grazed at a stocking rate of 1.1 ha $AUM^{-1}$. Animals were provided a 5-day warm-up period in an additional pasture in June and July to acclimate to the forage on the site before grazing the treatment pastures.

Plant Species Composition

Forage available to cattle and sheep was measured in each pasture prior to cattle grazing and at post-cattle/pre-sheep grazing using a modified Daubenmire Canopy Coverage Method with seven classes (Bailey and Poulton 1968). Percent canopy cover of all species was recorded at 2-m intervals along a permanent, 60-m transect (n=30 quadrats) in each pasture, using the following coverage classes: class 1) 0-1%; class 2) 1-5%; class 3) 5-25%; class 4) 25-50%; class 5) 50-75%; class 6) 75-95%; and class 7) 95-

100%. Canopy cover was calculated for each species per pasture prior to cattle grazing and at post-cattle/pre-sheep grazing in June and July. Plant species composition of each pasture was determined by dividing percent canopy cover of each plant species by the summed canopy cover of all plant species within each pasture.

Botanical Composition of Livestock Diets

Botanical composition of sheep and cattle diets was determined using microhistological analysis of fecal samples. Fresh fecal samples were collected from cattle and sheep on days five through seven and then composited for each grazing period (n=3 composite samples species$^{-1}$ month$^{-1}$ year$^{-1}$). Samples were analyzed with fecal microhistological analysis (Sparks and Malecheck 1968) to determine the botanical composition of cattle and sheep diets. Slides were prepared as described by Davitt and Nelson (1980). Six slides were analyzed per sample. Twenty-five microscope fields were randomly selected and viewed per slide (n=150 views/sample). Slides were analyzed at 100x magnification; however, 200x magnifications were used for better resolution of fragments that were difficult to identify (Holechek and Valdez 1985). Plant epidermises were identified by life form (i.e., graminoid, forb, and shrub), with the exception of spotted knapweed, which was identified by species. The presence of all identifiable epidermises in each view was recorded. The frequency addition method (Holechek and Gross 1982b) was used to calculate diet composition.

Correction factors are recommended to improve the accuracy of microhistological analysis (Dearden et al. 1975; Vavra and Holechek 1980; Leslie et al. 1983; Holechek et al. 1982a). Forage mixtures were prepared following the procedure of Vavra and

Holechek (1980) and digested for 48 hours using the ANKOM Daisy$^{II}$ incubator (ANKOM Technology, Fairport, NY). Rumen fluid was obtained from cows fed a grass/alfalfa hay diet.

Botanical composition of digested samples was analyzed via microhistological analysis using the same procedures described above for fecal samples. Correction factors were calculated following the procedure of Leslie et al. (1983). Correction factors were applied to the botanical composition estimates derived from the microhistological analysis of fecal samples to arrive at the final estimates of the botanical composition of cattle and sheep diets.

Relative Preference Indices

Relative preference indices (RPI) were used to evaluate diet selection by cattle and sheep during each grazing period. Preference or avoidance of available forage species was determined by dividing each species' percent composition in cattle and sheep diets by its percent composition in the corresponding pasture (Krueger 1972). Confidence intervals were calculated per Hobbs and Bowden (1982). When confidence intervals did not include 1.0, RPI > 1.0 indicated preference, whereas RPI < 1.0 indicated avoidance.

Relative Forage Utilization

Relative utilization (Frost et al. 1994) of spotted knapweed and perennial graminoids was measured after cattle (relative utilization by cattle) and sheep (relative utilization by cattle + sheep) grazing in June and July using the Grazed Class Method (McKinney 1997; USDA-USDI 1996). Percent utilization of the nearest graminoid (basal width ≥ 3 cm) and spotted knapweed plant were measured at 2-m intervals along a 60-m permanent transect in each pasture. Each plant was were assigned to one of six utilization categories (0%, 0-20%, 20-40%, 40-60%, 60-80%, 80-100%) (n=30 spotted knapweed plants, n=30 graminoid plants) (McKinney 1997; USDA-USDI 1996).

Livestock Foraging Behavior

Cattle and sheep foraging behavior was monitored in June and July by recording the length of time an individual animal spent at a feeding station, defined as a feeding station interval (Ruyle and Dwyer 1985), and the number of steps between feeding stations (El Aich et. al. 1989). A feeding station is the area accessible to a grazing animal without moving its forefeet (Goddard 1968). I observed animals near dawn, during peak foraging, on days 2-7 of the grazing period. Within each pen, the three cattle and three randomly selected focal sheep were selected and observed for five minutes each. I documented animal behavior (i.e., feeding station interval and steps between feeding stations) using a tape recorder in the field and later transcribed the data to an observation data form.

Statistical Analyses

The experimental design for this study was a split-plot in time with two times of grazing (June, July) and two years (2006, 2007). The whole plot factor was time of grazing and the sub-plot factor was year. Data were analyzed using the GLM procedure of SAS (SAS 2004). Differences in diets, relative preference indices, foraging behavior, and relative utilization between June and July for cattle and sheep were determined using analysis of covariance, with the pre-grazing percent canopy cover of spotted knapweed in each pasture used as the covariable (Table 1). Differences were considered significant at $P \leq 0.10$.

Table 1. Analysis of covariance table with sources and degrees of freedom for the 2-factor split-plot in time.

| Source | Degrees of Freedom |
|---|---|
| Covariable | 1 |
| Month | 1 |
| Error a | 3 |
| Year | 1 |
| Month | 1 |
| Error b | 4 |
| Total | 11 |

## Results

### Relative Forage Utilization

Graminoid utilization by cattle varied by year (year x month interaction; *P*=0.09; Table 2). In 2006, graminoid use by cattle was less in June and July (*P*=0.06) with 11% and 27% relative utilization, respectively. In 2007, graminoid use by cattle did not differ (*P*=0.33) between June and July, with an average of 29% utilization. Graminoid utilization by cattle and sheep combined also varied by year (year x month interaction; *P*=0.10; Table 2). In 2006, graminoid use by cattle and sheep combined did not differ (*P*=0.20) between June and July, with an average of 39% utilization. In 2007, graminoid

Table 2. Relative utilization of graminoids and spotted knapweed (± SE) by cattle and cattle + sheep in June or July on foothill rangeland in western Montana.

| | Year | | | | | |
|---|---|---|---|---|---|---|
| | 2006 | | 2007 | | Mean | |
| | June | July | June | July | June | July |
| | (%) | | | | | |
| Cattle | | | | | | |
| Graminoid | 10.9 (2.1)a | 26.9 (4.6)b | 26.9 (2.9)a | 31.1 (1.1)a | 18.9 (3.9) | 29.0 (2.3) |
| Spotted Knapweed | 44.0 (7.0)a | 34.6 (5.3)b | 41.7 (1.7)a | 43.8 (3.3)a | 42.8 (3.3)a | 39.2 (3.5)b |
| Cattle + Sheep | | | | | | |
| Graminoid | 35.8 (3.0)a | 42.6 (4.5)a | 42.2 (5.9)a | 38.3 (1.8)a | 39.0 (3.3) | 40.5 (2.4) |
| Spotted Knapweed | 62.8 (7.8)a | 61.7 (1.3)b | 61.1 (1.8)a | 60.6 (3.6)a | 61.9 (3.6)a | 61.1 (1.7)a |

[1]Means within rows, within years with the same letter did not differ ($P \geq 0.10$).

use by cattle and sheep combined did not differ (*P*=0.52) between June and July, with an average of 40% utilization.

Spotted knapweed utilization by cattle was greater in June than July (*P*<0.01) with relative utilization of 43% and 39%, respectively (Table 2). Spotted knapweed use by cattle and sheep combined did not differ (*P*=0.20) between June and July, with an average of 61.5% relative utilization.

Botanical Composition of Livestock Diets

Graminoids   Cattle diets contained more graminoids in June than July (*P*<0.01), with 44% and 34% graminoids in their diets, respectively (Table 3). Sheep diets also contained more graminoids in June than July (*P*<0.01), with 39% and 31% graminoids in their diets, respectively (*P*=0.06).

Spotted Knapweed   The amount of spotted knapweed in cattle diets differed between June and July (*P*=0.03), with 12% and 26%, respectively (Table 3). Sheep diets also differed between June and July, with 11% and 28% spotted knapweed in their diets, respectively (*P*=0.05).

Forbs   Amounts of forbs (minus spotted knapweed) in cattle diets did not differ between June and July, with an average of 42% forbs in their diet (*P*=0.37; Table 3). Forb (minus spotted knapweed) composition of sheep diets varied by year (year x month interaction; *P*=0.05; Table 3). In 2006, sheep diets did not differ between June and July

Table 3. Perennial graminoids, spotted knapweed, and forbs (minus spotted knapweed) (±SE) in cattle and sheep diets in June or July on foothill rangeland in western Montana.

| | Year | | | | | |
|---|---|---|---|---|---|---|
| | 2006 | | 2007 | | Mean | |
| | June | July | June | July | June | July |
| | --------------------------------------------- | ------------------------------------------------------ | % | ------------------------------------------------------ | ------------------------------------------------------ | --------------------------------------------- |
| Cattle | | | | | | |
| Graminoids | 49.8 (2.1)a | 35.2 (2.0)b | 37.2 (1.6)a | 32.5 (2.6)a | 43.5 (3.1)a | 33.9 (1.6)b |
| Spotted Knapweed | 8.2 (1.8)a | 25.1 (3.1)a | 16.1 (2.6)a | 26.0 (5.5)a | 12.2 (2.3)a | 25.6 (2.8)b |
| Forbs | 42.0 (0.4)a | 39.7 (1.2)a | 46.7 (2.9)a | 41.5 (3.2)a | 44.3 (1.7)a | 40.5 (1.6)a |
| Sheep | | | | | | |
| Graminoids | 41.8 (2.1)a | 35.0 (2.9)b | 36.6 (1.0)a | 27.7 (1.6)b | 39.2 (1.6)a | 31.4 (2.2)b |
| Spotted Knapweed | 7.7 (1.8)a | 19.5 (5.7)a | 13.4 (3.3)a | 36.5 (2.4)b | 10.6 (2.1)a | 28.0 (4.7)b |
| Forbs | 50.5 (0.8)a | 45.5 (3.3)a | 50.0 (2.3)a | 35.8 (0.8)b | 50.2 (1.1) | 40.6 (2.6) |

[1]Means within rows, within years with the same letter did not differ (*P*≥0.10).

and consisted of 48% forbs (*P*=0.44). In 2007, sheep diets differed between June and July, with 50% and 36% forbs present, respectively (*P*=0.03).

Relative Preference Indices

In 2006, both cattle and sheep avoided spotted knapweed in June (RPI=0.5 and 0.4, respectively) and graminoids in July (RPI=0.7 and 0.7, respectively) (Table 4). Sheep also avoided graminoids in June 2006 (RPI=0.7). Cattle and sheep preferred forbs (minus spotted knapweed) in July 2006 (RPI= 1.3 and 1.5, respectively). In 2007, cattle avoided graminoids in July (RPI=0.7), while sheep avoided graminoids in both June and July (RPI=0.7 and 0.6, respectively). Sheep preferentially selected spotted knapweed in July 2007 (RPI=3.5).

Overall preference or avoidance was determined by pooling 2006 and 2007 data. Cattle and sheep preferred forbs in June (RPI=2.3 and 2.6, respectively) (Table 4). In July, cattle avoided graminoids (RPI=0.7), but preferred spotted knapweed and forbs (RPI=2.1 and 1.3, respectively). Sheep avoided graminoids in both June and July (RPI=0.7 and 0.6, respectively).

Livestock Foraging Behavior

Feeding station intervals (FSI) for cattle did not differ between June and July (*P*=0.62) and averaged 16 seconds per feeding station (Table 5). FSI for sheep also did not differ (*P*=0.77) between June and July, with an average of 12 seconds per feeding station.

Table 4. Relative preference indices (RPI) with confidence intervals (CI) for cattle and sheep grazing graminoids, spotted knapweed, and forbs (minus spotted knapweed) in June or July on foothill rangeland in western Montana.

| | | | June | | July | |
|---|---|---|---|---|---|---|
| Year | Species | Forage Class | RPI | 90% CI[1] | RPI | 90% CI |
| 2006 | Cattle | Graminoids | 0.9 | 0.7 – 1.1 | 0.7 | 0.5 – 0.8 |
| | | Spotted Knapweed | 0.5 | 0.0 – 0.9 | 1.8 | 0.9 – 2.7 |
| | | Forbs | 2.3 | 0.5 – 4.1 | 1.3 | 1.2 – 1.5 |
| | Sheep | Graminoids | 0.7 | 0.5 – 0.9 | 0.7 | 0.5 – 0.9 |
| | | Spotted Knapweed | 0.4 | 0.0 – 0.9 | 1.4 | 0.1 – 2.7 |
| | | Forbs | 2.8 | 0.7 – 4.9 | 1.5 | 1.2 – 1.9 |
| 2007 | Cattle | Graminoids | 0.7 | 0.5 – 1.0 | 0.7 | 0.5 – 0.9 |
| | | Spotted Knapweed | 1.0 | 0.2 – 1.8 | 2.5 | 0.5 – 4.4 |
| | | Forbs | 2.3 | 0.7 – 3.9 | 1.2 | 0.9 – 1.5 |
| | Sheep | Graminoids | 0.7 | 0.5 – 0.9 | 0.6 | 0.4 – 0.7 |
| | | Spotted Knapweed | 0.9 | 0.1 – 1.6 | 3.5 | 1.6 – 5.3 |
| | | Forbs | 2.5 | 0.8 – 4.2 | 1.1 | 0.9 – 1.2 |
| Means | Cattle | Graminoids | 0.8 | 0.6 – 1.0 | 0.7 | 0.6 – 0.8 |
| | | Spotted Knapweed | 0.7 | 0.2 – 1.2 | 2.1 | 1.2 – 3.0 |
| | | Forbs | 2.3 | 1.3 – 3.4 | 1.3 | 1.1 – 1.5 |
| | Sheep | Graminoids | 0.7 | 0.6 – 0.9 | 0.6 | 0.5 – 0.8 |
| | | Spotted Knapweed | 0.6 | 0.2 – 1.1 | 2.3 | 1.0 – 3.6 |
| | | Forbs | 2.6 | 1.4 – 3.8 | 1.3 | 1.0 – 1.5 |

[1]Confidence 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.

Table 5. Feeding station interval (FSI) and number of steps between feeding stations (steps) (± SE) of cattle and sheep in June or July on foothill rangeland in western Montana.

| | Year | | | | | |
|---|---|---|---|---|---|---|
| | 2006 | | 2007 | | Mean | |
| | June | July | June | July | June | July |
| | (seconds) | | | | | |
| FSI | | | | | | |
| Cattle | 15.7 (1.3)a | 16.8 (1.3)a | 14.2 (0.8)a | 16.6 (0.5)a | 14.9 (0.8)a | 16.7 (0.7)a |
| Sheep | 11.4 (0.8)a | 13.2 (0.8)a | 10.7 (0.5)a | 12.4 (0.5)a | 11.0 (0.5)a | 12.8 (0.5)a |
| | (no.) | | | | | |
| Steps | | | | | | |
| Cattle | 2.4 (0.3)a | 2.1 (0.2)b | 1.9 (0.1)a | 1.6 (0.1)b | 2.2 (0.2)a | 1.9 (0.1)b |
| Sheep | 4.3 (0.4)a | 3.1 (0.2)b | 3.0 (0.2)a | 2.4 (0.1)b | 3.7 (0.2)a | 2.7 (0.1)a |

[1]Means in the same row within years with the same letter are not different ($P \geq 0.10$).

Steps between feeding stations for cattle differed (*P*<0.01) between June and July with 2.2 and 1.9 steps, respectively (Table 5). Steps between feeding stations for sheep did not differ (*P*=0.30) between June and July with an average of 3.2 steps between feeding stations.

## Discussion

Relative utilization of spotted knapweed averaged 61.5% when cattle and sheep grazed sequentially in June (spotted knapweed in bolting stage) or July (spotted knapweed in late bud/early flowering stage). This level exceeds the predicted 30% utilization threshold level where the application of herbicides is uneconomical on high producing sites (Griffith and Lacey 1991). Similar to my results, prescription sheep grazing of spotted knapweed in Idaho resulted up to 85% utilization on spotted knapweed in all grazing seasons (Hale 2002). Spotted knapweed utilization by cattle and sheep combined (61.5%) in my study fits in the range found by Hale (2002), however, it was 30% greater than that found by Thrift et al. (2008) when only sheep grazed foothill rangeland with similar spotted knapweed composition. In light spotted knapweed infestations (13% vegetative composition), sheep averaged 46% relative utilization on spotted knapweed (Thrift et al. 2008).

Greenhouse studies showed a single 75% relative utilization clipping during the bolting stage reduced spotted knapweed vigor and standing crop, however, the same results were not found with a single 25% relative utilization clipping during the bolting stage (Kennet et al. 1992). Newingham and Callaway (2006) reported that clipping 50%

of the above ground biomass of spotted knapweed in early summer and again in late summer reduced its biomass 40% at the end of the season. These studies indicate that the 61.5% utilization on spotted knapweed in June or July in my study is high enough to adversely impact spotted knapweed.

When cattle and sheep grazed sequentially in June or July, relative utilization of graminoids was moderate (36-43%). The combined effect of cattle and sheep utilization was safely within sustainable graminoid utilization levels (40-60%) recommended for foothill rangelands in western Montana (Lacey and Volk 1993). My results indicate that grazing cattle and sheep sequentially in either June or July can effectively be used to negatively impact spotted knapweed while maintaining optimal utilization levels of desirable graminoids on foothill rangeland.

Sheep consumed 60% more spotted knapweed in July than June in my study, which may have been due to the higher forage quality of spotted knapweed than graminoids in July (Olson and Wallander 2001; Thrift 2005). In western Montana, sheep diets averaged 26% spotted knapweed in light spotted knapweed infestations (Thrift et al. 2008). When diets were compared to the amount of relative forage available on my study site, sheep avoided graminoids in both months and sheep consumed spotted knapweed in quantities proportional to its relative availability. Similar trends were reported by Thrift et al. (2008). Since sheep use forage relative to its availability (Thrift et al. 2008), these results are consistent with the idea that grazing cattle prior to sheep grazing may induce utilization of spotted knapweed while minimizing use on desirable graminoids.

Sheep in my study consumed less graminoids in July than June. On a moderate spotted knapweed infestation in western Montana (36% composition), similar trends were reported of sheep diets having a lower proportion of graminoids in July compared to June (Thrift et al. 2008). Conversely, sheep diets in a light spotted knapweed infestation had higher proportion of graminoids in July compared to June (Thrift et. al. 2008). Availability of forage life forms in the moderate spotted knapweed infestation (more knapweed, less graminoids than the light infestation) may have more closely resembled forage availability on my lightly infested sites following cattle grazing.

Sheep preferred forbs over graminoids in June and showed no preference or avoidance of forbs in July. Similar to my study, in a light spotted knapweed infestation in western Montana, forbs were a major component of sheep diets in either June or July (averaging 39%), and sheep did not show any preferences or avoidances of forbs (Thrift et al. 2008).

Cattle diets were mainly composed of graminoids and forbs, but cattle also included spotted knapweed in their diets both months (12% in June and 26% in July). There is little to no historic data that has documented spotted knapweed inclusion in cattle diets. My study indicates that cattle will include spotted knapweed in their diets. In fact, cattle preferred spotted knapweed in July, which may be due to higher forage quality of spotted knapweed than graminoids in July (Olson and Wallander 2001; Thrift 2005).

Livestock change their foraging behavior according to the amount of forage available (Arnold 1981) and utilize resources by selective grazing (Prache et al 1998). However, the small differences in foraging behavior of cattle and sheep in my study indicate that both species perceived the available forage similarly in June and July. Cattle took more steps between feeding stations in June than July. Similar results were found in the Great Basin, where cattle grazed more selectively during the bolting stage and grazed less selectively when plant phenology advanced later in the growing season (Ganskopp et al. 1977). An animal's threshold of acceptance changes according to the palatability of plants recently grazed; when animals graze high quality forage their threshold increases, and if they graze low quality forage their threshold decreases (Bailey et al. 1996).

## Management Implications

Spotted knapweed is capable of creating large monocultures that reduce available forage for cattle and wildlife. Concern in Montana is growing because spotted knapweed infests over 1.5 million hectares of native rangeland (MWSSC 2005) and costs the state over $42 million in losses per year (Hirsch and Leitch 1996). The high cost (minimum of $61.75 per hectare) (MWSSC 2005) and the need for frequent application of herbicides (Sheley 1999) make herbicide use uneconomical for treating large-scale infestations and has land managers and livestock producers looking for more economical methods for spotted knapweed control. Prescribed sheep grazing can effectively suppress spotted knapweed, but cattle producers are concerned that sheep may over-utilize the graminoids in spotted knapweed-infested pastures and reduce forage available to cattle. In my study, relative utilization of spotted knapweed averaged 61.5% when cattle and sheep grazed sequentially. Previous research indicates that this level of utilization may make the use of herbicides uneconomical (Griffith and Lacey 1991), and also may reduce the vigor and standing crop of spotted knapweed (Kennet et al. 1992; Lacey et al. 1994; Benzel 2008). The 61.5% relative utilization of spotted knapweed exceeded the 46% relative utilization achieved by sheep grazing without cattle on a similar site in western Montana (Thrift et al. 2008). Relative utilization of graminoids was moderate (<45%) when cattle and sheep grazed sequentially. This level is safely within sustainable graminoid utilization levels (40-60%) recommended for foothill rangelands in western Montana (Lacey and Volk 1993). Additionally, a recent study done on foothill rangeland in western Montana showed that defoliating spotted knapweed during the bolting stage (June) and late-bud/early flower (July) or full flowering stage (August) reduced its viable seed production by 90-100% (Benzel 2008). Therefore, cattle ranches with large spotted knapweed infestations can effectively use prescribed sheep grazing immediately following cattle grazing in June or July to achieve high levels of use on spotted knapweed, thus reducing viable seeds incorporated into the soil, while minimizing over-use of desirable cattle forage.

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