DEVELOPING PRESCRIPTION GRAZING GUIDLINES FOR CONTROLLING SPOTTED KNAPWEED WITH SHEEP

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AUTHORIZATION TO SUBMIT THESIS

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Abstract

Spotted knapweed (*Centaurea stoebe* L. subsp. *micranthos*)[1], a perennial herbaceous plant, is considered one of the most troublesome rangeland weeds in the western United States and Canada. Contemporary weed management focuses on herbicide and biocontrol, yet often overlooks livestock grazing in control strategies. A study was initiated to examine the potential of sheep grazing to control spotted knapweed. The objectives were to (1) assess nutritional quality of spotted knapweed, (2) examine sheep preference for spotted knapweed in three phenological states, and (3) examine utilization and diet quality by sheep grazing spotted knapweed-infested rangeland. Research was conducted with dry ewes in cooperation with the USDA-ARS U.S. Sheep Experiment Station near Dubois, Idaho. Knapweed samples were collected from a knapweed-dominated sagebrush steppe community, and analyzed for nutritional quality. Nutrient value decreased with the season (crude protein declined from 16-18% in May to 4-5% in September; neutral detergent fiber increased from 33% in May to 58% in Sept.). A cafeteria trial offered sheep spotted knapweed in the rosette, bolting, and flowering stages. Sheep readily consumed knapweed in all growth stages, but generally preferred rosette and bolting stages This suggested that spotted knapweed can be viewed as potential forage, and grazing is a potential tool to contain its spread.

Grazing trials were established in summer 2000 and continued through summer 2001.Trials were conducted on rangelands with average foliar cover of 14% spotted knapweed. The study site was fenced into small paddocks (26 x 26 m) and sheep were grazed at two stocking rates in the rosette, bolting, or flowering growth stages. The low stocking rate consisted of 12 sheep days (1.2 AUM/ha) while the high rate consisted of 20 sheep days per

[1] Scientific name of spotted knapweed follows research on molecular data confirming plants introduced into North America from same taxon native to Europe (Ochsmann, J. 2001).

paddock (2 AUM/ha). During 2001, eight ewes were esophageally fistulated to facilitate the assessment of diet quality. Biomass measured before, during, and after each grazing trial determined utilization experienced by knapweed, other forbs, and grasses. Spotted knapweed utilization exceeded 40% regardless of season or stocking rate. Grass utilization was similar to knapweed though native forbs experienced the greatest utilization. Utilization of knapweed, native forbs, and grass was greater with the high stocking rate ($p< 0.01$). The highest levels of knapweed utilization occurred during the bolting stage (i.e., July). Spotted knapweed was the dominant forage in sheep diets (49% compared to 15% and 37% for native forbs and grass, respectively). Throughout the summer, diet quality met sheep daily maintenance energy requirements. This study suggests that the optimal season for sheep grazing in a prescription-grazing program would be mid-summer (i.e., July), when spotted knapweed is in the bolting stage. At this time, spotted knapweed received more grazing pressure than associated grasses, and is nutritional forage.

Acknowledgements and Dedication

At the end of every journey comes a time to reflect on the relationships that were formed along the way. For those people who have supported, driven, and cajoled me through the process of higher education, thank you. For those who taught the science of range research, a valuable skill that complements the art of herding big grazing animals (excluding elephants and giraffes), thank you. And for those who tolerated my moods and cryptic sense of humor, thank you.

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This body of work is dedicated to my wife, Sara Miller, without whose steadfast love none of this would have been possible, and to my children, Gabriel, Prairie Rose, and Ezekial, each a unique being who provides marvel, wonder and challenge to my life.

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CHAPTER I

Overview of Research on Grazing Spotted Knapweed

Introduction

Weeds on North American rangelands are an immense ecological and economical concern. Grazing by wild ungulates and livestock is a dominant use of rangelands. Therefore, weed management plans need to be designed and implemented with grazing in mind.

When weeds begin to invade, eradication may be possible and is often accomplished with the use of herbicides (Zamora et al. 1989). In these situations, grazing plans should be adjusted to accommodate chemical or mechanical control. As weeds become abundant, grazing could be applied strategically to increase weed control (i.e., prescription grazing). Noxious weeds are an additional vegetative component of rangelands, and can enhance diet choice of grazing animals. In addition, grazing may increase the efficacy of introduced biological control agents impacting noxious weeds.

Noxious rangeland weeds continue to spread at an estimated rate of 8 to 14% per year (Whitson 1998), and in localized areas may increase in acreage by 60% per year (Prather and Callihan 1989). Herbicides, insects, pathogens, and fires have not effectively contained the spread of noxious weeds (Olson et al. 1997, DiTomaso 2000).

Grazing management strategies for weed-infested plant communities may shift toward more realistic goals of using weeds as forage and preventing the proliferation of other exotic plants that may be less palatable or more ecologically damaging (Wright and Kelsey 1997). Grazing may suppress or promote weed dominance depending on the weed's density and the season or stocking rate at which grazing is applied, therefore herbivory must be studied in an ecological context.

Spotted Knapweed

Spotted knapweed (*Centaurea stoebe* L. subsp. *micranthos*[1]), an aggressive Eurasian perennial forb, is present in almost every region of the United States, and is considered one of the most infestive rangeland weeds in the northern United States and Canada (Chicoine et al. 1985, Bogs and Story 1987, Sheley et al. 1998, 1999b). Obligatory out-crossing of spotted knapweed promotes genetic diversity allowing invasion of many habitats (Harrod and Taylor 1995). In Oregon, the presence of spotted knapweed increased from nine townships in 1982 to 177 townships in 1992 (Oregon Department of Agriculture 2001). In Montana, spotted knapweed increased from 1.82 million hectares in 1989 to 4.73 million hectares in 1993, a 40% increase in 4 years.

Spotted knapweed is a designated noxious weed in 35 states including the 11 western states, and the plains states of Minnesota, North and South Dakota, and Nebraska (USDA, NRCS 2001). It is mandatory to control noxious weeds and eradication is the goal of many weed control plans. However, as weed densities increase and weeds become permanent residents in North American plant communities, their potential uses should be evaluated.

Wright and Kelsey (1997) found that wild cervids will graze spotted knapweed, and infestation didn't necessarily reduce carrying capacity of the Selway River winter-spring range. If spotted knapweed is managed as a forage, then nutritional value, diet preference and plant selectivity are important factors to be studied.

[1] Scientific name of spotted knapweed follows research on molecular data confirming plants introduced into North America from same taxon native to Europe (Ochsmann, J. 2001).

Research has shown that spotted knapweed provides adequate forage for sustaining wild and domestic ungulates during the growing season, and is relatively nutritious early in the season (Kelsey and Mihalovich 1987, Wright and Kelsey 1997). In the rosette form, knapweed contains about 24% neutral detergent fiber, 15-20% crude protein, 25% total non-structural carbohydrates, and may exceed 80% *in vitro* digestibility. In late phenological stages, NDF levels increase to 45-50% (Chapter 2). Nutritive value of spotted knapweed decreased as the season progressed, and was primarily due to decreased leaf to stem ratios (Chapter 2). However, leaves on mature plants and new rosettes did not vary in quality throughout the growing season. Consequently, even mature knapweed plants have adequate nutritional quality, and ungulates may selectively harvest the most nutritious parts of the plant.

As spotted knapweed matures, levels of cnicin, a sesquiterpene lactone, increase (Olson and Kelsey 1997). Spotted knapweed seed heads contained the lowest concentrations of cnicin of any plant part, while rosette leaves consistently showed much higher concentrations. Cnicin concentrations remained relatively constant in senescent tissues from December through April and did not increase in rosette leaves with the onset of spring growth (Wright and Kelsey 1997). Cnicin was found to be a probable cause for depressing *in vitro* rumen microbial activity (Olson and Kelsey 1997). This bitter tasting allelochemical is also thought to reduce knapweed palatability, but has not been confirmed as a grazing deterrent (Olson et al. 1997). On the contrary, research has shown domestic sheep (*Ovis aries*) initially preferred rosette plants, but readily consumed spotted knapweed at three growth stages (Chapter 2). This suggests that fiber content, and or allelochemicals in spotted knapweed provide little deterrence to sheep grazing.

Livestock as Weed Control Agents

Historically, livestock have contributed to degradation of rangelands through extensive overgrazing. Improving grazing strategies may be an economical tool to restore ecological condition of grazed systems. In many range plant communities, constant grazing pressure of cattle has caused an increase in non-native forbs and a decrease of native grasses. The class of livestock is important when designing prescription grazing. Domestic sheep can obtain daily nutritional requirements from a variety of forages, including fibrous weeds (Olson and Lacey 1994). Sheep generally consume larger quantities of forbs and include a greater proportion of forbs in their diet than cattle and horses (Hanley 1982). Most noxious weeds are forbs and during the growing season, forbs can provide a high quality diet. Relative to their small size, sheep have a relatively large rumen and a long small intestine. Because of these characteristics, Hoffman (1989) categorized sheep as bulk and roughage eaters, which have slow passage rates and low fermentation rates. Sheep have a muscular pad in the upper jaw, a cleft upper lip and relatively narrow muzzle, which allows them to take small bites and select specific parts of a plant (Arnold and Dudzinski 1978, Hofmann 1989). Thus, sheep graze selectively, can harvest prostrate plants, strip leaves from branches, break and chew twigs, and pick off individual leaves (Hofmann 1989, Valentine 1990, Olson and Lacey 1994).

Herbivory and competition greatly affect plant abundance and distribution (Crawley 1983, Louda et al. 1990). Three summers of repeated sheep grazing was shown to negatively impact spotted knapweed, but minimally affect the surrounding native grass community (Olson et al. 1997). This study found that sheep preferred younger, smaller spotted knapweed plants, and repeated grazing reduced reproduction potential. Another study reported that defoliation at monthly intervals reduced root and crown weights, and carbohydrate concentrations in roots, crown and stems (Kennett et al. 1992).

Herbivory may decrease growth, stimulate regrowth, or cause mortality (Olson and Lacey 1994). Therefore, the effective use of sheep to control noxious weeds depends on strategies that reduce the population at critical life-cycle stages, (e.g., early summer juvenile survivorship, late summer adult survivorship, transition from juvenile to adult, and seeds produced by adults; Jacobs and Sheley 1998). It is critical that strategies negatively impact target weed species, while increasing competitiveness of the associated plant community. Basic plant-animal interactions that mediate a weed's persistence must be understood. This requires knowledge of a plant’s ability to tolerate and avoid grazing (Briske 1996). Prescription grazing for spotted knapweed will require that herbivory is applied when knapweed is most susceptible to damage by grazing and is most palatable to the herbivore. Furthermore, grazing should be applied when the associated plant community is the most grazing tolerant or relatively least palatable.

A study examining the effects of sheep grazing spotted knapweed infested range in eastern Idaho found knapweed flower production was lower in grazed areas, particularly when grazed during the rosette stage. Later season grazing reduced density of young knapweed plants (Patten 2002). Plant community data will help determine when knapweed is most susceptible to grazing and when the associated plant community is most tolerant to grazing, both essential components of prescription grazing.

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CHAPTER II

Nutritional Value of Spotted Knapweed and Seasonal Preference by Sheep[2]

Introduction

Invasion of western rangelands by exotic plant species is one of the most significant ecological threats facing North America (Vitousek et al. 1996, Mullin et al. 2000). Weed invasions into rangeland ecosystems threaten ecological integrity by reducing biodiversity, altering native plant communities, increasing soil erosion, degrading wildlife habitat, and reducing carrying capacity for domestic and wild ungulates (Lacey et al. 1989, Tramell and Butler 1995, Mirsky 1999, Olson 1999a, DiTomaso 2000). These detrimental impacts yield degradation of economic and social values of rangeland such as reduced forage quality, increased costs of livestock production, and reduced recreational opportunities (Olson 1999a, DiTomaso 2000).

Livestock grazing is a notable use of rangeland ecosystems throughout the world. Overgrazing by livestock has often been implicated in the spread of noxious weeds (Bedunah 1992). However, carefully managed grazing could be employed in the battle against weeds if the specific time of grazing and necessary stocking rate were known for specific weeds. Recent success with the use of sheep and goats to control some rangeland weeds, such as leafy spurge (*Euphorbia esula* L.), has fueled interest in grazing for weed control (Walker et al. 1994, Olson and Lacey 1994).

The animal production consequences of employing grazing for weed control must also be elucidated. Despite the potential biological efficacy of using livestock to control

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[2] This chapter was prepared with assistance of Amy Ganguli and Karen Launchbaugh and will be submitted for publication with these authors.

weeds, managed grazing will not be widely used for weed control until it is shown to be compatible with production goals (Olson and Lacey 1994). Some rangeland weeds constitute a good forage resource. For example, sheep grazing leafy spurge-infested rangeland outperform their counterparts on non-infested rangelands (Fay 1991, Williams et al. 1996). However, employing animals to control course low-quality weeds, such as mature knapweed (*Centaurea spp.*) or rush skeletonweed (*Chondrilla juncea* L.), will undoubtedly result in some production losses (Laca et al. 2001).

Some argue that sheep grazing, for example, will never be an effective weed management tool because sheep availability is limited (Fay 1991). However, sheep enterprises based on weed control are becoming more abundant on rangelands of Western North America and opportunities may increase if shown to be economically favorable. Established livestock enterprises may also consider including prescription grazing for weed control as part of their grazing plan if it is proven effective for weed control and not substantially detrimental to livestock production goals.

Converting grazing from a ubiquitous rangeland practice to a weed control strategy will require information on potential grazing value of the target plant, and the effects of prescription grazing on livestock production.

Spotted knapweed (*Centaurea stoebe* L. subsp. *micranthos*[3]), was selected for this research because it's invasive ability has allowed it to infest more than 2.9 million hectares of North American rangeland (DiTomaso 2000). Knapweed is particularly troublesome in the western states north of New Mexico and Arizona and west of the plains states (i.e., the Dakotas, Nebraska, and Kansas; Mullin et al. 2000). Knapweed is of ecological concern because it displaces native plant communities, degrades wildlife habitat, reduces forage

[3] Molecular data confirms spotted knapweed introduced into North America came from the same taxon native to Europe (Ochsmann, J. 2001).

production and can yield increased soil erosion (Lacey et al. 1989, Wright and Kelsey 1997, Sheley et al. 1999). The forage palatability of spotted knapweed was examined with domestic sheep because sheep are considered the most effective livestock species for control of herbaceous forbs (Olson and Lacey 1994, Olson 1999b) and have been shown to readily graze spotted knapweed (Olson et al. 1997). However, little is known about the forage value of spotted knapweed throughout the growing season and the phonological stage for which sheep show the greatest preference. The objectives of this research were to (1) assess nutritional quality of spotted knapweed, and (2) examine sheep preference for spotted knapweed in three phenological states.

Materials and Methods[4]

Spotted knapweed plants for the nutrient quality and preference trials were collected from a knapweed-dominated sagebrush steppe community near the U.S. Sheep Experiment Station[5], Idaho (45° 20' N long., 112° 30' E lat.). The site was dominated by three-tip sagebrush (*Artemisia tripartita* Rydb.), gray horsebrush (*Tetradymia canescens* DC.), and antelope bitter brush (*Purshia tridentata* [Pursh] DC.). Grasses on the site included bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve), and sandberg bluegrass (*Poa secunda* J. Presl.). Several native forbs including tapertip hawksbeard (*Crepis acuminata* Nutt.), and tailcup lupine (*Lupinus caudatus* Kellogg) were also present on the site.

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[4] All procedures involving animal subjects were approved by the University of Idaho Animal Care and Use (protocol # 9063).
[5] USDA-ARS U.S. Sheep Experiment Station, Dubois, ID 83423

Nutritional Quality of Knapweed Diets

Seasonal differences in the nutritional value of spotted knapweed must be determined to develop grazing guidelines for effectively controlling this noxious weed. In 1999 and 2000, knapweed samples were harvested from five collection sites. Harvesting in 1999 occurred on May 18, June 14, July 15, and September 07. Harvesting in 2000 occurred on May 24, June 19, July 19, and August 10. At each collection site, plants were randomly selected in three age and size categories: Immature plants were in their first season of growth signified by lack of previous year's stems; small mature plants were plants with fewer than five dormant stems from previous year's growth; and large mature plants had relatively large basal area and more than five stems from previous year's growth. In addition, in September, plant regrowth supplied new knapweed rosettes, and these were included as Fall rosettes. Knapweed plants were collected in the evening, by clipping to ground level, placing herbage in a paper bag and putting quickly on ice to reduce respiration. At least 10-50 g of forage were collected of each age and size classes at each collection site. Samples from the five sites were averaged by age and size class to form samples for May, June, July, and September.

Within 1 hour of collection, samples were heated in a microwave to 70°C to halt respiration losses (Wolf and Carson 1973), and samples were oven dried at 55°C, for 18 hrs. In the second year of study (2000), plants were also separated into leaf, stem, and flowering portions. Dried knapweed samples were ground to pass a 1-mm screen in a cyclone sample mill (UDY Corp., Fort Collins, CO). Samples were run in triplicate to assess nutritive value (crude protein, fiber and lignin content, digestibility, and non-structural carbohydrates). Neutral detergent fiber (NDF) was determined using the filter bag technique for the ANKOM analyzer (ANKOM Technology, 1998a), which is a modification of the conventional detergent fiber analysis described by Van Soest et al. (1991). Crude protein (CP) concentration was assessed by persulfate digestion of samples (Purcell and King 1996) followed by nitrate concentration determined by absorbance read at 220 and 270nm with a spectrophotometer (Beckman DU 640, Beckman Coulter, Inc., Crumpton et al. 1992). Absorbance was related to crude protein by comparison with eight samples of known crude protein content determined by Kjeldahl analysis (AOAC, 2000a). Total non-structural carbohydrates were extracted through a modification of the procedure described by Smith (1969) using 0.2 N HCl rather than 0.2 N H_2SO_4. Carbohydrate levels were determined using an anthrone reagent and the absorbance read at 620 nm on a spectrophotometer (Beckman DU 640, Beckman Coulter, Inc.; Dashek 1997), with dextrose as a referent to develop a standard curve. *In vitro* dry matter digestibility (IVDMD) was determined using the filter bag technique (ANKOM Technology, 1998b) based on the first stage of the conventional *in vitro* methods outlined by Tilley and Terry (1963). Diet samples were initially fermented for 8 hours to estimate the composition of soluble and easily fermented compounds, and finally fermented for 48 hours to estimate total dry matter digestibility. Lignin was determined using the 72% H_2SO_4 acid detergent lignin (ADL) method in the Daisy^{II} Incubator (ANKOM Technology, 1998c).

Preference Trial

Knapweed preference was examined with 12 medium-weight (72 to 83 kg) mature whiteface dry range ewes. Sheep were predominantly Columbia-Rambouillet breeds, and were furnished by the U.S. Sheep Experiment Station. Sheep were ranked by weight, and treatments were randomly applied across weights so each treatment group consisted of a similar total weight of animals. Sheep were housed in individual pens (1.25 x 2 m), with shade and *ad libitum* access to water.

The preference trial was conducted in July of 2000. Spotted knapweed for the preference trial was harvested by hand in 1999, from a range site about 6 km northwest of the U.S. Sheep Experiment Station, and at three growth stages: rosette, bolting, and flowering/seedset. Plants were harvested in June, July, and August. Samples were dried in a forced-air oven at 55°C for 48h, put into brown plastic bags, and stored in cool dry dark place.

The preference trial lasted nine days and had three phases, i.e. knapweed conditioning, protocol conditioning, and preference testing. The five-day knapweed-conditioning phase familiarized animals with each knapweed growth stage, (i.e., rosette, bolting, and flowering/seedset). Sheep received 200 g alfalfa pellets twice daily (0630 and 1830), to reduce hunger to enhance selectivity among diets offered, and were then offered 90 g of a single growth stage of knapweed after receiving the alfalfa pellets (i.e., 0700 and 1900). Sheep received each growth stage in chopped form so that by the fifth day each animal received each growth stage three times. To meet daily basal requirements, sheep were also offered alfalfa pellets at 0830 and 2030 to total 10 g/kg body weight (NRC 1985).

The two-day protocol-conditioning phase familiarized animals with the feeding protocol of the cafeteria-style preference trial. Sheep were first fed 200 g alfalfa pellets twice daily (0630 and 1830), to reduce hunger to enhance selectivity among diets offered. Sheep were simultaneously offered 100 g each of chopped oat, grass, and alfalfa hay in a cafeteria setting after receiving the alfalfa pellets (i.e., 0700 and 1900). Feeds were offered in three, 4.7 L plastic containers set in a row, and removed when 90% of one of the offered feeds was consumed. To meet daily basal requirements, sheep were also offered alfalfa pellets at 0830 and 2030 to total 10 g/kg body weight (NRC 1985).

A two-day preference trial was conducted to determine sheep preference among the three growth stages of spotted knapweed. Feeding was conducted as during the protocol-conditioning phase except after receiving the alfalfa pellets, sheep were simultaneously offered 90 g of chopped knapweed in the rosette, bolting, or flowering/seed-set growth stage. The trial ceased when 90% of one of the offered feeds was consumed. Samples for each knapweed growth stage were combined daily for a composite sample from chopped knapweed foliage offered during the preference trial. Nutritional quality of the composite samples was assessed for NDF and CP. Crude protein was analyzed by combustion analysis using a Carlo Erba NA Series 2 analyzer (Carlo Erba/ Fisons Instruments, Valencia, Calif); CHN; AOAC 2000b).

Preference was assessed as the intake of each knapweed growth stage, expressed as a percent of total eaten for each sheep. Preference was evaluated in a split-plot in time analysis of variance (Steel and Torrie 1980), using PROC GLM, SAS Version 8.1 software (SAS 2000) with stages of growth as treatments, and trial number as the repeated measure. Significant treatments x trial number interactions were further analyzed with a Duncan's multiple-range test (Duncan 1955).

Results and Discussion

Spotted Knapweed Nutritive Quality

Spotted knapweed has moderate forage quality with low fiber and high digestible dry matter early in the season (Table 2.1). Knapweed chemical composition was affected by the size/age class of plants with differences becoming more pronounced as the growing season progressed (Table 2.1). Knapweed plants collected in May and June had lower fiber (NDF, ADF) and higher CP, TNC, and 48 hour IVDMD (Table 2.1). Large mature plants (i.e., with more than five stems from previous year's growth) had more stem material later in the season and therefore had greater fiber content than small mature plants. Digestibility and CP content in plants decreased while fiber (NDF, ADF) increased as the plants matured (Table 2.2). Total non-structural carbohydrate content peaked in June and subsequently decreased as the plants matured (Table 2.2). Decreasing forage value as the season progressed was primarily a result of decreasing leaf to stem ratios and the development of flowers late in the season (Table 2.3). Leaves from rosettes were generally less fibrous than leaves from mature plants in June, July, and August (represented by NDF and ADF). As the season progressed, leaf fiber values from mature and rosette plants became similar (Table 2.3). Stems had the highest fiber content and were the least digestible. Lignin content was only a small proportion of biomass (4-9%) and it was equally present in leaves, stems, and flowers (Table 2.3). Flowers developed in mid-to late-summer and had forage quality intermediate to leaves and stems (Table 2.3).

Spotted Knapweed Preference Trial

During the two-day protocol conditioning, the ewes selected from all the forage offered, but ate on average 50% greater proportion of alfalfa (Table 2.4). Protocol conditioning revealed a consistent preference for alfalfa over oat or grass hay, and demonstrated that the sheep were sufficiently prepared for the preference trial.

In the first knapweed preference trial, ewes expressed the greatest preference for rosette foliage followed by bolting and flowering knapweed (Fig. 2.1). Proportion eaten of rosette, bolting, and flowering knapweed was 62%, 22%, and 15%. In the second trial, equal preference was expressed for all growth stages. In the third trial, sheep expressed equal preference for rosette and bolting though flowering/seedset was least preferred. On the day following the preference trial, sufficient biomass from bolting and flowering/seedset stages existed for a paired preference trial. This test revealed a preference for bolting over flowering/seed set foliage, with 62% bolting over 38% flowering/seedset of foliage consumed (Table 2.5; $p < 0.05$). Selection of knapweed diets was related to the nutritional composition of the different knapweed growth stages with CP explaining 51.3% of the variation in the diet selected ($p < 0.03$), and NDF explaining 50.1% of the variation in the diet selected ($p < 0.03$).

Conclusion and Implications

Data from this study indicates that spotted knapweed may provide high quality forage for sheep in the first part of the season before flowering and seed production. The May / June average for NDF and CP was 34.7 % and 13.6 %, compared to 26 % and 11.5 % reported by Kelsey and Mihalovich (1987). Those authors agree there is no nutritional reason to restrict animal's consumption of spotted knapweed prior to flowering. Spotted knapweed rosettes have the best quality nutrition because of low fiber and high crude protein content. Concentrations of CP in early summer samples exceed daily nutrient requirements for sheep at maintenance and lactation by 4.2%, but late season samples fell below maintenance requirements by 2% to 7% (NRC 1985). Leaves on mature plants and new rosettes did not vary in quality throughout the growing season. Consequently, even mature knapweed plants have nutritional quality, and sheep may selectively harvest the most nutritional parts of the plant as the season progresses.

Sheep readily consumed knapweed in all growth stages suggesting that spotted knapweed is acceptable forage for sheep. Sheep generally preferred knapweed in the rosette or bolting growth stage, with less preference expressed for plants in the flowering/seed-set stage; though this preference was variable. Because sheep readily accept spotted knapweed throughout the growing season, opportunity exists for prescription grazing at a time set by plant growth characteristics. Grazing at strategic times during the plant's life cycle could increase the opportunities to negatively impact spotted knapweed while increasing competitiveness of the associated plant community.

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Table 2.1. Forage quality parameters (mean ± SEM[1]) of spotted knapweed plants collected from sagebrush steppe rangelands in eastern Idaho in 1999. Three age-size classes were examined for crude protein (CP), total non-structural carbohydrates (TNC), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), and in vitro dry matter digestibility (IVDMD) fermented for 8 and 48 hours.

Month & Age-Size Class[2]	CP	TNC	NDF	ADF	ADL	IVDMD (8 hour)	IVDMD (48 hour)
	------------------------------	------------------------------	------------------------------	% dry matter	------------------------------	------------------------------	------------------------------
May							
Immature	-	16.3 ± 0.6[a]	29.4 ± 0.6[a]	18.9 ± 0.6[a]	7.6 ± 0.4[a]	44.2 ± 0.7[a]	72.7 ± 1.7[a]
Small Mature	17.4 ± 0.3[a]	17.6 ± 0.3[a]	35.0 ± 0.8[b]	23.0 ± 0.4[b]	13.2 ± 0.7[b]	41.6 ± 1.0[b]	70.5 ± 1.3[a]
Large Mature	17.8 ± 0.8[a]	16.3 ± 0.6[a]	33.9 ± 1.0[b]	21.5 ± 0.5[b]	11.6 ± 1.1 [b]	43.6 ± 0.7[ab]	69.3 ± 1.1[a]
June							
Immature	11.9 ± 0.9[a]	23.2 ± 1.1[a]	34.8± 1.3[a]	25.6 ± 1.1[a]	12.3 ± 1.4[a]	44.1 ± 1.1[a]	72.1 ± 2.9[a]
Small Mature	10.5 ± 0.3[a]	22.2 ± 1.8[a]	37.8 ± 0.9[a]	27.5 ± 0.7[a]	13.9 ± 1.3[a]	39.1 ± 0.7[b]	67.5 ± 1.4[a]
Large Mature	10.5 ± 0.3[a]	26.8 ± 1.9[a]	37.7 ± 0.5[a]	27.3 ± 0.5[a]	12.0 ± 0.6[a]	39.2 ± 1.4[b]	67.9 ± 1.7[a]
July							
Immature	7.8 ± 0.4[a]	13.7 ± 0.4[a]	41.7 ± 1.2[a]	29.2 ± 0.9[a]	7.6 ± 0.2[a]	34.8 ± 1.2[a]	59.4 ± 1.5[ab]
Small Mature	7.9 ± 0.5[a]	12.5 ± 0.5[ab]	41.7 ± 0.9[a]	29.3 ± 0.8[a]	7.5 ± 0.8[a]	40.7 ± 1.6[b]	63.2 ± 0.8[a]
Large Mature	6.4 ± 0.5[b]	11.6 ± 0.53[b]	45.9 ± 1.1[b]	31.7 ± 0.4[b]	7.0 ± 0.3[a]	39.2 ± 1.5[ab]	58.1 ± 1.4[b]
September							
Fall Rosette	8.2 ± 0.7[a]	18.2 ± 0.6[a]	28.1 ± 0.6[a]	20.9 ± 0.2[a]	7.2 ± 0.5[a]	45.2 ± 1.7[a]	64.0 ± 1.0[a]
Immature	5.9 ± 0.3[b]	10.9 ± 0.4[b]	53.3 ± 0.4[b]	38.1 ± 0.4[b]	9.6 ± 0.5[b]	32.4 ± 1.9[b]	48.4 ± 1.5[b]
Small Mature	3.8 ± 0.2[c]	10.0 ± 0.3[bc]	58.2 ± 1.6[c]	41.4 ± 1.1[c]	9.9 ± 0.7[b]	25.8 ± 1.3[c]	42.6 ±1.4[c]
Large Mature	3.1 ± 0.2[c]	9.5 ± 0.5[c]	62.7 ± 1.0[d]	44.7 ± 0.6[d]	9.8 ± 0.3[b]	26.6 ± 1.4[c]	40.3 ± 1.2[c]

[1]Values in the same month with similar subscripts are not statistically different(α<0.05).

[2]Immature, plants in their first season of growth, Small Mature plants with fewer than 5 stems from previous year's growth, and Large Mature, plants with 5 or more stems from previous year's growth.

Table 2.2. Forage quality parameters (mean ± SEM[1]) of mature spotted knapweed plants collected from sagebrush steppe rangelands in eastern Idaho in 1999 expressed and compared by month collected during the growing season. Herbage samples were examined for crude protein (CP), total non-structural carbohydrates (TNC), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), and in vitro dry matter digestibility (IVDMD) fermented for 8 and 48 hours.

	Month of Collection			
	May	June	July	September
	----------------------------------	% dry weight	----------------------------------	
Crude Protein	17.6 ± 0.4[a]	11.0 ± 0.4[b]	7.4 ± 0.3[c]	5.3 ± 0.5[d]
TNC	16.7 ± 0.3[a]	24.1 ± 1.0[b]	12.6 ± 0.4[c]	12.2 ± 0.8[c]
NDF	32.8 ± 0.8[a]	36.8 ± 0.6[a]	43.1 ± 0.8[b]	50.6 ± 3.1[c]
ADF	21.2 ± 0.5[a]	26.8 ± 0.5[b]	30.1 ± 0.5[b]	36.3 ±2.1[c]
IVDMD (8 hour)	43.1 ± 0.5[a]	40.8 ± 0.9[ab]	38.2 ± 1.0[b]	32.5 ± 1.9[c]
IVDMD (48 hour)	70.8 ± 0.8[a]	69.2 ± 1.2[a]	60.2 ± 0.9[b]	48.8 ± 2.2[c]
ADL	10.8 ± 0.8[a]	12.7 ± 0.7[b]	7.4 ± 0.3[c]	9.1 ± 0.4[d]

[1]Values in the same row with similar superscripts are not statistically different (α <0.05).

Table 2.3. Forage quality parameters (mean ± SEM[1]) of rosette and mature spotted knapweed plants collected from rangelands in eastern Idaho in 2000. Foliage from mature plants was separated into leaves, stems, and flowers.

Month & Phenology	Plant Part	Biomass	NDF	ADF	IVDMD (48 hour)	ADL
May		---------------	---------------	% dry weight	---------------	---------------
Rosette	leaf	100	29.7 ± 1.4[a]	18.7 ± 0.3[a]	73.5 ± 1.9[a]	6.6 ± 0.5[a]
Mature	leaf	100	20.9 ± 0.4[b]	15.2 ± 0.3[b]	72.1 ± 0.8[a]	4.0 ± 0.3[b]
June						
Rosette	leaf	100	24.5 ± 0.4[a]	17.7 ± 0.4[a]	71.0 ± 1.0[a]	5.4 ± 0.3[a]
Mature	leaf	49.0 ± 1.4[a]	32.3 ± 1.6[b]	19.4 ± 0.2[b]	70.7 ± 1.6[a]	6.9 ± 0.3[b]
	stem	51.0 ± 1.4[a]	50.2 ± 0.9[c]	34.5 ± 0.7[c]	56.8 ± 1.1[b]	5.6 ± 0.1[a]
July						
Rosette	leaf	100	29.3 ± 0.4[a]	21.4 ± 0.4[a]	64.4 ± 1.2[a]	7.7 ± 0.8[a]
Mature	leaf	21.3 ± 1.1[a]	30.6 ± 0.6[a]	20.5 ± 0.5[a]	67.7 ± 1.6[a]	7.8 ± 0.4[a]
	stem	47.3 ± 1.6[b]	57.3 ± 1.3[b]	39.4 ± 0.7[b]	41.9 ± 1.3[b]	8.0 ± 0.3[a]
	flower	31.3 ± 1.3[c]	43.1 ± 0.6[c]	27.6 ±0.4[c]	54.0 ± 1.3[c]	8.6 ± 0.6[a]
August						
Rosette	leaf	100	31.0 ± 1.5[a]	21.1 ± 0.7[a]	64.7 ± 0.6[a]	8.7 ± 0.5[a]
Mature	leaf	25.2 ± 2.0[a]	31.6 ± 0.3[a]	23.7 ± 0.3[b]	62.3 ± 1.3[a]	10.2 ± 0.9[a]
	stem	43.8 ± 1.2[b]	66.2 ± 0.9[b]	46.2 ± 0.6[c]	35.8 ± 0.9[b]	9.5 ± 0.3[a]
	flower	31.1 ± 1.2[c]	54.4 ± 0.6[c]	35.1 ± 0.3[d]	44.2 ± 0.5[c]	9.7 ± 0.7[a]

[1]Values in the same month with similar superscripts are not statistically different ($\alpha < 0.05$).

Table 2.4. Proportion of forage consumed (mean ± SEM[1]) in the protocol-conditioning phase of a cafeteria preference trial to determine sheep dietary preference for alfalfa hay, oat grain hay, and meadow grass hay.

Trial Number	Alfalfa Hay	Oat Hay	Grass Hay
	---------------------------% consumed	------------------------------	
1	70.8 ± 4.7^{a}	16.8 ± 3.0^{b}	12.5 ± 3.3^{b}
2	52.8 ± 10.0^{a}	28.4 ± 9.7^{b}	18.8 ± 3.9^{b}
3	69.9 ± 8.5^{a}	8.9 ± 3.1^{b}	21.2 ± 7.6^{b}
4	74.5 ± 4.8^{a}	9.5 ± 2.9^{b}	16.0 ± 4.6^{b}

[1]Values in the same row with similar superscripts are not statistically different ($\alpha < 0.05$)

Table 2.5. Percent crude protein (CP) and neutral detergent fiber (NDF) of spotted knapweed samples (mean ± SEM[1]) compared to proportion eaten by sheep in a preference trial using three phenologies of knapweed.

Spotted knapweed Phenology	CP	NDF	Proportion Eaten (%)
Rosette	19.5 ± 0.2[b]	24.9 ± 1.0[b]	48.0 ± 7.2
Bolting	11.6 ± 0.5[b]	29.2 ± 0.3[a]	30.3 ± 6.0
Flowering	11.3 ± 0.2[a]	40.4 ± 0.08[c]	21.7 ± 6.1

[1]Values with similar superscripts are not statistically different (α <0.05)

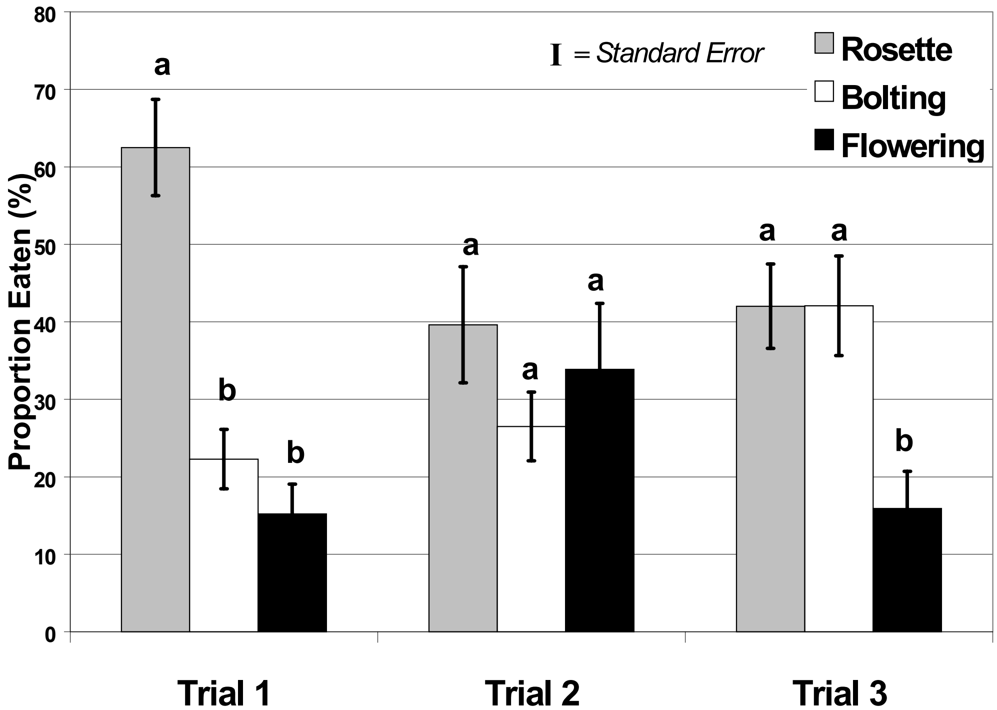

Figure 2.1. Sheep preference among three growth sages of spotted knapweed expressed as a percent of total intake for each sheep. Research was conducted in a cafeteria trial with dried plant material. Values with similar superscript are not statistically different ($\alpha < 0.05$)

CHAPTER III

Seasonal Differences in Utilization and Diet Quality by Sheep Grazing Spotted Knapweed at Two Stocking Rates

Introduction

Invasive noxious weeds aggressively compete with native vegetation for local resources and replace native plant communities in many areas (Belcher and Wilson 1989, Miller et al. 1994). Noxious range weeds possess invasive growth strategies and spread at an estimated rate of 8 to 14% per year (Whitson 1998). Weed populations may increase in area by 60% per year in localized areas (Prather and Callihan 1989). Consequences of rangeland weed invasion include degradation of wildlife habitat, reduced carrying capacity for grazing herbivores, increased soil erosion, and loss of biodiversity (Lacey et al. 1989, Sheley et al. 1998, 1999a). Herbicides, insects, pathogens, and fires have contained the spread of only a few noxious weeds (Olson et al. 1997, DiTomaso 2000).

Integrated Weed Management (IWM) is a contemporary strategy for managing noxious weeds that combines chemical, mechanical, cultural, and biological control methods in a strategic fashion to minimize inputs and maximize weed control (Thill et al. 1991). Release of host-specific biological agents on rangeland weed infested areas shows promise, but results require added analysis (Sheppard 1992). Although IWM methods are integral to effective weed control, inclusion of livestock grazing in control strategies is often overlooked. Shifting the emphasis from weed control programs that accommodate livestock grazing to programs employing prescription grazing could provide a highly effective weed management tool.

The appropriate use of grazing for weed control, must be applied at specific times and stocking rates to effectively control a target species, and minimize negative impacts to the associated plant community. The basic plant-herbivore interactions that mediate a weed's persistence must be understood (Briske 1996). Prescription grazing for weed control requires defoliation when the target weed is most susceptible to damage by grazing and when livestock find the weed most palatable. Furthermore, grazing should be implemented when the associated plant community expresses the most grazing tolerance or lowest relative palatability.

Spotted knapweed, (*Centaurea stoebe* L. subsp. *micranthos*[6]) is considered one of the most troublesome rangeland weeds in the northern United States and Canada (Bogs and Story 1987, Chicoine et al. 1985, Sheley et al. 1998, 1999b). In the Pacific Northwest, spotted knapweed is estimated to have infested 2.9 million ha of western rangelands (DiTomaso 2000), and surveys estimate spotted knapweed to be increasing in acreage at 13.4% per year (Roché 1994). Spotted knapweed infestations can reduce native grasses and forbs by 60 to 90%, and can increase soil erosion (Watson and Renney 1974, Lacey et al. 1989). Herbicides, insects, pathogens, and fires have not effectively contained the spread of this noxious weed (DiTomaso 2000, Olson et al. 1997).

Research confirms the potential for grazing weeds as a management strategy (Lacey et al. 1984, Olson et al. 1997). Sheep readily grazed leafy spurge (*Euphorbia esula*) and spotted knapweed, consequently reducing density and biomass of leafy spurge (Lacey et al. 1984), and reproductive output of spotted knapweed (Olson et al. 1997). Dietary value of spotted knapweed was found to be adequate for sustaining wild and domestic ungulates

[6] Scientific name of spotted knapweed follows research on molecular data confirming plants introduced into North America from same taxon native to Europe (Ochsmann, J. 2001).

during the growing season, and spotted knapweed is relatively nutritious early in the season (Kelsey and Mihalovich 1987, Wright and Kelsey 1997).

The objective of this study was to examine the seasonal differences in forage utilization and diet quality of sheep grazing spotted knapweed-infested rangeland at high and low stocking rates. Research was conducted when spotted knapweed was at three growth stages: early-summer rosette stage; mid-summer bolting stage; and, late-summer flowering/seedset. This research was designed to enhance the application of prescriptive grazing strategies for managing spotted knapweed infested rangelands. A companion study measured sheep grazing effects on plant community attributes (i.e. density and flower production of spotted knapweed, and cover components of the associate plant community; Patten 2000). Results of this study will help determine when spotted knapweed is most susceptible to grazing, and when the associated plants are most tolerant to grazing.

Materials and Methods[7]

Study Area

The study was conducted during 2000 and 2001 on rangeland at the U.S. Sheep Experiment Station near Dubois, Idaho (44° 14' N. Lat., 112° 12' W. Long.). The vegetation type was a sagebrush steppe, with an over-story mix of threetip sagebrush (*Artemisia tripartita* Rydb.)[8], big sagebrush (*Artemisia tridentata* Nutt. spp. *tridentata*), bitterbrush (*Purshia tridentata* Pursh.), Douglas rabbitbrush (*Chrysothamnus viscidiflorus* [Hook] Nutt.), snowberry (*Symphoricarpos albus* [L.] Blake), and gray horsebrush (*Tetradymia canescens* DC.). The understory consisted of native and non-native forbs and grasses. Native grasses

[7] All procedures involving animal subjects were approved by the University of Idaho Animal Care and Use (protocol # 9063).

[8] Plant names follow those presented in the National PLANTS Database (USDA, NRCS 2001).

included bluebunch wheatgrass (*Psuedoroegneria spicata* [Pursh] A. Love), thickspike wheatgrass (*Elymus macrourus* [Turcz.] Tzvelev), Indian ricegrass (*Achnatherum hymenoides* [Roemer & J.A. Schultes] Barkworth), needle-and-thread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth), prairie junegrass (*Koleria macrantha* [Ledeb.] J.A. Schultes), and Sandberg bluegrass (*Poa secunda* Vasey). Native forbs included arrowleaf balsamroot (*Balsamorhiza sagittata* [Pursh] Nutt.), granite prickly gilia (*Leptodactylon pungens* [Torr.] Nutt.), tapertip hawksbeard (*Crepis acuminata* Nutt.), milkvetch (*Astragulus spp*.), and lupines (*Lupinus caudatus* [Kell]). The study area had an estimated 15 to 20% canopy cover of spotted knapweed.

Annual precipitation of the research area averages 280 to 350 mm primarily from winter snow and spring rain (Fig. 3.1). Average annual temperature is 6.1°C with extreme temperatures of 37.8°C in summer, and –31.7°C in winter. Topography at the research site was level to undulating with 0 to12% slopes, lava outcrops, and approximately 1700 m. above sea level. Soils are primarily alluvium and residuum formed from basalt and dominated by fine-loamy, mixed, frigid, Calcic Argixerolls (NRCS 1995).

Paddock Arrangement

Grazing trials were conducted during summers 2000 and 2001, on two sites with similar plant composition in sagebrush steppe. The sites were separated by a county road and were about 0.4 km apart; referred to as the East and West site based on their relation to this road. Paddock size was set to provide three ewes sufficient forage for a 4-day grazing period given 50% use of herbaceous plants including spotted knapweed, and an estimated 750 kg/ha of available herbaceous biomass resulting in paddocks of 0.068 ha each 26 × 26 m (NRCS 1995). Shrub canopy cover was estimated for each paddock along three, 12 m transects by a line-intercept method (Canfield 1941). Paddocks were categorized as high (31 to 40%), medium (27 to 30%), and low (16 to 26%) for shrub canopy cover. Treatments were randomly applied to each paddock within shrub abundance category to stratify or block the effects of shrub cover.

Vegetation Assessment

Three 12-m permanent transects were established in each paddock. One transect was centered in each paddock, and the others were 8 m from the center transect. Plots were randomly placed along each transect, with a distance perpendicular to the transect that randomly varied between 0.5 m and 4 m. The first plot was randomly placed either left or right of the transect line, and subsequent quadrats were alternately placed at random points until all 8 plots were located (Figure 3.2). Two 40-penny nails were set into the ground on the diagonal corners of a rectangle quadrat (30.5 x 61 cm) to enable accurate quadrat placement for repeated measurements. Each transect had 8 plots to total 24 permanent sampling plots per paddock.

Grazing Treatments

Grazing trials were conducted each year of study during the initial rosette growth of spotted knapweed, the bolting stage, and flowering/seed-set. Grazing trial dates for 2000 were June 8-16, July 11-18, and August 10-17. In 2001, grazing trials occurred during June 8-19, July 7-18, and August 8-20. In each season or knapweed phenological stage, two stocking rates were applied with three replications per treatment per site. The high stocking rate was accomplished with 20 sheep days of grazing per paddock (2 AUM/ha) and the low stocking rate was accomplished with 20 sheep days of grazing (1.2 AUM/ha). In 2001, fistulated sheep were used to assess diet quality, and were grazed separately from non-fistulated (intact) sheep. Diet collection with fistulated sheep required that each grazing trial last 12 days instead of 8 days as in 2000. However, sheep grazing days for high and low treatments remained the same for both years, with one exception. In 2001, the initial grazing trial used eight fistulated sheep to ensure adequate fistula samples. This resulted in a higher stocking rate for the low treatment (i.e., 14 sheep days compared to 12 sheep days in year 2000). Subsequent to the rosette-grazing season, three fistulated sheep were used in the high and three in the low treatment groups resulting in the same stocking rates for the bolting and flowering/seedset grazing trials as in year 2000.

Grazing Animal

Sheep used for this study were whiteface range sheep predominantly Columbia-Rambouillet breeds, and were furnished by the U.S. Sheep Experiment Station. Mature dry ewes, weighing about 80 kg each, were ranked by weight, and treatments (high and low stocking rates) were randomly assigned across weights so each treatment group consisted of a similar total weight of animals. The same sheep were used during both years of investigation.

During summer 2001, eight of the research ewes were esophageally fistulated to facilitate collection and analysis of diets (Pfister et al. 1990). The fistulated sheep grazed each paddock before and after the paddocks were grazed by intact sheep. To assess nutritional response to season and stocking rate, intact sheep were used to apply grazing pressure required by stocking rates (four and two ewes for high and low rate, respectively). In the initial trial of 2001, four fistulated ewes were used to examine high stocking rate and four ewes low stocking rate. In subsequent trials (July and August), three ewes were assigned to the high and three to the low stocking rate.

Sheep grazing of plants was measured by quantifying progressive defoliation in each season. Ocular estimation in a double sampling protocol was used to estimate biomass (Bonham 1989). Biomass of grasses, knapweed, and other forbs was estimated in all permanent plots (n=24) on each grazed paddock. Biomass for each site was measured before, in the middle (after 2 days), and after each grazing trial (i.e., after 4 days). Utilization was estimated as loss of biomass compared to the pre-grazing measurements.

Diet Characteristics

Diet quality was examined by collecting esophageal extrusa from the eight-fistulated sheep. Each evening, the fistulated sheep were penned in the corners of a paddock with access to water but no feed. Each morning at about 0630, extrusa collection bags were harnessed around each ewe’s neck, cannulas removed, and sheep were turned out to graze. After 15 to 20 minutes, sheep were herded to the holding pens, and diet samples were collected. Sheep were then returned to the paddocks for the remainder of the grazing period.

Extrusa samples were rinsed in cool water, placed in zip-lock plastic bags, put on ice, and taken to the lab for processing. Each sample was rinsed through a number 18 mesh screen. Excess water was pressed out and samples were placed on paper plates to be dried at 55°C for 24 hours. Dried samples were placed in paper bags and stored in a cool dry place until ground. Samples were ground to pass through a 2 mm screen in a Wylie mill (Arthur H. Thomas Co., Philadelphia, Penn.), and then passed a 1 mm screen of a Cyclone mill (UDY Corp., Fort Collins Colo.).

Extrusa samples were examined to assess nutritive value including neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), *in vitro* dry matter digestibility (IVDMD), and *in vitro* organic matter digestibility (IVOMD). The filter bag technique for the ANKOM analyzer (ANKOM Technology, 1998a,b) was used to determine NDF and ADF, which is a modification of the conventional detergent fiber analysis described by Van Soest et al. (1991). Lignin was determined using acid detergent lignin (ADL) method in the Daisy[11] Incubator (ANKOM Technology, 1998c). *In vitro* dry matter disappearance was determined using the filter bag technique (ANKOM Technology 1998d) based on the first stage of the conventional *in vitro* methods outlined by Tilley and Terry (1963). *In vitro* organic matter disappearance was calculated following methods of Harris (1970). Digestibility was also estimated with the lignin ratio method (LR Digestibility) described by Hill et al. (1961) and Ellis et al. (1946). Fecal grab samples were collected from the intact sheep (n = 18), at the conclusion of each seasonal grazing trial, after an overnight fast. Fecal samples were dried at 55°C for 48 hr and ground to pass a 1 mm screen of a Wylie mill. Lignin was determined as described above.

Total digestible nutrients (TDN) were calculated to estimate the feed value of spotted knapweed-infested rangeland relative to the energy requirements of animals (NRC 1985). The formulas for calculating TDN vary by region and by nutritionist; therefore, a comparison was made between methods of Reid (1988) and Moore (1999). Digestible dry matter (DDM) can be estimated using ADF values (Reid 1988), and 95% of DDM is considered equal to TDN (unpublished). In addition, Moore et al. (1999) suggests that forage TDN can be assumed to be equivalent to digestible organic matter (IVOMD).

Statistical Analysis

The design for this experiment was a randomized split-plot in time factorial (Steel and Torrie 1980). The treatments were stocking rate and season of grazing, which were randomly applied to paddocks and replicated three times on two sites (Table 3.1). Means of biomass, utilization, and diet quality were averaged by paddocks (n = 36). The fixed variables were the two sites (east and west), class of forage (i.e., knapweed, other forbs, and grass) and paddocks. The random variables were the three seasons of grazing and two stocking rates. The whole plot included site, stocking rate, season of grazing, and all possible combinations. The split plot included measurement time over two years. Interactions between all possible combinations of measurement time with other variables from the whole plot were examined (Table 3.1).

The SAS procedures used were the general linear and mixed models (SAS 2000). Data from the grazing trial were analyzed using analysis of variance (Conover 1980). Measurements of forage classes were analyzed before, mid-way, and after grazing periods. Diet quality variables were averaged by paddocks, and examined for effects of stocking rate and grazing season. Data expressed as a percentage were arc sine transformed (Steel and Torrie 1980) to achieve a normal distribution of variables.

Results and Discussion

Bitterbrush and three-tip sagebrush were the dominant shrub species on the study sites, with a smaller percent of big sagebrush, rabbitbrush, gray horsebrush, and snowberry present. The east site had a 28% canopy cover of sagebrush and 2% canopy cover of bitterbrush (Table 3.2). The west site had a 16% canopy cover of sagebrush and a 6 % canopy cover of bitterbrush (Table 3.2). Spotted knapweed foliar cover also varied between sites with 15% on the east, and 13% on the west (Table 3.3; $p < 0.01$). Species composition and biomass production was variable between year, site, and season (Table 3.3), however there was an interaction of year by site ($p < 0.03$), and year by season ($p < 0.01$). Biomass of spotted knapweed was consistently higher on the east site for both years of study ($p < 0.01$), but was variable between year and season ($p < 0.01$). Total biomass was less in 2001 compared to 2000, and peak biomass occurred in August for both years and sites (Table 3.3; $p < 0.01$). The two years of this study were conducted in drought years, and the precipitation varied between years (Fig. 3.1). In 2001, after a drier spring than the previous year, June and July experienced higher rainfall. These differences help explain the overall decline in biomass for the second year and seasonal variation in biomass production.

Utilization

Spotted knapweed utilization was variable depending on year, site, and season, and ranged from 36% to 85% in all seasons of grazing and both stocking rates (Fig. 3.3a, b). There was a year by site and season interaction ($p = 0.03$). To clarify utilization pattern, sites were analyzed separately. On the east site, seasonal pattern of utilization varied by year ($p < 0.02$), while stocking rate had no effect. The same held true on the west site, though the high stocking rate yielded greater utilization of spotted knapweed, on average, over both years and grazing seasons (Fig.3.3; $p < 0.01$).

Utilization rates of native forbs varied by site ($p <0.01$), and stocking rate ($p < 0.01$), but not by year (Fig. 3.4). Utilization was greater with the high stocking rate throughout the growing season (Fig. 3.4). The high stocking rate resulted in, on average, 80% on the east site and 87% on the west site. The low stocking rate resulted in, on average, 73% for the east site, and 80% on the west site. Native forbs utilization was, overall higher on the west site, and may be attributed to a lower 2001 forb biomass on the east site compared to the west site (Table 3.3).

Utilization of grass was consistently lowest in July during the bolting stage of spotted knapweed ($p < 0.01$; Fig. 3.5a, b). This may reflect increased preference of spotted knapweed by sheep as availability of knapweed increased. Later in the growing season, sheep utilized grasses at higher levels, perhaps because of decreasing availability and palatability of spotted knapweed. Utilization of grass also varied by year ($p < 0.01$), site ($p < 0.01$), and stocking rate ($p < 0.01$). Utilization of grasses was greater for both years of study on the west site, and with the high stocking rate (Fig. 3.5a, b). In 2000 grass utilization was 48% on the east site, and 62% on the west site. In 2001, utilization of grass was 58% on the east site, and 71% on the west site. These differences may have been caused by difference in precipitation pattern, or the previous year's grazing effect.

Utilization of all forage classes was measurably greater at the end of each seasonal trial (after 4-days) than mid-way through the trial (after 2-days; Table 3.4; $p < 0.01$). The 2-day measurement can be viewed as a stocking rate adjustment compared to the total utilization at the 4-day measurement (Table 3.3). Stocking rate are calculated by the number of animals per unit area, over a period of time, and number of animals, or amount of time can be adjusted. For example, if a manager is concerned about exceeding a 50% utilization standard, duration of grazing can be adjusted following the rate of defoliation in table 3.3. Comparison of utilization throughout the trial did not reveal any patterns of diet changes in response to progressive defoliation and increasing grazing pressure.

Relative Proportion Removed

The proportion of each class of forage removed by sheep was calculated relative to the total herbage removed in each paddock. This measurement reflects the percent of each forage class in sheep diets. Spotted knapweed clearly constituted a high percent of the diet (Fig. 3.6a, b), but a year by site by season interaction ($p < 0.04$) made it difficult to ascertain the effect of these variables on proportion of knapweed removed. If sites are viewed independently, the east site contributed the greatest amount of knapweed to the sheep diet in July ($p < 0.01$), while on the west site, the season of greatest knapweed consumption varied by year ($p < 0.03$; Fig. 3.6a, b). The proportion of spotted knapweed in sheep diets did not differ significantly between stocking rates. Average spotted knapweed biomass on the east site was 415 kg/ha, compared with 324 kg/ha for the west site (Table 3.3). This may have resulted in the higher proportion of knapweed in the sheep diets on the east site.

Native forbs had the smallest presence in the plant community (Table 3.3), and although heavily utilized (53-91%; Fig. 3.4), contributed only 9 to 23% to the sheep diets (Fig. 3.7a, b). There was a year by site, and year by season interaction ($p < 0.01$). To clarify site effect, sites were analyzed separately. Sheep in both stocking rates had a similar proportion of native forbs in their diet over both years of study and over both sites, except on the east site in 2001 the proportion native forbs removed was 12% for the high stocking rate, and 6% for the low ($p < 0.01$). Year and season interacted ($p < 0.03$) on the west site, and in 2000, proportion of forbs removed in August was less than half of the proportion removed in June and July (Fig. 3.7a). Biomass estimates of native forbs were 88 kg/ha for 2000 and 58 kg/ha for 2001 (Table 3.3). This may be a reflection of the precipitation difference between years. Native forbs appeared to respond well to summer rains and persisted as a minor component of the plant community.

The grass proportion in the sheep diets during the July grazing period was the least compared to the other seasons ($p < 0.01$), and reflects a switch from grass to spotted knapweed during the time when knapweed was bolting (Fig. 3.8a, b). Grass consumption increased as knapweed quality decreased, and grass again contributed more to sheep diets (Fig. 3.8a, b). In seven out of 12 observations, the high stocking rate removed a greater proportion of grass from available forage than the low stocking rate (Fig. 3.8a, b). This reflects a minimal stocking rate effect on grass selection by sheep. Yearly differences may be attributed to the effect of variable precipitation, and quality and availability of forage at specific sites.

Diet Quality

Nutritional quality of sheep diets in the grazing trial was determined by fiber and *in vitro* digestibility. Pre-grazing measurements provided a diet baseline, and post-grazing measurements provided results of the treatment effects.

The pre-grazing dietary NDF varied by site and season (site by season interaction; $p < 0.01$). Stocking rates did not affect proportion of NDF in sheep diets (Fig. 3.9a). Post-grazing dietary NDF varied by season ($p < 0.01$), and both sites yielded an increasing proportion of NDF in sheep diets as the seasons advanced (Fig. 3.9b). Overall, variation in percent NDF by site and season was slight.

Lignin (ADL) was a small proportion of the sheep diets (11-19%), and was affected by site ($p < 0.01$), and season ($p < 0.01$). The pre-grazing samples on the east site had little ADL variation by season and averaged 12% (Fig. 3.10a). The west site yielded more lignin with 18% in June, and a slight declining trend for July and August. Post-grazing dietary ADL for the east site increased 2% for the June trial, but decreased slightly in July and August

(Fig. 3.10b). Browsing by sheep on lignified shrub biomass, may have contributed to lignin proportion in sheep diets. The shrub canopy cover and overall forage production varied between the two sites (Table 3.2, 3.3). The dominant shrubs were bitterbrush and sagebrush. The west site canopy cover of bitterbrush, and sagebrush was 6% and 16%. The east site canopy cover of bitterbrush, and sagebrush was 2% and 28% (Table 3.2). Sheep appeared to browse bitterbrush more on the west site than the east, which may have contributed to greater dietary ADL on the west site.

Diet digestibility (IVDMD) measured before grazing treatments were applied, averaged 48% for both sites. A season by treatment interaction ($p < 0.01$) makes it difficult to interpret response of digestibility to these variables, but August provided the lowest IVDMD (42%) for both sites (Fig. 3.11a). Post-grazing IVDMD varied by site ($p < 0.01$), and stocking rate ($p < 0.01$). July grazing on the east site provided the greatest digestibility at 42% (Fig. 3.11b). The low stocking rate provided greater post-grazing digestibility four out of six times (Fig. 3.11b).

Some have criticized the use of TDN as a useful measures of energy feed values (Moore et al. 1999, Van Soest 1997), but using TDN was a practical way to assess diet quality with available lab procedures, and then comparing with published table values. Percent TDN indicate that sheep were supplied with adequate nutrition throughout much of the grazing trial, following a recommended 55% TDN daily maintenance requirement (Table 3.5; NRC 1985). Pre-grazing TDN averaged 59% on the east site, and 56% on the west site (Table 3.5). Post-grazing TDN averaged 55% on both the east and west sites. The pre-grazing TDN measurements were affected by a site and season interaction ($p < 0.01$), but were not affected by stocking rate (Table 3.5).

Digestible organic matter (IVOMD), as an estimate of TDN, varied between site and season ($p = 0.02$), and average values did not meet TDN daily maintenance requirements (NRC 1985, Table 3.6). Pre-grazing IVOMD measurements from June grazing on the east site was 63% for the high, and 56% for the low stocking rate. August post-grazing IVOMD on the west site was 38% for the high, and 40% for the low stocking rate. Four out of six times, the low stocking rate expressed improved digestibility but a stocking rate effect was not significant. Procedures used for determining IVDMD and IVOMD followed ANKOM *In Vitro* Digestibility, and excluded the second step of the Tilley and Terry method (i.e. final bag weight after NDF determination; ANKOM 1998c, Tilley and Terry 1963). This may account for lower digestibility values compared with TDN.

Differences between the pre-grazing and post-grazing analysis may reflect differences of forage availability and diet quality from grazing pressure being applied to the paddocks. Precipitation differences between years affected the season of growth for each class of forage, and may have reflected differences of forage availability and diet quality. Residual effects of the previous year's grazing trial, is another factor that may have affected forage availability and diet quality in 2001 (Fig. 1).

The lignin ratio method (LR Digestibility; Hill et al. 1961) provided another estimate of diet digestibility (Fig. 3.12a, b). The lignin ratio method had similar dietary values when compared with IVDMD measurements, with the exception of the west site pre-grazing measurements. On the west site, pre-grazing LR Digestibility averaged 27%, and a site by season interaction ($p < 0.01$) makes it difficult to discern the reason for low digestibility values. Post-grazing LR Digestibility was different by site ($p < 0.01$) and season ($p < 0.01$), and an increasing trend in LR Digestibility occurred (Fig. 3.12b). LR Digestibility averaged 45% for the east site, and 36% for the west site. A stocking rate effect was not significant

(Fig. 3.12a, b). Fecal collection from intact sheep occurred subsequent to each grazing period, but pre-grazing samples were not obtained. This may have resulted in the differences between pre and post-grazing samples. Both methods to assess digestibility had similar post grazing values, and conclude that the grazing trial diets did not limit sheep energy requirements.

It is not clear why in some instances, higher stocking rates resulted in greater diet digestibility. High stocking rates are generally thought to reduce diet quality by limiting the amount of available forage per animal (Heitschmidt and Taylor 1991). The results of this study may have reflected the higher stocking rates from the previous year removing more standing dead biomass and yielding greater access to green forage in 2001. Differences between stocking rates may also reflect confounding effects of treatment and individual animals within these treatments. Sheep were assigned to stocking rate groups for the whole study. Therefore, stocking rate effects were completely confounded with individual animals for the whole study. It is possible that animals randomly selected for the high stocking rate were better able to select high quality diets.

Conclusion and Implications

Study results support the idea that sheep will accept spotted knapweed as forage and will graze it preferentially to grasses throughout the growing season. Consumption of each class of forage was dependent on plant phenology. When knapweed was most abundant (i.e., July), utilization of the associated plants declined.

Spotted knapweed experienced greater than 38% utilization regardless of grazing season or stocking rate, except in July when utilization exceeded 40%. The high stocking rate yielded the greatest utilization of knapweed, grasses and native forbs. However, similar apparent knapweed consumption at both stocking rates suggests that sheep were not limited in diet selection and forced to eat knapweed. The level of utilization of grasses was similar to knapweed, and native forbs experienced greatest levels of utilization. Knapweed dominated the herbage removed in each season and was readily accepted as a forage.

Spotted knapweed cover for the general study area was on average 14%. Although a relatively low cover component of the whole plant community, spotted knapweed was dominant in herbaceous biomass production (Table 3.2) and proportion in sheep diets. The heterogeneous plant community provided a diverse diet with opportunities for the sheep to develop a preference for spotted knapweed. There are abundant rangeland plant communities that have similar foliar cover of spotted knapweed. Since the decline of the sheep industry in the mid 1940's, weed populations have been increasing exponentially (Olson 1999). This may be a result of reducing sheep selectively grazing forbs, while increasing cattle grazing pressure of grasses. With available sheep, and an abundant supply of non-native forage, the economic incentives of grazing noxious weeds need to be examined.

Livestock grazing can be manipulated to achieve specific resource objectives over temporal and spatial scales. Data from controlled grazing studies, such as this one, can help determine the time of grazing and the necessary stocking rates to effectively control spotted knapweed, while minimizing negative impacts to the associated plant community. Grazing spotted knapweed in the bolting stage provided the best quality forage for sheep in this study. High stocking rates had the greatest impact on knapweed and native forbs. To increase the grass component in similar rangeland plant communities, a high stocking rate of sheep during spotted knapweed bolting would be the optimal grazing prescription.

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Table 3.1. Experimental design. Split-plot includes measurement time (2 and 4 days) over 2 years. Diet quality data was for year 2001 only; therefore, error degrees of freedom (df) were 48 for this data set.

	Source	df
Whole Plot	site (si)	1
	stocking rate (st)	1
	grazing season (gs)	2
	si * st	1
	si * gs	2
	st * gs	2
	si * st * gs	2
Split-plot	measurement time (mt)	3
	mt * si	1
	mi *st	1
	mt * gs	2
	mt * si * st	2
	mt * si * gs	2
	mt * st *gs	2
	mt * si * st * gs	2
	Error	46
	Total	71

Table 3.2. Percent canopy cover of dominant shrub species at east and west sites in a grazing trial with sheep in a three-tip sagebrush steppe plant community.

Species	East	West
	------------------ % Cover -------------------	
Bitterbrush	2 ± 0.2	6 ± 0.6
Sagebrush	28 ± 1.3	16 ± 0.7
Rabbitbrush	< 1	< 1
Prickly gilia	< 1	< 1
Snowberry	< 1	< 1
Gray horsebrush	< 1	< 1
Total shrub cover	30 ± 2	22 ± 2

Table 3.3. Biomass estimates (mean ± SEM) of forage classes by year, site, and season measured prior to each seasonal grazing trial (June, July, August) with sheep in a three-tip sagebrush steppe plant community.

		East	West
2000		----------------- kg / ha	---------------
June	Knapweed	259 ± 35	219 ± 38
	Native forbs	75 ± 20	99 ± 29
	Grass	212 ± 32	203 ± 40
	Total	546 ± 84	520 ± 96
July	Knapweed	677 ± 111	508 ± 79
	Native forbs	100 ± 26	104 ± 12
	Grass	339 ± 30	312 ± 35
	Total	1116 ± 89	924 ± 71
August	Knapweed	644 ± 71	542 ± 60
	Native forbs	91 ± 17	58 ± 12
	Grass	419 ± 62	339 ± 28
	Total	1154 ± 93	939 ± 67
2001			
June	Knapweed	196 ± 16	175 ± 48
	Native forbs	38.0 ± 4	68 ± 6
	Grass	198 ± 37	228 ± 12
	Total	432 ± 30	471 ± 59
July	Knapweed	381 ± 74	266 ± 72
	Native forbs	49 ± 13	70 ± 14
	Grass	163 ± 7	223 ± 34
	Total	593 ± 70	560 ± 64
August	Knapweed	334 ± 44	239 ± 20
	Native forbs	48 ± 10	78 ± 32
	Grass	205 ± 6	258 ± 52
	Total	597 ± 52	575 ± 46

Table 3.4. Percent utilization of forage observed on day 2 and day 4, and percent difference between these measurements in a grazing trial with sheep at low and high stocking rates in a three-tip sagebrush steppe plant community. Averaged over 2 years and 2 sites.

Forage	Grazing Season	Stocking Rate					
		High			Low		
		---------------------------- % Utilization ----------------------------					
		Day 2	*Day 4*	*Difference*	*Day2*	*Day 4*	*Difference*
Knapweed	June	41	69	28	28	62	34
	July	42	66	24	32	51	19
	August	47	62	15	35	59	24
Native Forbs	June	66	84	18	65	79	14
	July	64	87	23	57	68	11
	August	57	81	24	56	70	14
Grass	June	47	71	24	39	62	23
	July	27	50	23	28	40	12
	August	50	70	20	44	65	21

Table 3.5. Total digestible nutrients (TDN expressed on a 100 percent dry matter basis) of diets sampled from esophageally fistulated sheep (mean ± SEM). Measured before and after grazing treatments were applied to paddocks in a grazing trial with sheep at high and low stocking rates in a three-tip sagebrush steppe plant community.

	Pre-grazing TDN			
Site	East		West	
Stocking Rate	---- High ---	--- Low ---	--- High ---	--- Low ---
June	60.6 ± 0.4	60.5 ± 0.3	57.1 ± 0.3	56.3 ± 0.4
July	57.8 ± 0.5	58.0 ± 0.8	56.5 ± 0.5	56.6 ± 0.6
August	58.1 ± 0.6	59.2 ± 0.3	55.8 ± 0.7	56.5 ± 0.3

	Post-grazing TDN			
Site	East		West	
Stocking Rate	--- High ---	--- Low ---	--- High ---	--- Low ---
June	55.5 ± 0.8	55.3 ± 0.6	55.2 ± 0.4	56.8 ± 1.0
July	56.2 ± 0.6	55.8 ± 0.4	56.5 ± 0.6	55.8 ± 0.8
August	54.3 ± 0.3	54.7 ± 0.7	53.7 ± 0.9	53.3 ± 1.3

Table 3.6. *In vitro* organic matter disappearance (IVOMD) of diets sampled from esophageally fistulated sheep (mean ± SEM). Measured before and after grazing treatments were applied to paddocks in a grazing trial with sheep at high and low stocking rates in a three-tip sagebrush steppe plant community.

	Pre-grazing IVOMD			
Site	East		West	
Stocking Rate	---- High ---	--- Low ---	--- High ---	--- Low ---
June	63.3 ± 5.5	55.7 ± 2.2	49.0 ± 1.4	50.7 ± 1.6
July	54.3 ± 1.7	54.6 ± 1.3	51.8 ± 3.3	53.3 ± 1.5
August	44.0 ± 2.2	45.2 ± 1.5	42.2 ± 1.3	43.9 ± 1.0

	Post-grazing IVOMD			
Site	East		West	
Stocking Rate	--- High ---	--- Low ---	--- High ---	--- Low ---
June	40.4 ± 3.4	42.9 ± 1.8	43.6 ± 0.9	44.7 ± 1.0
July	47.4 ± 0.1	46.8 ± 2.0	41.4 ± 2.8	43.5 ± 2.4
August	42.7 ± 0.5	41.9 ± 0.8	37.6 ± 1.7	40.0 ± 0.9

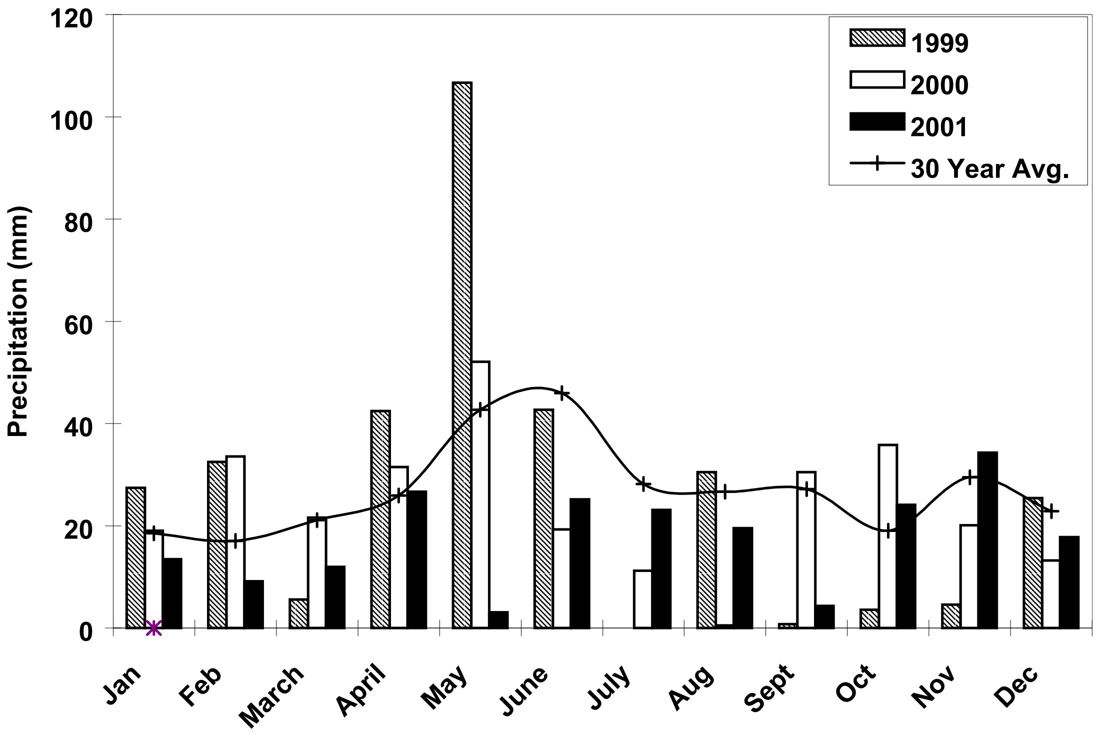

Fig. 3.1. Precipitation pattern for 3-year period compared to 30-year average. Data from Dubois, ID weather station. <http://snow.ag.uidaho.edu/main.html>

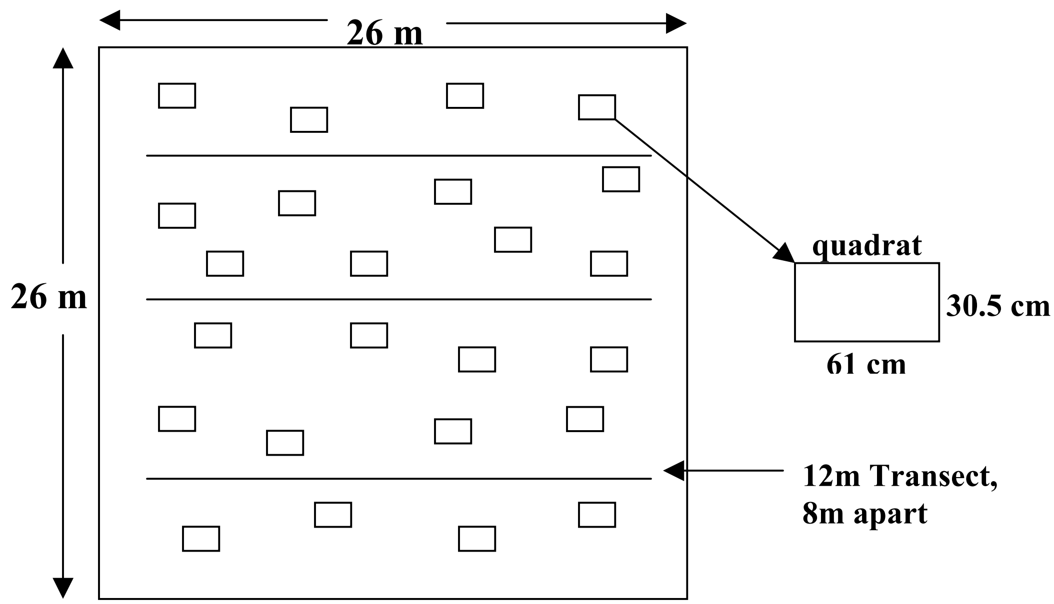

Fig. 3.2. Sheep grazing trial paddock with 3 transects, and 24 randomly placed quadrats for estimating biomass attributes. Grazing trial included 36 paddocks, 2 sites and occurred over summers 2000, and 2001.

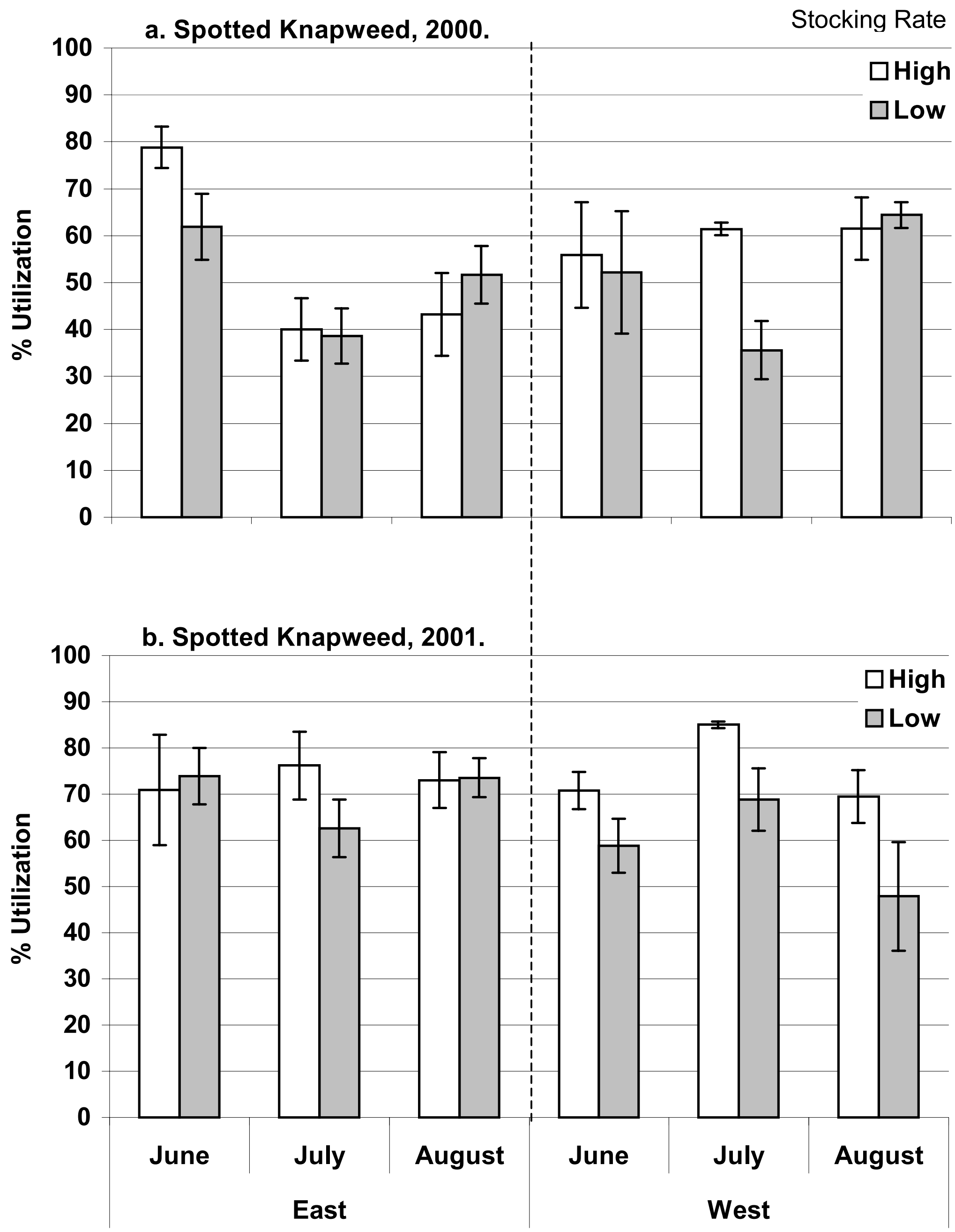

Fig. 3.3. Percent utilization (biomass removed) of (a) spotted knapweed in 2000, and (b) spotted knapweed in 2001 in a grazing trial with sheep at high and low stocking rates in a three-tip sagebrush steppe plant community. Measurements reflect utilization after a 4-day grazing trial. Compared by year, grazing season, and 2 study sites.

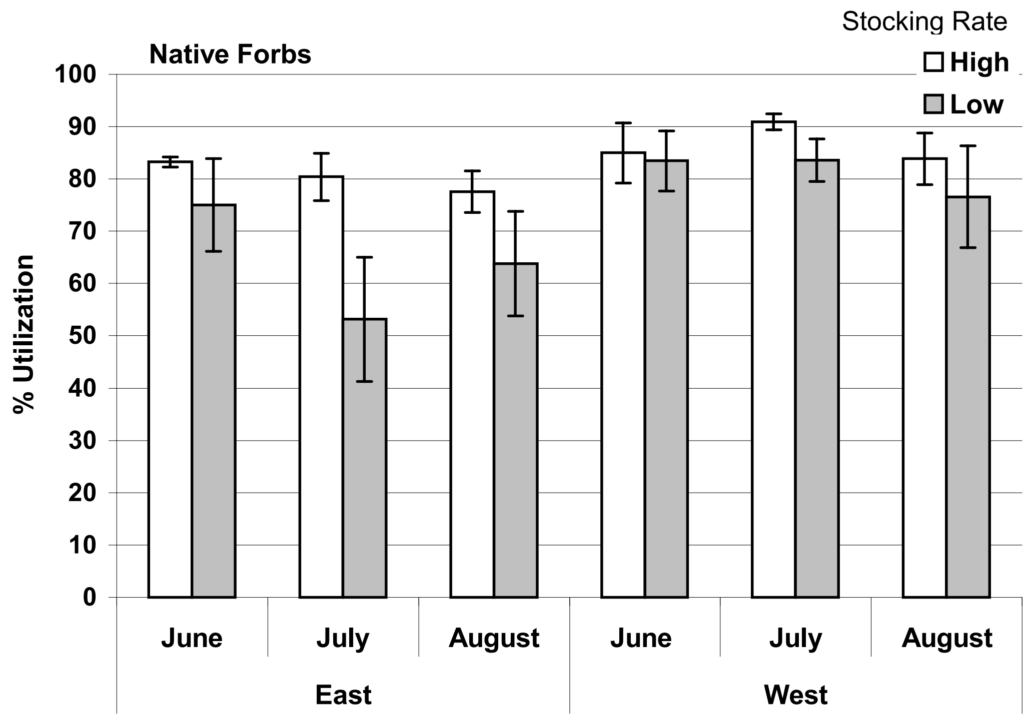

Fig. 3.4. Percent utilization (biomass removed) of native forbs in a grazing trial with sheep at high and low stocking rates in a three-tip sagebrush steppe plant community. Measurements reflect utilization after a 4-day grazing trial. Compared by site, grazing season, and averaged over 2 years.

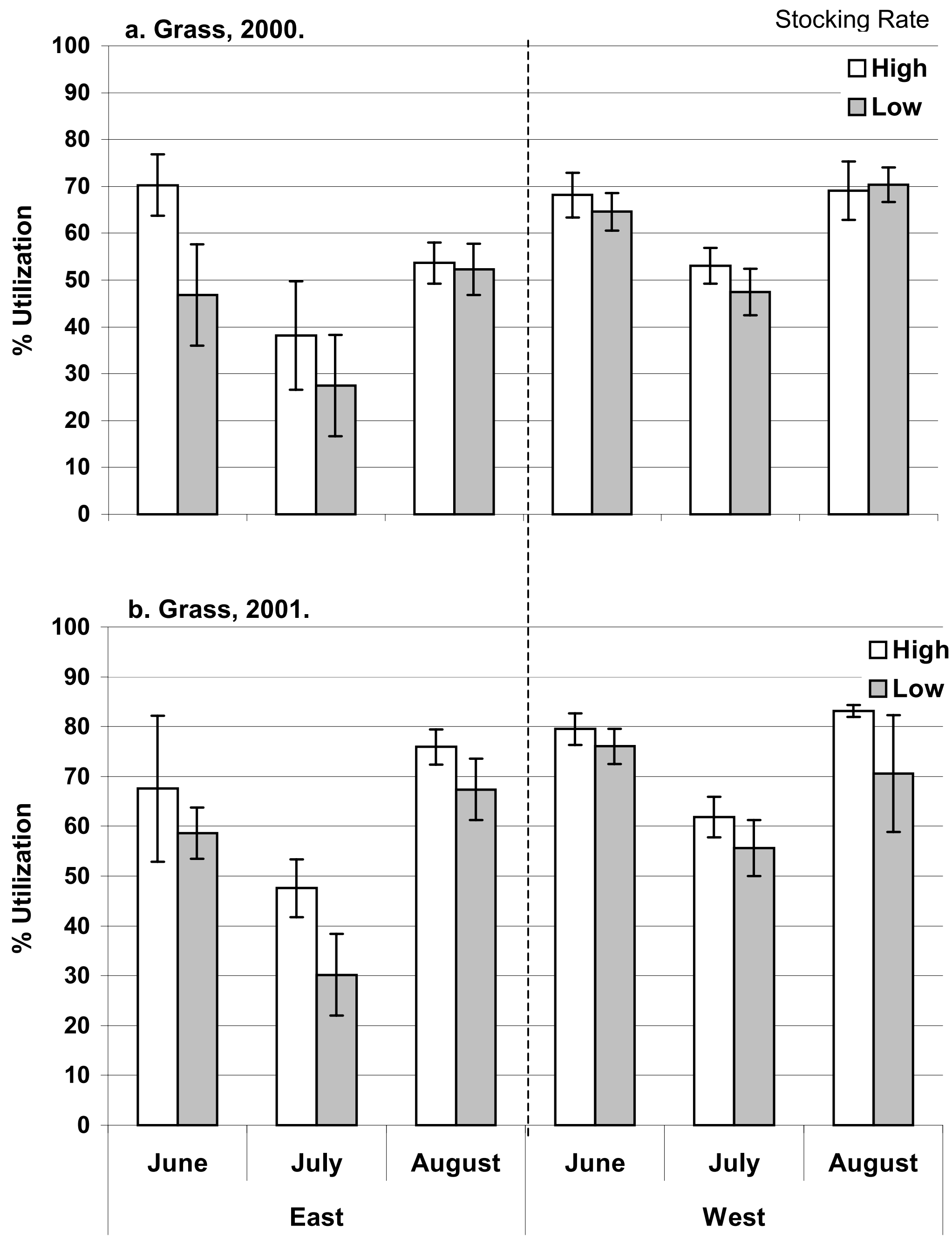

Fig. 3.5. Percent utilization (biomass removed) of (a) grass in 2000, and (b) grass in 2001 in a grazing trial with sheep at high and low stocking rates in a three-tip sagebrush steppe plant community. Measurements reflect utilization after a 4-day grazing trial. Compared by year, grazing season, and 2 study sites.

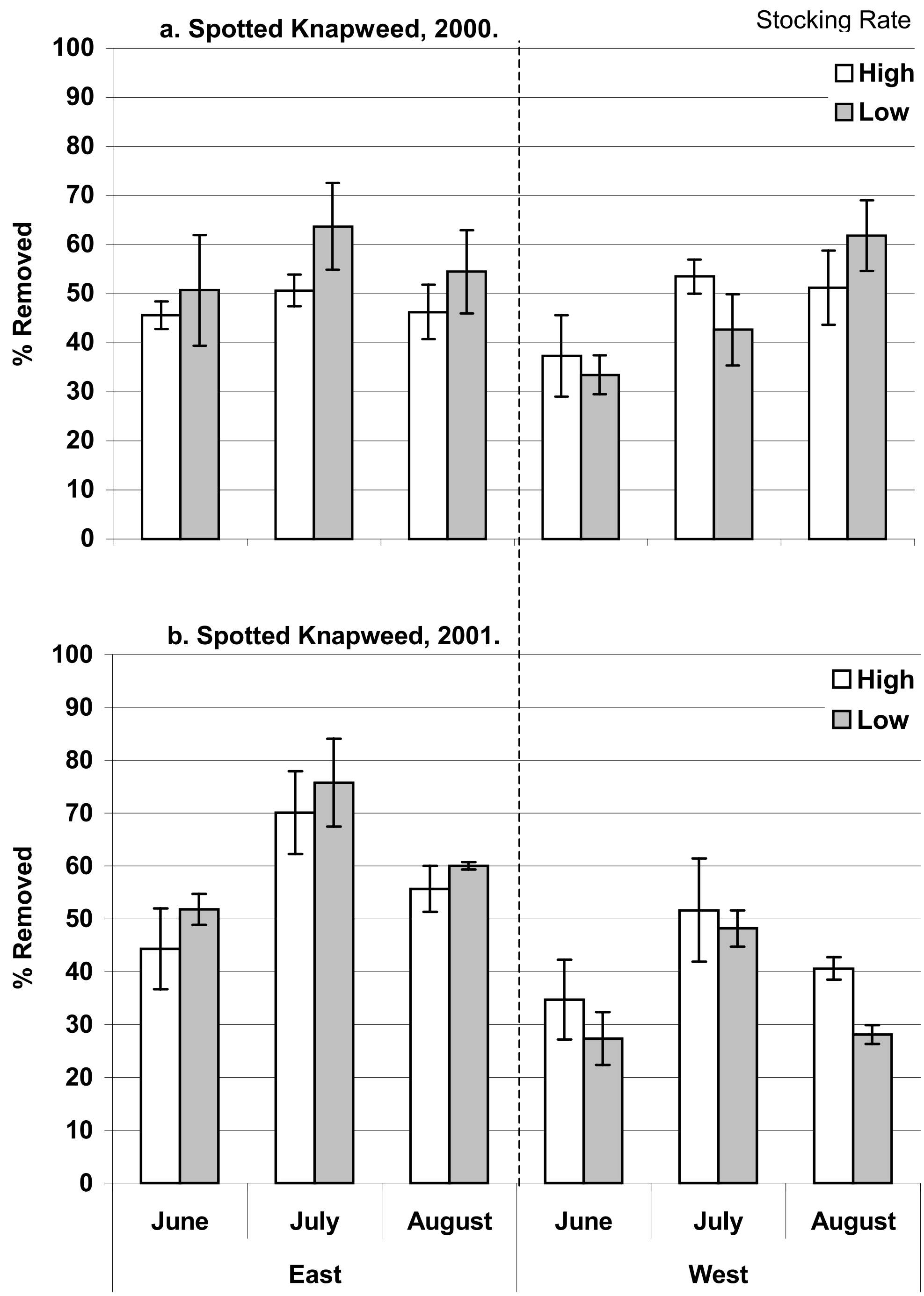

Fig. 3.6. The relative proportion removed of (a) spotted knapweed in 2000, and (b) spotted knapweed in 2001 by sheep relative to the to total herbage removed in a grazing trial at high and low stocking rates in a three-tip sagebrush plant community. Compared by grazing season and 2 study sites.

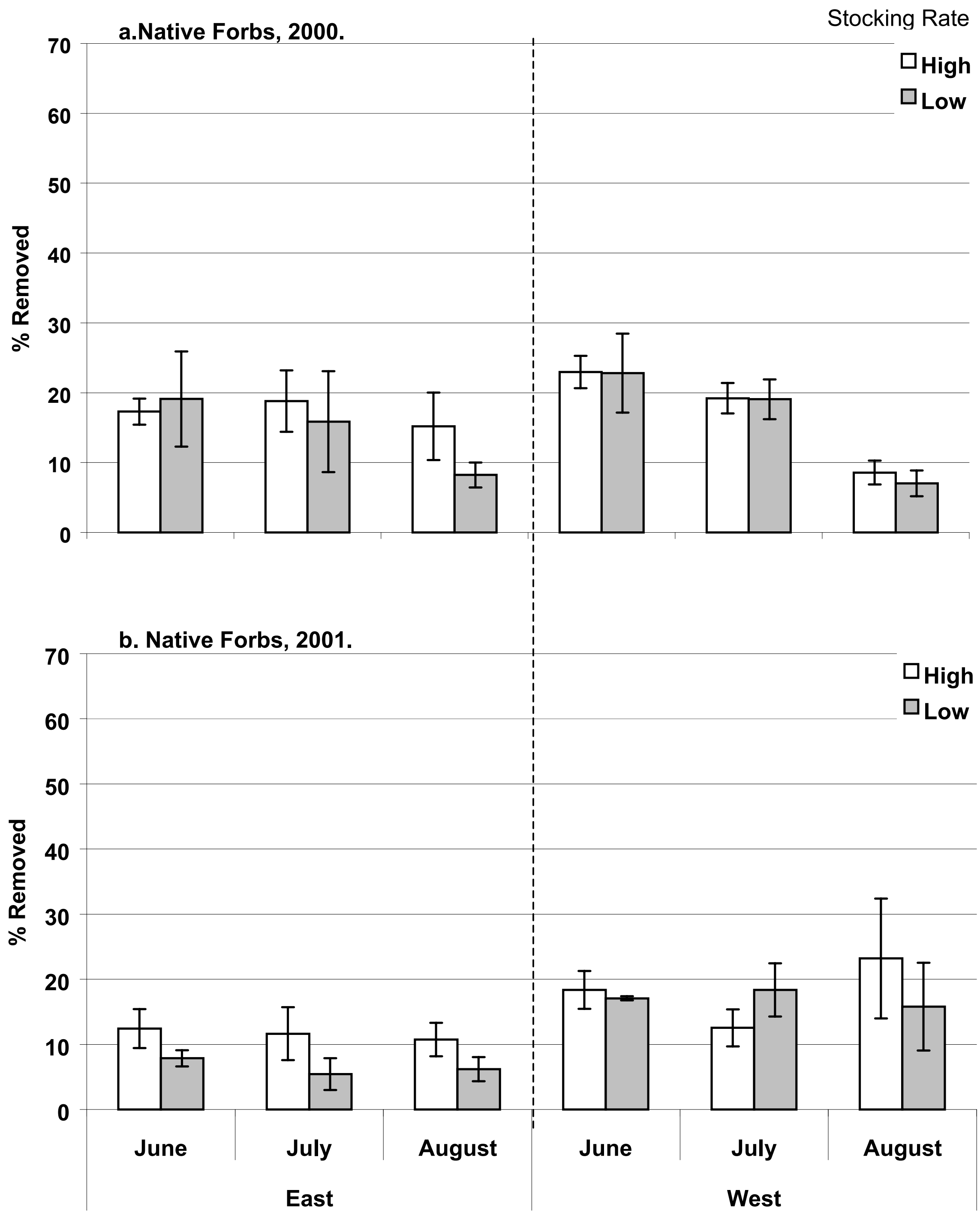

Fig. 3.7. The relative proportion removed of (a) native forbs in 2000, and (b) native forbs in 2001 by sheep relative to the to total herbage removed in a grazing trial at high and low stocking rates in a three-tip sagebrush plant community. Compared by grazing season and 2 study sites

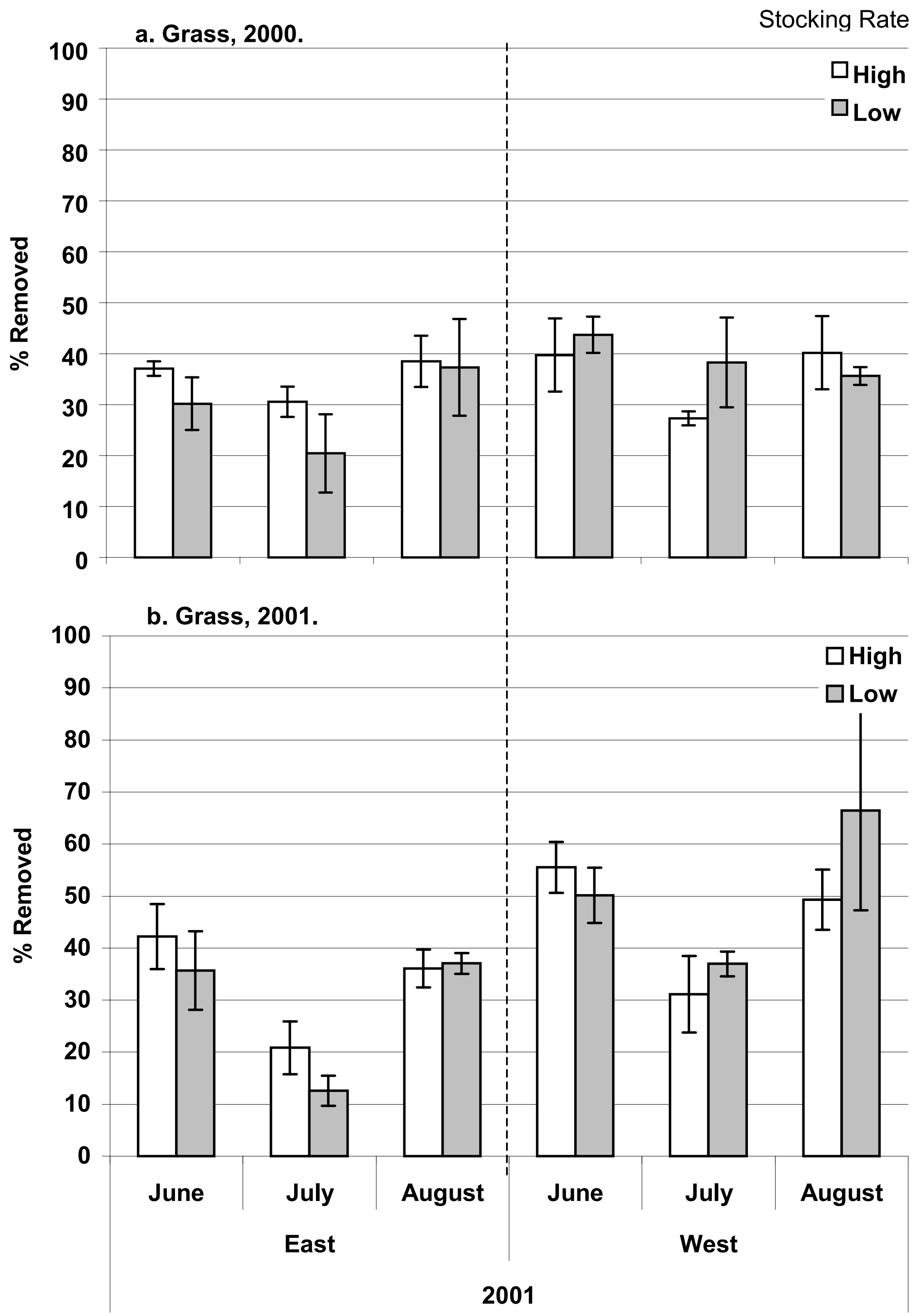

Fig. 3.8. The relative proportion removed of (a) grass in 2000, and (b) grass in 2001 by sheep relative to the to total herbage removed in a grazing trial at high and low stocking rates in a three-tip sagebrush plant community. Compared by grazing season and 2 study sites.

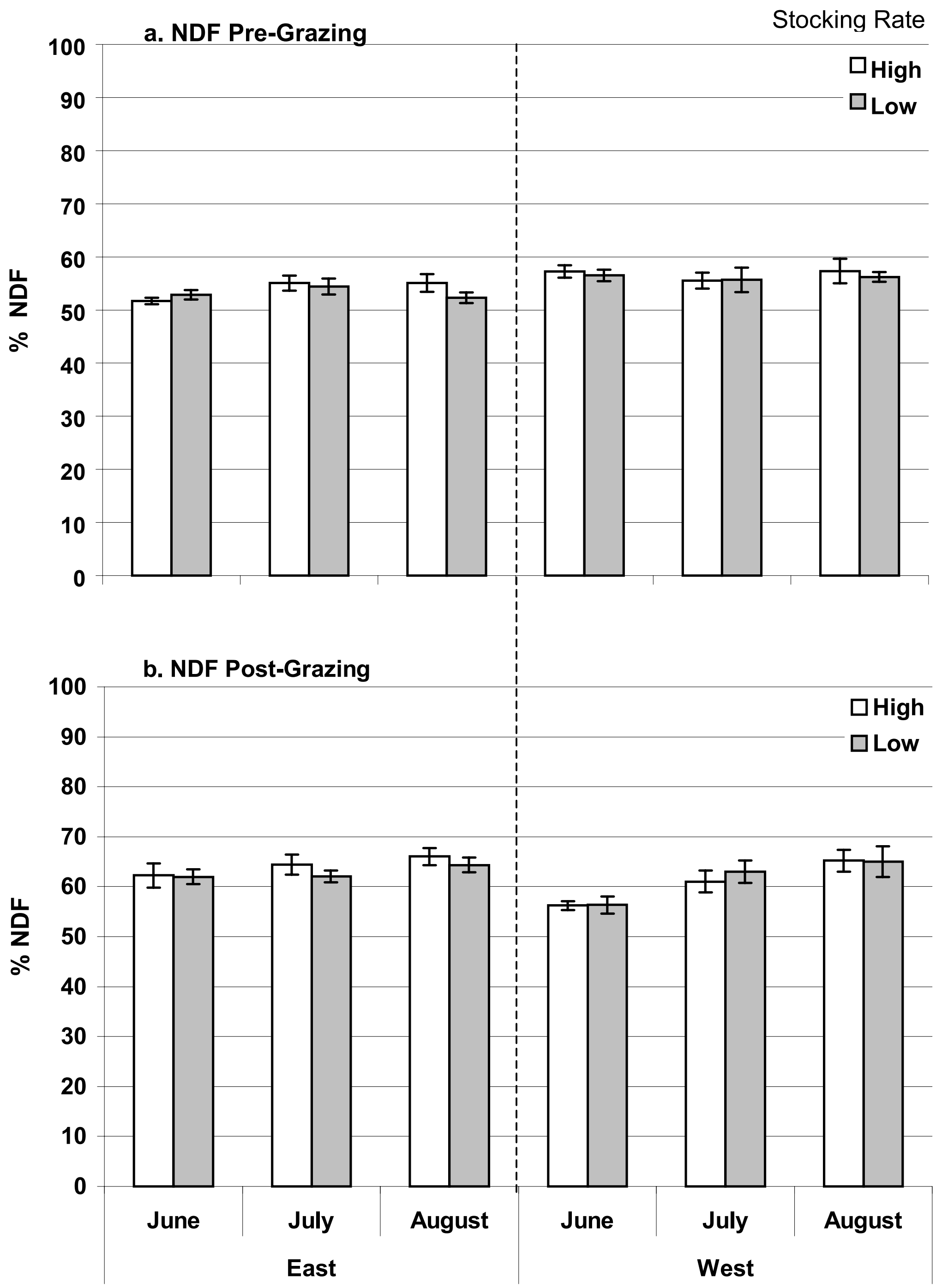

Fig. 3.9. Pre-grazing measurements (a) of neutral detergent fiber (NDF), and post-grazing measurement (b) of NDF. Pre-grazing data provides baseline measurement; post-grazing measurements provides a stocking rate (i.e., high and low), site, and season comparison. Samples were collected from esophageally fistulated sheep, and averaged by paddocks.

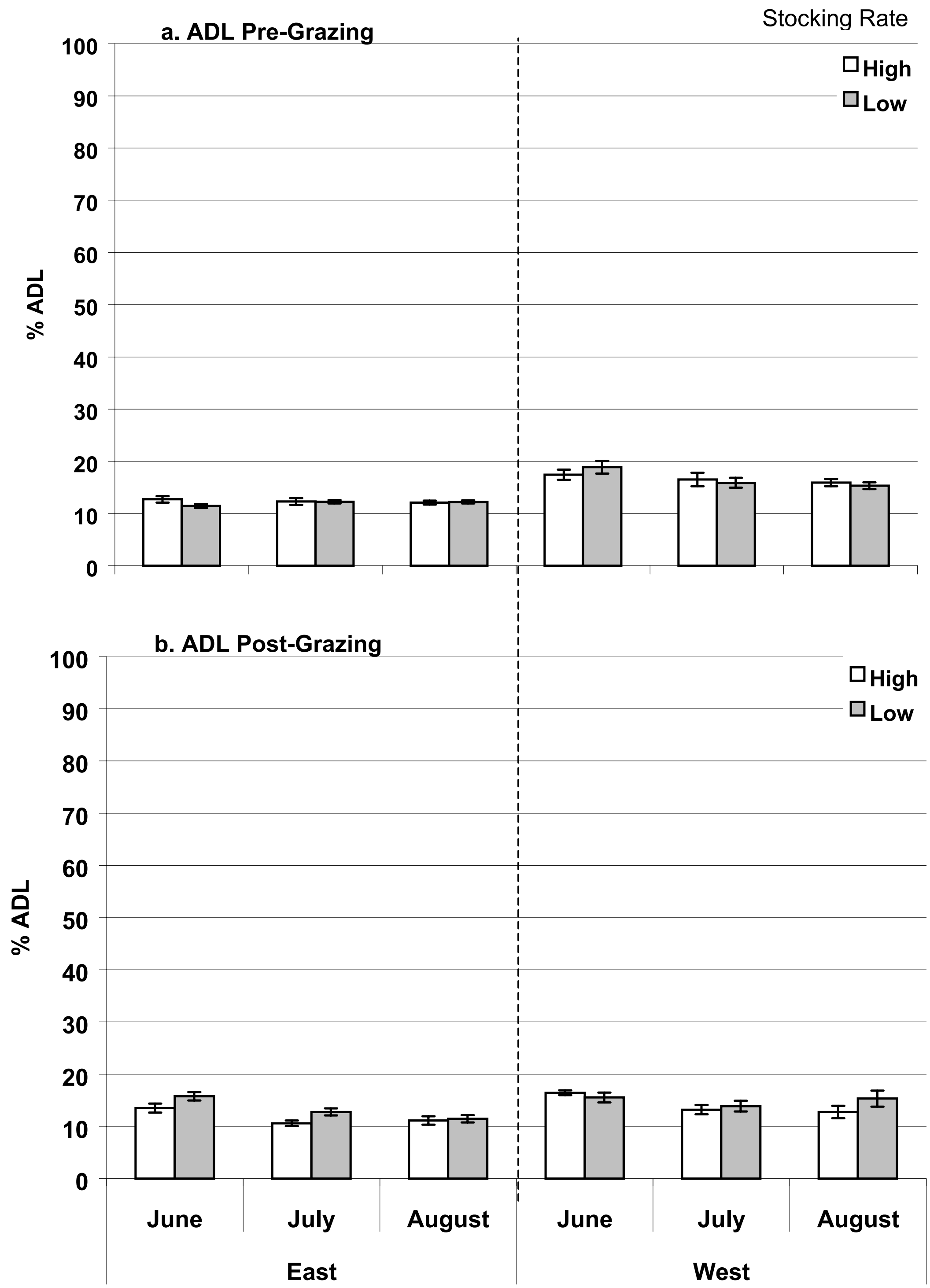

Fig. 3.10. Pre-grazing measurements (a) of acid detergent lignin (ADL), and post-grazing measurement (b) of ADL. Pre-grazing data provides baseline measurement; post-grazing measurements provides a stocking rate (i.e., high and low), site, and season comparison. Samples were collected from esophageally fistulated sheep, and averaged by paddocks.

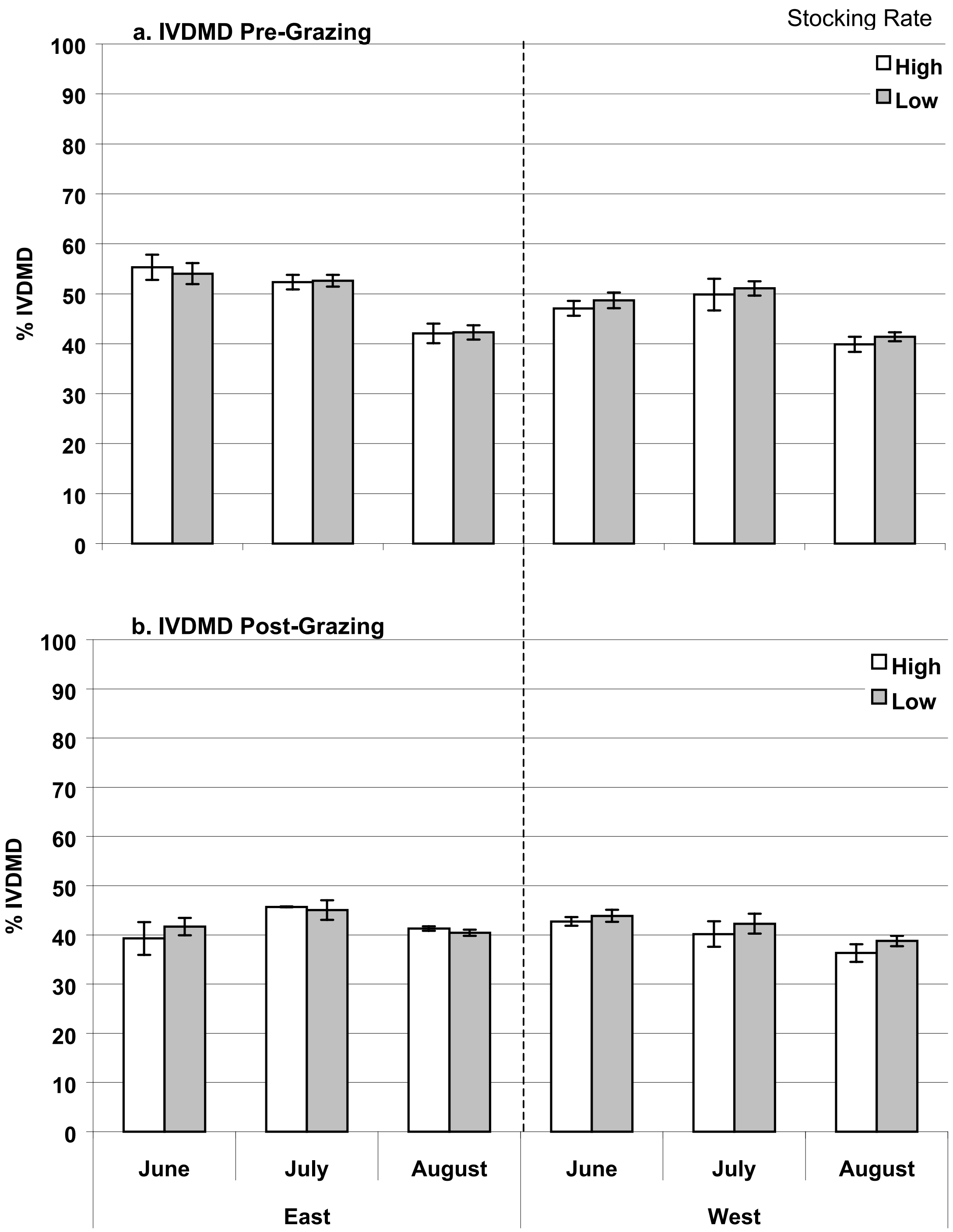

Fig. 3.11. Pre-grazing measurements (a) of IVDMD, and post-grazing measurements (b) of IVDMD. Pre-grazing data provides baseline measurement; post-grazing measurements provides a stocking rate (i.e., high and low), site, and season comparison. Samples were collected from esophageally fistulated sheep, and averaged by paddocks

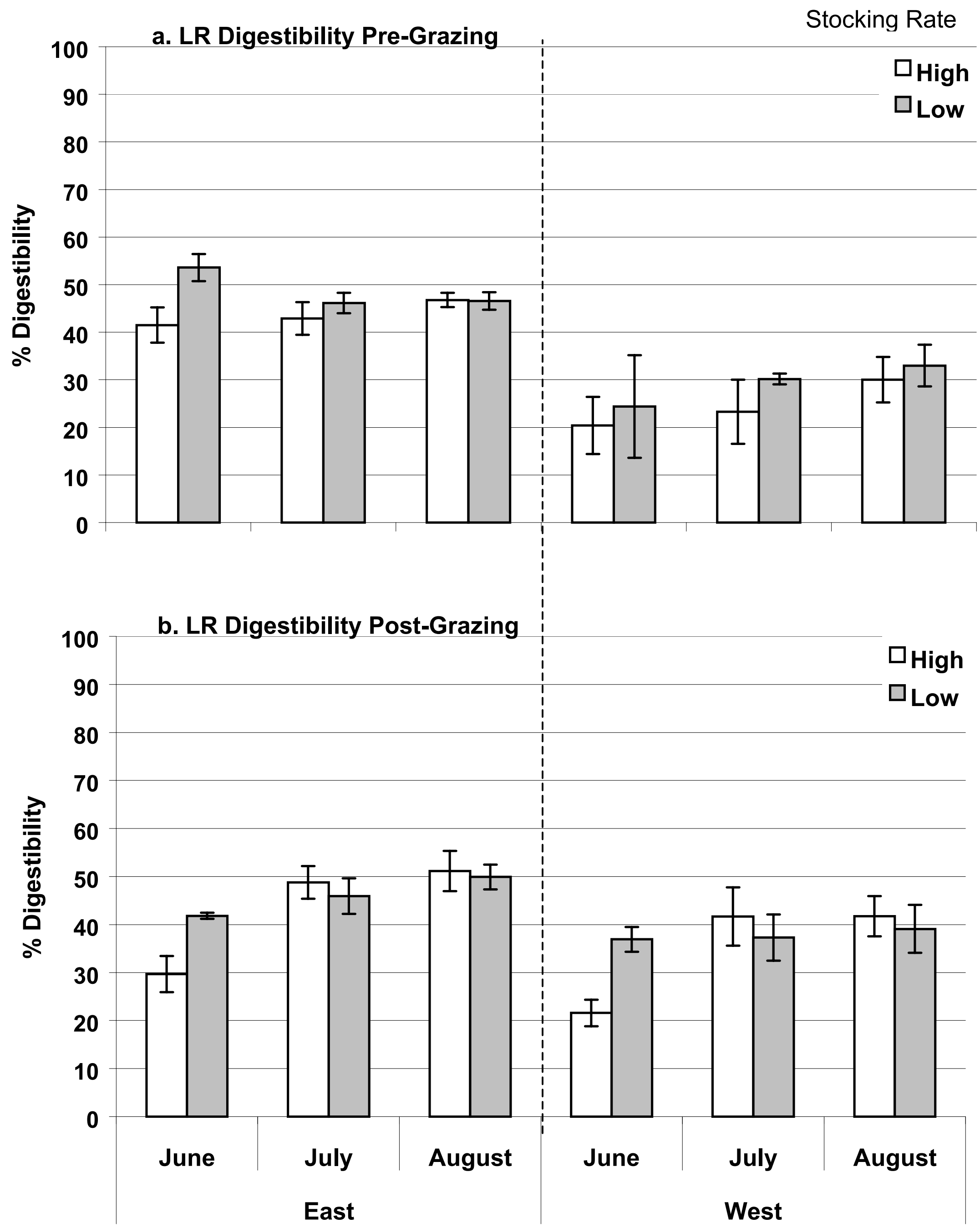

Fig. 3.12. Pre-grazing measurements (a) of LR Digestibility, and post-grazing measurements (b) of LR Digestibility. Pre-grazing data provides baseline measurement; post-grazing measurements provides a stocking rate (i.e., high and low), site, and season comparison. Samples were collected from esophageally fistulated sheep, and averaged by paddocks .