EFFECTS OF LONG-TERM WINTER-SPRING

GRAZING ON FOOTHILL RANGELAND

by

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ABSTRACT

In the Rocky Mountain foothills of Montana, elk (*Cervus elaphus*) often occupy the rough fescue/bluebunch wheatgrass (*Festuca campestris* Rydb./*Pseudoroegneria spicata* (Pursh) A. Löve) habitat type in winter and early spring. Previous research has demonstrated that moderate summer herbivory sustains dominant graminoids in this habitat type, but heavy summer grazing does not. This study compared the effects of heavy and light, long-term winter-spring grazing on bluebunch wheatgrass, rough fescue, and Idaho fescue (*Festuca idahoensis* Elmer), plant yield, ground cover, and soil properties in this habitat type. Eight sites were sampled with similar slope, aspect, soil type, elevation, and precipitation that were grazed nearly exclusively by elk in winter-spring for 56 years, with 4 sites each located within heavily and lightly grazed areas. Basal diameter (P=0.04), June and July leaf height (P<0.01 and P=0.01, respectively), number of seedheads per plant (P=0.03), percent filled florets per plant (P<0.01), percent canopy cover (P=0.01), and percent species composition (P=0.02) of rough fescue were less on heavily than lightly grazed sites. June leaf height (P=0.01), and percent filled florets (P<0.01) were less and number of seedheads per plant (P=0.01) of bluebunch wheatgrass was greater on heavily grazed sites. Percent filled florets (P<0.01) and June and July leaf height (P=0.01 and P<0.01, respectively) of Idaho fescue were less on heavily grazed sites. Plant yield did not differ between heavily and lightly grazed sites (P>0.10). Total ground cover was not different between heavily and lightly grazed sites (P>0.10), however, ground cover of graminoids and forbs was less (P=0.04) and ground cover of dense clubmoss (*Selaginella densa* Rydb.) was greater on heavily grazed sites (P=0.04). Soil bulk density was greater (P=0.02) and the Ah horizon was not as deep (P<0.01) on heavily grazed sites. Comparisons of canopy cover with a near-pristine site in this habitat type indicate that rough fescue did not tolerate many successive years of heavy grazing in winter-spring, but long-term light grazing in winter-spring sustained rough fescue in proportions found within the potential natural community. Heavy or light long-term grazing in winter-spring decreased the abundance of bluebunch wheatgrass but had minimal impact on Idaho fescue.

CHAPTER 1

INTRODUCTION

Impacts of grazing intensity on foothill rangeland plant communities have become more important as increasing elk (*Cervas elaphus*) populations and reduced habitat availability force elk to use resources more intensely. This is particularly important in winter-spring when snow accumulations force elk out of higher elevations onto foothill rangeland. Previous foothill rangeland research studies that have focused on the impacts of grazing on specific grass species or plant communities have primarily been short-term and evaluated effects of spring or summer defoliation. The effects of winter-spring grazing over long periods of time have not been investigated on specific bunchgrasses, such as bluebunch wheatgrass *(Pseudoroegneria spicata* (Pursh) A. Löve), Idaho fescue (*Festuca idahoensis* Elmer), and rough fescue (*Festuca campestris* Rydb.), within foothill rangeland plant communities.

Elk rely heavily on foothill rangeland forage in winter and spring and domestic livestock also often utilize these areas in summer (Torstenson et al. 2006). Some researchers suggest that foothill rangeland habitat is becoming increasingly diminished as urbanization, conversion to cropland, and recreational use increase, forcing elk to occupy sites more frequently and at higher densities during winter and spring (Kasworm et al. 1984; Sheehy and Vavra 1996; Burchman et al. 1999). When elk occupy foothill rangeland sites in winter and spring, 80% of their diet is usually comprised of graminoids (Nelson and Leege 1982; Ngugi et al. 1992; Jones et al. 1996; Torstenson et al. 2006).

On foothill rangeland, the rough fescue/bluebunch wheatgrass habitat type is more productive than any other foothill habitat type, with graminoids comprising between 65% and 90% of plant species present (Mueggler and Stewart 1980). Of the graminoid species present on the rough fescue/bluebunch wheatgrass habitat type, rough fescue is the primary forage producer, is sensitive to overgrazing, and consequently, is considered a decreaser on these sites (Mueggler and Stewart 1980). Bluebunch wheatgrass and Idaho fescue are not selected as heavily as rough fescue in this habitat type and may increase or decrease irrespective of habitat type or location (Mueggler and Stewart 1980).

Light and moderate grazing intensities typically maintain plant vigor, canopy cover, and species composition of dominant grasses on foothill rangeland, however, heavy grazing intensities do not if grazing occurs during early summer while bunchgrasses are in the mid-boot or inflorescence emergence stage (Mueggler 1975; Willms 1991; Clark et al. 2000). It is not clear, however, if heavy grazing in winter and spring will maintain plant vigor, canopy cover, and species composition of dominant graminoids on foothill rangeland if grazing occurs on the same sites for many consecutive years. Therefore, this experiment was conducted to examine the effects of long-term heavy and light winter-spring grazing on the rough fescue/bluebunch wheatgrass habitat type. The goal was to develop grazing management recommendations for the rough fescue/bluebunch wheatgrass habitat type in the Northern Rocky Mountains. The objectives were to:

1) compare the effects of heavy and light long-term winter-spring grazing on plant vigor, species composition, and canopy cover of bluebunch wheatgrass, Idaho fescue, and rough fescue on a rough fescue/bluebunch wheatgrass habitat type on foothill rangeland,
2) compare the effects of heavy and light long-term winter-spring grazing on herbaceous plant yield and ground cover on a rough fescue/bluebunch wheatgrass habitat type on foothill rangeland, and
3) compare the effects of heavy and light long-term winter-spring grazing on soil properties on a rough fescue/bluebunch wheatgrass habitat type on foothill rangeland.

CHAPTER 2

LITERATURE REVIEW

Foothill rangeland is important seasonal foraging habitat for wild and domestic ungulates (Berg and Hudson 1982; Powell et al. 1986; Hart et al. 1991; Sheehy and Vavra 1996). Of the 4 million hectares of foothill rangeland in Montana, foothill grassland comprises approximately 1.9 million hectares (Payne 1973). In the Rocky Mountain foothill grasslands of Montana, elk often occupy sites within the rough fescue/bluebunch wheatgrass habitat type in winter and early spring (Peek 1966; Knight 1970; Jourdonnais and Bedunah 1985).

Understanding the effects of long-term heavy and long-term light grazing is increasingly important for managing foothill rangeland and maintaining species composition of bluebunch wheatgrass, Idaho fescue, and rough fescue. Graminoids comprise between 65% and 90% of the total biomass within the rough fescue/bluebunch wheatgrass habitat type and the dominant graminoids in this habitat type are rough fescue, bluebunch wheatgrass, and Idaho fescue (Mueggler and Stewart 1980). These grass species are desirable forage species for wild and domestic ungulates due to their palatability and relatively high nutritional quality on foothill rangeland (Knight 1970; Kasworm et al. 1984; Mueggler and Stewart 1980).

The effects of grazing on plants are determined by the timing, frequency, intensity, and selectivity of grazing bouts (Mueggler 1975; Briske and Richards 1994). Timing and frequency of grazing affect a plant's ability to photosynthesize and may also affect plant vigor (McLean and Wikeem 1985a). The growth stage of a plant at the time of defoliation plays an important role in determining plant response to herbivory in bluebunch wheatgrass, Idaho fescue, and rough fescue (Willms 1991; Clark et al. 1998; Brewer 2002). Most bunchgrasses in Montana are cool season perennials, with the majority of tiller and reproductive culm formation occurring in the spring when ground moisture is higher and temperatures are lower than other portions of the growing season.

Removing the majority of leaf sheaths reduces the amount of photosynthetic material present on a plant and delays regrowth (Briske and Richards 1994). When the apical meristem is removed, the tiller ceases growth. If grazing frequency is too high or soil moisture is limiting there may not be adequate time for tiller regrowth before plant senescence. Therefore, grazing during spring at high frequencies and during sensitive growth stages may lower plant vigor and yield, increase plant mortality, and alter composition of the plant community (Caldwell 1984; Briske and Richards 1994).

Grazing intensity relates to the level of defoliation accrued by plants during an individual grazing bout or throughout the grazing period. The grazing intensity a plant can withstand depends on the frequency and timing of grazing. Previous research has demonstrated that on foothill rangeland, moderate levels of grazing during summer generally maintain plant vigor and species composition, but heavy grazing does not (Mueggler 1975; Willms 1991; Clark et al. 1998; Clark et al. 2000). Although several plant physiologists have suggested that dormant season grazing is not harmful to dormant plants (Caldwell 1984; Briske and Richards 1994), there is limited research data to support these claims. Dormant season grazing of prairie sandreed (*Calamovilfa* *longifolia* (Hook.) Scribn.) or sand bluestem (*Andropogon hallii* Hack.) did not alter organic reserves compared with plants that had been rested for 4 years from grazing in the mixed-grass prairie of western Nebraska (Reece et al. 1996). Whether heavy grazing maintains plant vigor and composition when grazing occurs in winter-spring is yet undetermined for foothill rangeland.

Large ungulates select plant species based upon palatability and availability (Bunnell and Gillingham 1985). As a result, more palatable plant species are grazed more frequently and intensely than other species within the plant community (Briske 1991). The upright stature of bunchgrasses makes them more accessible than other lower growing plant species (Hodgson 1982; Briske 1991). Selection of these species and increased grazing pressure on them reduces their competitive ability within the plant community and may reduce their relative composition within a plant community compared with other less palatable or less accessible plant species (Briske 1991).

Bluebunch Wheatgrass on Foothill Rangeland

Effects of Timing and Frequency of Defoliation

Plant yield is an important factor to consider when managing foothill rangeland, as it directly impacts the amount of available forage for grazing ungulates throughout the year. Plant yield is impacted by both timing and frequency of defoliation (Mueggler 1975). Clipping bluebunch wheatgrass on a foothill rangeland site in northern Utah during the boot stage in April reduced plant yield more than clipping during other growth stages (Stoddart 1946). In south-central British Columbia, bluebunch wheatgrass clipped to 5 cm at 10-day intervals from mid-April through the end of May or from mid-May to late June had increased mortality and reduced plant yield in June and July compared with bluebunch wheatgrass plants clipped at any other growth stage (McLean and Wikeem 1985a). Plant yield declined in both experiments resulting from frequent clipping in late spring.

Bluebunch wheatgrass clipped to 9-cm in April on a mountain grassland site in southwestern Montana had 46%, 60%, and 51% higher yield in June and 79%, 79%, and 80% higher yield in July compared with plants receiving 3-cm, 6-cm, or no clipping, respectively (Brewer 2002). Plants clipped to 3 cm or 6 cm in May had 89% and 78% less yield, respectively, in June than unclipped plants (Brewer 2002). These results provide further evidence that heavy grazing in late spring may reduce plant yield in summer.

Indicators of plant vigor include leaf length, number of reproductive culms, percent filled florets, and basal diameter (Hanson and Stoddart 1940; Weaver and Darland 1947; Evanko and Peterson 1955; Heady 1957; Mueggler 1975). On foothill rangeland in southwestern Montana, vigor of bluebunch wheatgrass plants clipped prior to flower stalk emergence in early summer (June) was adversely affected by a single clipping. Bluebunch wheatgrass plants, when compared with unclipped plants, had reduced plant vigor, indicated by shorter leaf lengths and fewer flower stalks the following summer when 50% of the total herbage was removed in early summer prior to full flower stalk emergence (Mueggler 1975). As a result of heavy clipping, bluebunch wheatgrass plants with moderately low vigor may require 6 or more years of rest to fully recover and plants with very low vigor, as a result of severe clipping, may require a minimum of 8 years to recover (Mueggler 1975).

On a game range in northeastern Oregon, basal area of bluebunch wheatgrass clipped to 7.6 cm in spring and to 2.5 cm in winter decreased by 7% when whole plants were clipped in the mid-boot stage and by 8% when whole plants were clipped in the inflorescence emergence stage (Clark et al. 1998). When whole plants were clipped at inflorescence emergence and again in early winter, basal area of bluebunch wheatgrass plants declined by 13%, while basal area of plants clipped at mid-boot and in early winter decreased by 8.5%. In the same study area, bluebunch wheatgrass grazed by sheep during the boot stage in early summer (June) did not affect the number of reproductive culms present in June when utilization was approximately 50%, compared with ungrazed plants (Clark et al. 2000).

Heavy and severe defoliation in late spring or early summer, as well as frequent but moderate levels of defoliation in late spring or early summer, reduces plant vigor and plant yield of bluebunch wheatgrass. Bluebunch wheatgrass plants in a state of low vigor, resulting from heavy and severe grazing in late spring or early summer, may require many years of rest to regain vigor.

Effects of Intensity of Defoliation

Moderate grazing during early summer (June), when plants were in the mid-boot stage, reduced bluebunch wheatgrass yield (Clark et al. 2000). Four consecutive years of moderate sheep grazing on a foothill site in west-central Montana from fall through spring caused a 16% decrease in total herbage yield and a 16.7% decrease in bluebunch wheatgrass yield compared with ungrazed sites (Vogel and Van Dyne 1966). In northeastern Oregon, bluebunch wheatgrass standing crop in fall decreased by 46% when sheep grazed to 50% utilization in early summer (June) during the boot stage for 2 years, compared with ungrazed areas (Clark et al. 2000). Based on these findings, moderate early summer grazing may reduce bluebunch wheatgrass yield when grazing occurs for 2 or more successive years.

Heavy grazing negatively impacts bluebunch wheatgrass yield and may also reduce plant vigor. Plants clipped to 2.5 cm at the flowering stage in central Montana had 5.5 cm shorter flower stalks, had 14 fewer flowering stalks per plant, and produced fewer fertile florets than plants clipped to 15 cm, causing a subsequent decrease in the seed crop the year following defoliation (Heady 1950). Moderate sheep grazing in fall, winter, and spring for 4 consecutive years on a mountain grassland site in west-central Montana reduced bluebunch wheatgrass longest leaf length by 17% and increased average basal area by 22% compared with ungrazed plants (Vogel and Van Dyne 1966).

On a mountain grassland site in southwestern Montana, bluebunch wheatgrass clipped to 3 or 6 cm for 3 consecutive years in May had 11 and 9 cm shorter leaf heights in June, respectively, and plants clipped to 3 cm in May had 9 cm shorter leaf heights in July compared with unclipped plants (Brewer 2002). On a sagebrush grassland site in the same study, clipping to 3, 6, or 9 cm in May for 3 consecutive years reduced leaf heights in June by 11, 6, and 7 cm, respectively, compared with unclipped plants, but clipping in May did not adversely affect leaf heights in July (Brewer 2002). Bluebunch wheatgrass plants clipped in April to 9 cm actually produced more seedheads than unclipped plants on the mountain grassland site. Similar to previous research, heavy and moderate defoliation negatively affected plant vigor, however, light intensities improved plant vigor, indicated by an increase in the number of seedheads produced (Brewer 2002).

Heavy and moderate grazing in fall, winter, spring and early summer reduced bluebunch wheatgrass plant vigor and yield in short-term experiments, suggesting that heavy grazing may also reduce plant vigor of bluebunch wheatgrass if continued over longer periods of time. Plant yield of bluebunch wheatgrass was also adversely impacted by short-term grazing, providing further evidence that long-term grazing may have even greater impacts on plant yield.

Previous research is limited regarding the effects of timing, frequency, or intensity of grazing on canopy cover of bluebunch wheatgrass. Lightly grazed areas in southwestern Montana had 58% more vegetal cover of bluebunch wheatgrass after 50 years compared with areas that were heavily grazed for the same time period (Evanko and Peterson 1955). Heavily grazed areas also had 42% and 60% less bluebunch wheatgrass cover than lightly or moderately grazed areas, respectively (Evanko and Peterson 1955). Herbage cover of bluebunch wheatgrass decreased by 5.5% after 4 years of moderate grazing compared with an equivalent amount of rest in a study conducted on foothill rangeland in central Montana (Vogel and Van Dyne 1966). In the foothill grasslands of British Columbia, McLean and Tisdale (1972) found that 30 years of rest were needed to improve range condition from poor (early seral) to good (late seral) and 40 years were needed to achieve excellent range condition (climax) on previously overgrazed sites, indicated by an increase in bluebunch wheatgrass canopy cover and frequency. This provides further evidence that bluebunch wheatgrass is susceptible to overgrazing and indicates that it may require a lengthy recovery period to improve its ecological status within heavily grazed rangeland (McLean and Tisdale 1972).

Idaho Fescue on Foothill Rangeland

Effects of Timing and Frequency of Defoliation

Idaho fescue yield and vigor is reduced by grazing that occurs during the boot stage or flower development stage (Mueggler 1975) or by grazing from fall through spring for 4 consecutive years (Vogel and Van Dyne 1966). Idaho fescue plants grazed moderately by sheep in fall, winter, and spring for 4 consecutive years on mountain grassland in west-central Montana had 60% less herbage yield per plant than ungrazed Idaho fescue (Vogel and Van Dyne 1966). In southwestern Montana, Mueggler (1975) studied the effects of a single year of clipping Idaho fescue plants exposed to full and partial competition, and heavy or severe clipping at the flowering development and seed-ripe stages. Idaho fescue plants exposed to full competition and clipped to remove 75% of the herbage volume at flower development and clipped again to remove 75% of regrowth when control plants reached the seed ripe stage exhibited an 85% reduction in total herbage volume compared with unclipped plants exposed to full competition, and flower stalk production was nearly eliminated the year following treatment (Mueggler 1975).

On a study in northeastern Oregon, 32% utilization of Idaho fescue plants in early summer (June) did not affect the number of reproductive culms compared with ungrazed plants (Clark et al. 2000). Long-term heavy winter elk grazing on mountain grassland in Yellowstone National Park caused a 29% decline in biomass of Idaho fescue plants compared with ungrazed plants and grazed plants also had 49% shorter vegetative culms than ungrazed plants (Singer 1995).

Results from these studies suggest that heavy and moderate grazing in fall through spring for 4 years reduces yield of Idaho fescue, while heavy and severe grazing in mid to late summer reduces plant yield and decreases plant vigor. Long-term winter grazing may also reduce plant biomass and leaf height, however, light grazing in early summer does not affect plant vigor of Idaho fescue.

Effects of Intensity of Defoliation

Jaindl et al. (1994) compared the effects of defoliation on transplanted Idaho fescue plants from heavily grazed areas and ungrazed areas in central and eastern Oregon. All plants were defoliated to 5 cm during the vegetative, boot, or anthesis stage or remained unclipped for 2 years and responses were measured at the end of the growing season. Idaho fescue plants from central Oregon that had historically been protected from grazing had 9% more total annual production than plants that had historically been heavily grazed. In one year of the study, Idaho fescue plants that were defoliated in the anthesis stage had 29% and 21% more annual production than undefoliated plants and plants clipped in the vegetative stage, respectively. These researchers concluded that grazing history did not affect Idaho fescue response to defoliation.

In southwestern Alberta, 17 years of light, moderate, heavy, and severe season-long grazing from mid-May to mid-November increased relative percent basal area of

Idaho fescue in grazed areas by 20%, 38%, 33%, and 60%, respectively, compared with ungrazed areas (Johnston et al. 1971). In the same study area, Idaho fescue grazed for 30 years at fixed rates in mid May through mid November had 59% shorter leaf heights in overgrazed areas than plants in ungrazed areas (Willms et al. 1988).

In north-central Wyoming, Pond (1960) compared vigor of Idaho fescue plants in response to light, moderate, or heavy grazing with those in ungrazed exclosures on sedimentary and granitic soils, using leaf height, herbage weight, and basal area as indicators of plant vigor. Idaho fescue plants inside exclosures were more vigorous than grazed plants. Ungrazed Idaho fescue plants had 39% greater leaf heights than heavily grazed plants and 33% and 45% larger basal areas and 47% and 60% more herbage production per plant than heavily grazed and moderately grazed plants, respectively. Light grazing was least detrimental to plant vigor of Idaho fescue plants.

In southwestern Montana, Evanko and Peterson (1955) compared Idaho fescue on sites that had been heavily, moderately, or lightly grazed for 50 years prior to the study from mid-summer to fall with sites that had not been grazed for 15 to 26 years prior to the experiment. Leaf height, ground cover, and number and size of plant clumps were evaluated. The number of Idaho fescue clumps averaged 2.5 and 4.1 more plants per plot in heavily and moderately grazed sites, respectively, than ungrazed exclosures. However, there were 2.2 more Idaho fescue plants per plot in the ungrazed exclosures than in the lightly grazed treatment. Basal area of Idaho fescue plants on grazed sites was 28% smaller than on ungrazed sites, with moderately grazed plants 3.1 cm^2 smaller than ungrazed plants and heavily grazed plants 3.4 cm^2 smaller than ungrazed plants. Basal area of lightly grazed plants was only 1 cm^2 smaller than ungrazed plants (Evanko and Peterson 1955).

Plant vigor and plant yield of grazed Idaho fescue was lower when moderately grazed by sheep in fall, winter, and spring for 4 consecutive years on a mountain grassland site in west-central Montana compared with ungrazed Idaho fescue plants (Vogel and Van Dyne 1966). Longest leaf length, tallest seedstalk height, and basal area of Idaho fescue were 28%, 6%, and 44% less, respectively, in the moderately grazed areas than in ungrazed areas, and Idaho fescue herbage yield was 60% lower on moderately grazed areas than ungrazed areas (Vogel and Van Dyne 1966).

Idaho fescue plants were sensitive to heavy and extreme clipping in summer when exposed to partial and full competition from surrounding vegetation in a study in southwestern Montana (Mueggler 1975). Idaho fescue plants exposed to severe clipping and full competition had 89% smaller basal areas, 34% shorter leaf lengths, and 81% less herbage volume than Idaho fescue plants exposed to heavy clipping with the same competition one year after clipping. Additionally, Idaho fescue plants exposed to severe clipping and full competition did not fully regain herbage volume or basal area 5 years after clipping compared with unclipped plants or with heavily clipped plants and produced 37% less herbage volume and had 12% smaller basal areas than heavily clipped plants. These results indicate that Idaho fescue may not regain vigor after severe grazing for 1 year and suggest that it will not tolerate subsequent years of grazing at this intensity.

In southwestern Alberta, Idaho fescue, after 37 years of light, moderate, or heavy grazing had 17%, 75%, and 1% fewer germinable seeds, respectively, than ungrazed

Idaho fescue (Willms and Quinton 1995). This indicates that Idaho fescue vigor may be adversely affected by long-term grazing.

Results from short-term studies suggest that plant vigor and yield of Idaho fescue is negatively impacted by moderate, heavy, and severe grazing in spring, summer, fall and winter, however, in a long-term study in the fescue grasslands of Alberta, the basal diameter increased as grazing intensity increased.

Limited research has been conducted that examined the effect of grazing intensity, frequency, or timing on canopy cover of Idaho fescue. Areas grazed lightly for 50 years had 44% less canopy cover of Idaho fescue than ungrazed areas and areas that were heavily grazed for 50 years had 33% and 60% less Idaho fescue canopy cover than lightly or moderately grazed areas, respectively (Evanko and Peterson 1955). Basal cover of Idaho fescue decreased by 53% after 4 years of moderate grazing compared with an equivalent amount of rest in a study conducted on foothill rangeland in central Montana (Vogel and Van Dyne 1966). Percent canopy cover of Idaho fescue was 71% lower in severely grazed areas than lightly grazed areas after 30 years of cattle grazing (Willms et al. 1988).

Rough Fescue on Foothill Rangeland

Effects of Timing and Frequency of Defoliation

Rough fescue is sensitive to frequent defoliation during spring, which may increase plant mortality and reduce plant vigor. The effects of 11 clipping regimes were evaluated on rough fescue vigor and survival, which varied in timing, frequency, and intensity of defoliation, in northwestern British Columbia (McLean and Wikeem 1985b). Individual rough fescue plants were clipped to a 5, 10, 15, or 20-cm stubble height at weekly intervals at various timings between the boot through seed development stages. Plant yield declined by 94% compared with unclipped plants when clipping occurred from mid-May to late June and again once in September, during the boot to full flower development stages, with a resulting mortality rate of 92% for this treatment. Plants clipped season-long or in May through June had 87% and 89% lower yield, respectively, than unclipped plants and averaged 78% mortality. Average leaf height of rough fescue was the most adversely affected by clipping to 5 cm from mid May to late June and again once in September (McLean and Wikeem 1985b). Average leaf height of plants that received this treatment was 46% shorter than unclipped plants. These results indicate that frequent defoliation of rough fescue from spring through fall to at 5-cm stubble height is extremely damaging to plant vigor and may cause high levels of mortality.

Rough fescue plants were highly susceptible to frequent defoliation during the period of active growth in a study conducted in the fescue grasslands of southwestern Alberta (Willms 1991). Rough fescue plants were clipped for 3 consecutive years during a 16-week period from mid-May to late August to 5, 10, or 15 cm every 1, 2, 4, 8, or 16 weeks. By the third year, rough fescue yield decreased non-linearly in relation to increased clipping frequency. Contrary to McLean and Wikeem (1985b), mortality of rough fescue plants clipped to 5 cm at weekly intervals in this study was zero (Willms 1991).

Rough fescue is highly susceptible to frequent defoliations during the period of active growth. Frequent defoliation of rough fescue during spring and fall causes high mortality rates, reduced plant vigor, and reduced plant yields under both short-term and long-term defoliation regimes.

Effects of Intensity of Defoliation

Heavy and moderate grazing adversely affects plant yield of rough fescue when clipping occurs in spring and fall. In northwestern British Columbia, the effects of 11 different clipping regimes of various timings, intensities, and frequencies of defoliation were studied on rough fescue vigor and survival (McLean and Wikeem 1985b). Clipping rough fescue to 5 cm from mid-May through mid August caused 54%, 77%, and 88% higher mortality rates than clipping to 10, 15, or 20 cm, respectively. Additionally, clipping to 10 cm reduced plant yield 44% and 64% compared with plants clipped to 15 and 20 cm, respectively, and clipping to 5 cm reduced plant yield 80% compared with rough fescue plants clipped to 20 cm. In the rough fescue grasslands of western Alberta, the effects of light, moderate, heavy, and very heavy stocking rates on percent basal area of rough fescue were studied in pastures that had been grazed at these levels in the summer for 32 years prior to the study (Willms et al. 1985). Basal area of heavily grazed rough fescue was 79% smaller than lightly grazed plants.

In the fescue grasslands of southwestern Alberta, Willms (1991) examined plant yield and mortality of rough fescue plants clipped for 3 consecutive years during a 16-week period from mid-May to late August to 5, 10, or 15 cm every 1, 2, 4, 8, or 16 weeks. Mortality rates of rough fescue plants clipped to 5 cm every 1, 2, or 4 weeks for

16 weeks was 37%, 33%, and 3%, respectively. Mortality of rough fescue plants clipped to 10 cm every 1, 2, or 4 weeks or 15 cm every 4 weeks was 3% at each interval. Plant yield of rough fescue clipped to 5 cm every 1, 2, 4, 8 and 16 weeks was 50.7 g, 35.7 g, 27.4 g, 12.6 g, and 9.7 g, respectively. These results indicate that rough fescue is sensitive to heavy clipping intensities and high clipping frequencies. In the same study area, Willms and Quinton (1995) studied the effects of 37 years of grazing at fixed rates, including light, moderate, and heavy, on the germinable seed bank. The amount of germinable rough fescue seeds declined as grazing pressure increased from light, moderate, and heavy by 7%, 83%, and 97%, respectively, compared with ungrazed rough fescue. These results suggest that rough fescue is sensitive to long-term moderate and heavy grazing, more so than long-term light grazing. High mortality and reduced amounts of germinable seeds produced will eventually lead to a decline in rough fescue composition on these sites.

Rough fescue plants grazed heavily throughout the growing season and into fall dormancy had smaller basal areas, produced fewer seedheads per plant, and had shorter leaves than ungrazed, lightly, and moderately grazed plants on fescue grasslands in southwestern Alberta (Johnston et al. 1971). Seventeen years of light, moderate, heavy, and extremely heavy season-long grazing from mid-May to mid-November reduced relative percent basal area of rough fescue in grazed areas by 23%, 35%, 76%, and 92%, respectively, compared with ungrazed areas (Johnston et al. 1971). Plains rough fescue (*Festuca hallii* [Vasey] Piper), a species similar to rough fescue, was exposed to heavy season-long grazing for 2 consecutive years and vigor of grazed plants was compared with plants inside ungrazed exclosures at Elk Island National Park in central Alberta. Plains rough fescue plants inside exclosures had 54% taller leaf height and 41% larger basal area than grazed plains rough fescue plants and only 3% of the heavily grazed plants produced seedheads compared with 25% of ungrazed plants (Best and Bork 2003).

In the rough fescue grasslands of Alberta, percent canopy cover of rough fescue grazed for 32 years was 40% greater in lightly grazed areas than in severely grazed areas and was 28% lower in areas that had severe grazing (>75% forage removal) than in areas received light grazing (<5% forage removal) (Willms et al. 1988). Additionally, leaf height of rough fescue plants was 54% shorter in areas receiving high grazing pressures than those receiving low grazing pressure.

Long-term studies indicate that rough fescue cannot tolerate many successive years of moderate or heavy defoliation. Long-term heavy grazing in spring through fall reduces plant vigor, yield, and canopy cover and substantially increases mortality of rough fescue.

Effects of Defoliation on Plant Community Composition on Foothill Rangeland

Grazing during the period of active growth at high intensities may alter species composition. In the rough fescue grasslands of western Alberta, the effects of light, moderate, heavy, and severe grazing on species composition were studied in pastures that had been grazed at these levels in the summer for 32 years (Willms et al. 1985). Species composition in pastures was compared with ungrazed exclosures. Increasing stocking rates from light grazing to moderate, heavy, and severe grazing altered species composition. Species composition of Idaho fescue was 7%, 58%, and 56% higher in moderately, heavily, and severely grazed pastures than in lightly grazed pastures, respectively. Species composition of rough fescue was 45%, 79%, and 93% lower in pastures grazed moderately, heavily, and severely, respectively, than in lightly grazed pastures. As species composition of rough fescue declined under very heavy grazing, it was replaced by parry oatgrass (*Danthonia parryi* Scribn.) and Idaho fescue (Willms et al. 1985).

In southwestern Montana, heavy to severe grazing, presumably in summer, caused replacement of bluebunch wheatgrass and Idaho fescue by big sagebrush (*Artemisia tridentata* Nutt.) (Wright and Wright 1948). Areas grazed lightly for 50 years had 58% more vegetal cover of bluebunch wheatgrass and 44% less cover of Idaho fescue than ungrazed areas (Evanko and Peterson 1955). Herbage composition of Idaho fescue decreased by 41% after 4 years of moderate grazing compared with an equivalent period of rest from grazing in a study conducted on foothill rangeland in central Montana (Vogel and Van Dyne 1966).

In the fescue grasslands of Alberta, moderately grazed rough fescue contributed about 90% of the total forage utilized by cattle in winter due to accessibility and stature of the plants, even when grazing was impaired by snow cover (Willms and Rode 1998). These researchers concluded that this intensity of winter grazing could sustain plant community composition as long as light grazing was maintained in summer. Further, it was suggested that in order to maintain rough fescue in the plant community, it is important that all plants are not heavily grazed (Willms and Rode 1998).

Long-term grazing and heavy grazing alters species composition. Heavy grazing favored Idaho fescue, when compared with rested areas, possibly due to the high amount of decadent plant matter that impeded growth in rested areas. However, it has been also shown that heavy grazing reduced species composition of desirable perennial grasses in favor of undesirable species.

Effects of Grazing on Foothill Rangeland Soils and Ground Cover

Few studies have examined the effects of long-term grazing on ground cover, bulk density, soil organic matter, percent soil carbon, percent soil nitrogen, and soil carbon to nitrogen ratios on foothill rangeland. Long-term heavy grazing can reduce ground cover of vegetation, while increasing the amount of bare ground. Further, long-term heavy grazing may also increase soil bulk density and, at the same time, have no effect on organic matter, or carbon and nitrogen content. Long-term grazing decreases ground cover of litter and increases percent bare ground, but may slightly decrease cover of graminoids and forbs.

In southwestern Montana, ungrazed exclosures had 15%, 26% and 7% more litter and 15%, 19%, and 7% less bare ground than heavily, moderately, and lightly grazed areas, respectively (Evanko and Peterson 1955). On foothill rangeland in northern Utah, Pickford (1932) compared the effects of 40 years of grazing on vegetal ground cover with areas that were ungrazed for 28 years. Ground cover of perennial grasses in 4 grazed study sites was 27%, 36%, 88%, and 89% less than in ungrazed areas. On foothill rangeland in central Montana, neither 4 years of moderate sheep grazing nor complete protection from grazing for 4 years altered total herbage cover, averaging 0.45% change, though a 14% increase in total ground cover in protected areas and only a 3% increase in grazed areas was observed (Vogel and Van Dyne 1966). This difference was largely due to an 18% increase in litter cover in protected areas.

Soil bulk density increases as grazing intensity and stock density increase, as a result of soil compaction, and is inversely related to infiltration rate. Long-term heavy elk grazing in fall, winter, and spring on foothill rangeland in Colorado increased bulk density by 7.5% in the Ah horizon (15 cm) when compared with exclosures that were ungrazed for 35 years (Binkley et al. 2003).

In southwestern Alberta, bulk density of soil on sites that were ungrazed or lightly grazed for 44 years from mid-May to mid-November was 38.5% and 24.5% less in the 0-3 cm and 3-6 cm depths, respectively, than in heavily or very heavily grazed areas (Dormaar and Willms 1998). The Ah soil horizon depth varied from 22 cm in ungrazed exclosures to 7.5 cm in heavily grazed areas, which was attributed to increased bulk density resulting from high grazing intensities and wind and water erosion (Dormaar and Willms 1998).

Soil organic matter content affects carbon and nitrogen nutrient cycling, which is important for plant growth and long-term heavy grazing may decrease soil organic matter. Little research has been conducted to evaluate the effects of grazing on soil organic matter on foothill rangeland. In a study conducted on foothill fescue grassland in southwestern Alberta, percent soil organic matter in the Ah horizon was not different between soils that had endured 17 years of light, moderate, heavy, or severe grazing from mid-May to mid-November, averaging 10.8% (Johnston et al. 1971). Although the study was not conducted on foothill rangeland, Burke et al. (1999) found results that are contrary to Johnston et al. (1971). Burke et al. (1999) concluded that 50 years of heavy grazing in northeastern Colorado had very little effect on soil organic matter compared with ungrazed exclosures.

Percent soil carbon, percent soil nitrogen, and soil carbon to nitrogen ratios on sites with long grazing histories are variable, indicating that conclusive evidence that grazing adversely affects these soil properties may not exist. No overall effect was observed on total carbon and total nitrogen due to 35 years of elk grazing in Rocky Mountain National Park, Colorado (Binkley et al. 2003). In the top 15 cm of soil, total soil carbon averaged 4.9 kg m^{-2} and total soil nitrogen averaged 0.39 kg m^{-2}. In the same study location, elk herbivory did not alter soil nitrogen content in upland grass/shrub communities after 4 or 35 years (Schoenecker et al. 2004). In southwestern Alberta, total soil nitrogen increased and total soil carbon decreased when grazing pressure increased from ungrazed to heavy or severe where 44-years of grazing occurred from mid-May to mid-November (Dormaar and Willms 1998). Total soil carbon was 25% and 34% lower and total soil nitrogen was 11% and 19% higher in ungrazed exclosures than heavily or severely grazed areas, respectively (Dormaar and Willms 1998). Although not on foothill rangeland, in southern Wyoming, Manley et al. (1995) compared soil carbon and nitrogen responses to 11 years of light and heavy grazing in season-long, rotationally deferred, and short-duration grazing and ungrazed exclosures. These researchers concluded that soil organic carbon and nitrogen were significantly lower in the top 7.6 cm of soil inside exclosures compared with all other grazing intensities and strategies.

CHAPTER 3

MATERIALS AND METHODS

Study Area

This study was conducted on 8 sites located within the Sun River Wildlife Management Area (SRWMA) in west-central Montana. The SRWMA is approximately 8,100 ha in size and is located 15 km northwest of Augusta, Montana and 162 km west of Great Falls, Montana. The SRWMA was established in late 1947 to protect elk winter range. Very small numbers of white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), and pronghorns (*Antilocapra americana*) are also present during the year, but the SRWMA has been grazed almost exclusively by elk in winter-spring since late 1947 when livestock grazing was eliminated (Jourdonnais and Bedunah 1990; MT FWP 2003).

The elk population in the Sun River area was 965 in 1913, but grew to 1,479 in 1916 and to 1,708 by 1917 (Picton and Picton 1975). Elk numbers continued to rise and in 1925 and 1928 an estimated 2,495 and 3,180 elk were counted, respectively. By 1928, wildlife biologists began to report that areas were severely overgrazed by elk. In 1930, the elk population was at its peak of 5,000 elk and game managers increased the amount of elk hunting licenses sold in an attempt to control elk numbers. By 1932, the combination of reduced forage and increased hunting reduced elk numbers to 2,098, but by 1950 numbers rose again to 3,265 and to 3,516 in 1955. Increased hunting reduced the elk population to 2,051 in 1965, and in 1970, the Montana State Legislature voted to maintain the elk population at 2,200. Since 1965, the SRWMA has maintained about 2,150 elk annually from mid-November to mid-May (Picton and Picton 1975; MT FWP 2003).

The SRWMA averaged 341 mm of total precipitation annually since it was established in late 1947, with an average of 30 mm, 60 mm, 71 mm, and 36 mm of precipitation recorded in April, May, June, and July, respectively (Western Regional Climate Center 2005). In 2004, total annual precipitation was 296 mm, with 39 mm, 61 mm, 31 mm, and 21 mm of precipitation in April, May, June, and July, respectively. In 2005, total annual precipitation was 296 mm, with 34 mm, 52 mm, 128 mm, and 0 mm in April, May, June, and July, respectively (Western Regional Climate Center 2005).

The 8 study sites were located within the rough fescue/bluebunch wheatgrass habitat type (Mueggler and Stewart 1980) and Beanlake-Winspect Stony Loam soil type (USDA-NRCS 2003). Dominant graminoid species in the area included rough fescue, bluebunch wheatgrass, Idaho fescue, Columbia needlegrass (*Achnatherum nelsonii* Scribn.), prairie junegrass (*Koeleria macrantha* Ledeb.), threadleaf sedge (*Carex filifolia* Nutt.), and elk sedge (*Carex garberi* Fern.). Dominant forb species included dotted gayfeather (*Liatris punctata* Hook), hairy golden aster (*Heterotheca villosa* Pursh.), fringed sagewort (*Artemisia frigida* Willd.), and wild onion (*Allium* spp. L.). Very few shrubs were present and included shrubby cinquefoil (*Potentilla fruticosa* L.), creeping juniper (*Juniperus horizontalis* Moench), and snowberry (*Symphoricarpos albus* (L.) Blake).

Data Collection and Laboratory Analyses

This study compared 56 years of heavy versus light long-term winter-spring grazing on plant vigor, canopy cover, and species composition of bluebunch wheatgrass, Idaho fescue, and rough fescue. Ground cover, herbaceous plant yield, and soil characteristics were also evaluated. Study sites were sampled in Summer 2004 and sampled again in Summer 2005.

Each of the 8 study sites was selected with GIS to have the same habitat type, soil type, percent slope, aspect, and elevation. To select the 8 study sites, polygons of areas documented as heavily or lightly grazed (MT FWP 1967-1987; MT FWP 2003) were overlaid on a digitized map of the SRWMA, and 4 random points with a minimum distance of 400 m between points were generated within each polygon. The minimum distance between the lightly and heavily grazed polygons was approximately 4,500 m. Elevation on each study site was approximately 1,350 m with an average slope of 7.5% and a northeastern aspect. Four study sites, located in the southeastern portion of the SRWMA, were chosen in an area that has historically been used lightly when elk are present from November through early May, due to the close proximity of a county road that receives moderate traffic year-round (MT FWP 2003). Four additional sites were chosen in the northwestern portion of the SRWMA where human influences are minimal and heavy grazing has historically occurred by elk from mid-November through mid-May (MT FWP 2003). Areas that had a history of light or heavy long-term grazing were determined from records of previous winter-spring grazing by elk, with heavily and lightly grazed areas averaging 68% and 30% relative utilization of rough fescue, respectively (MT FWP 1967-1987). A soil pit was dug near the center of each site and soils were classified to confirm that soils on all 8 study sites were Beanlake-Winspect Stony Loam (USDA-NRCS 2003). Three, 60-m transects were established at each study site in Summer 2004 and reestablished at the same locations in Summer 2005.

Plant vigor was quantified by measuring average leaf height (Mueggler 1975), basal diameter (Cook and Stubbendieck 1986), number of seedheads per plant (Mueggler 1975), and percent filled florets per plant (Patton et al. 1988) on the nearest bluebunch wheatgrass, Idaho fescue, and rough fescue plant at 3-m intervals along each transect (n=60 plants/grass species/site/year). Average leaf height of individual plants was measured in June and July 2004 and 2005 by measuring the average height of current year's leaves in their natural position. Measurements were recorded to the nearest centimeter and measurements were made from the center of the plant crown (USDA-USDI 1996). Basal diameter of individual plants was measured in July 2004 and 2005 by measuring the distance across the plant crown at the widest point to the nearest 0.5 cm. The number of seedheads produced per plant was determined in July 2004 and 2005. After counting, seedheads from each of the 3 grass species (bluebunch wheatgrass, Idaho fescue, and rough fescue) were collected and percent filled and empty florets was determined in the laboratory by placing the seedheads on a fluorescent light (Patton et al. 1988).

Canopy cover of all species present was determined in July 2004 and 2005 by estimating canopy cover of vegetation using a modified Daubenmire Canopy Coverage Method with 7 cover classes (Bailey and Poulton 1968). A 20 x 50-cm quadrat was placed at 20-m intervals along each transect at different locations each year (n=9/site/year). Species composition of bluebunch wheatgrass, Idaho fescue, and rough fescue on each site was determined by dividing total percent canopy cover of each of the 3 species by the total percent canopy of all species on the site and multiplying the answer by 100.

Herbaceous plant yield was measured in June and July 2004 and 2005 by clipping current-year's growth to ground level within 3, 50 x 50-cm quadrats per transect placed at different points each month and each year (n=9 quadrats/month/site/year). At 20-m intervals on each transect, vegetation was clipped and separated by perennial graminoids, annual graminoids, and forbs. Clipped samples were weighed to the nearest 0.01 g after oven-drying at 55 °C for 48 hours.

Bare ground and ground cover of litter, graminoids and forbs, dense clubmoss (*Selaginella densa* Rydb.), rock (>2 cm diameter), and gravel (0.5-2 cm diameter) were determined using the point-intercept method (USDA-USDI 1996) in July 2004 and 2005. On each of the 3, 60-m transects, ground cover was determined at 6 points on a 20 x 50-cm frame positioned at 20-m intervals along each transect (n=54 points/site/year).

Soil properties measured in June 2005 on each site included bulk density, percent organic matter (OM), percent carbon (C), percent nitrogen (N) and the carbon to nitrogen ratio (C:N). For determining percent OM, percent C, percent N, and the C:N ratio, soil samples were extracted from the Ah horizon using a 2.54-cm diameter soil probe, excluding the vegetation and litter on the soil surface (Tan 2005). Samples were collected at 20-m intervals along each of the 3, 60-m transects per site (n=9 samples/site).

Depth of the Ah horizon was determined by digging a soil pit near the center of each site, visually determining the extent of the Ah horizon, and measuring its depth to the nearest centimeter. Percent soil carbon and soil nitrogen were determined in the laboratory using the Carbo-Erba Combustion Method (AOAC 1997). The carbon to nitrogen ratio was then calculated for each site by dividing the average percent carbon by the average percent nitrogen. Percent organic matter was determined in the laboratory using a modified Walkley-Black Method (Nelson and Sommers 1982). Soil samples used to determine bulk density were collected using a 7.62-cm depth x 7.62-cm diameter metal ring inserted into the Ah soil horizon until the top of the ring was level with the soil surface. Contents of the ring were extracted from the ground and placed in sealed containers (Blake and Hartge 1986). Samples were dried at 105°C for 48 hours and then weighed to the nearest 0.01 g and bulk density was calculated by dividing the dry soil mass by the soil volume (Blake and Hartge 1986).

Statistical Analyses

Experimental design was an observational study (Cochran 1983; Eberhardt and Thomas 1991) because I did not control which of the 8 macroplots received heavy vs. light grazing. The 56-year grazing period (i.e., 1948-2003) was not replicated in time, and the SRWMA elk herd (n=2,150 elk) was not replicated in space. Unreplicated observational studies are appropriate if the statistical inferences drawn are limited to the particular study area (Wester 1992). Inferences from this study are limited to the rough fescue/bluebunch wheatgrass habitat type in the Northern Rocky Mountains (Mueggler and Stewart 1980). Inferences can be extended beyond the SRWMA to other sites within the rough fescue/bluebunch wheatgrass habitat type because habitat type classification integrates the environmental effects on plant growth, reproduction, and competition so that all sites within the same habitat type exhibit the same successional trajectories when subjected to similar disturbances (Daubenmire 1952; Hironaka et al. 1991).

Using the GLM procedure of SAS (SAS 2004), analysis of variance (ANOVA) was used to compare long-term, heavily grazed sites (n= 4) versus long-term, lightly grazed sites (n= 4) on bluebunch wheatgrass, Idaho fescue, rough fescue and plant community and soil characteristics (Table 1). Data from June and July were analyzed separately and 2004 and 2005 measurements were pooled in the final analyses because the study evaluated the cumulative effects from >55 years of grazing rather than a single year response. Pooling also incorporated variability in weather between 2004 and 2005.

Table 1. Analysis of variance table with sources and degrees of freedom.

Source	Degrees of Freedom
Treatment	1
Error	6
Total	7

The UNIVARIATE procedure of SAS (SAS 2004) was used to test for normal distribution of residuals. Percent data that were not normally distributed were arcsine transformed to stabilize variances and better approximate normal distribution of residuals (Kuehl 2000). For those variables whose normality was not satisfactorily improved by the arcsine transformation, the formula $\log(\sigma_i) = \log(\alpha) + \beta \log(\mu_i)$ was used to empirically estimate the appropriate power transformation (Kuehl 2000).

The null hypotheses tested were that: 1) plant vigor, percent canopy cover, and percent species composition of bluebunch wheatgrass, Idaho fescue, and rough fescue did not differ in summer between areas exposed to heavy and light, long-term winter-spring grazing, 2) plant yield and percent ground cover did not differ in summer between areas exposed to heavy and light, long-term winter-spring grazing, and 3) soil properties did not differ between areas exposed to heavy and light, long-term winter-spring grazing. Differences were considered significant at $P \leq 0.10$. Means presented are from non-transformed data.

CHAPTER 4

RESULTS

Plant Vigor

Bluebunch Wheatgrass

Leaf height of bluebunch wheatgrass plants that were heavily grazed was 4.3% shorter than lightly grazed plants in June (*P*=0.01; Table 2). No differences were observed in average leaf height (*P*=0.37) or in the basal diameter (*P*=0.53) of bluebunch wheatgrass between heavily and lightly grazed sites in July. Bluebunch wheatgrass plants on lightly grazed sites produced 50% less seedheads than plants on heavily grazed sites (*P*=0.01). Heavily grazed bluebunch wheatgrass had 43.2% fewer filled florets compared with lightly grazed plants (*P*<0.01).

Idaho Fescue

Leaf height of Idaho fescue was 32.4% shorter in June (*P*=0.01; Table 2) and 27.7% (2.4 cm) shorter in July (*P* <0.01) following long-term heavy grazing compared with long-term light grazing. Basal diameter was not different (*P*=0.65) in July between heavily and lightly grazed Idaho fescue plants and no difference was observed in the number of seedheads produced by Idaho fescue plants between heavily and lightly grazed sites (*P*=0.22). Heavily grazed Idaho fescue plants had 55% less filled florets

Table 2. Plant vigor of bluebunch wheatgrass, Idaho fescue, and rough fescue (±SEM) in June or July after long-term heavy or long-term light winter-spring grazing on foothill rangeland in west-central Montana.

Response Variable	Month	Bluebunch Wheatgrass		Idaho Fescue		Rough Fescue	
		Light	Heavy	Light	Heavy	Light	Heavy
Leaf Height (cm)	June	16.2 ± 0.1a[1]	15.5 ± 0.1b	7.4 ± 0.7a	5.0 ± 0.4b	17.4 ± 0.8a	11.5 ± 0.8b
	July	18.7 ± 0.5a	18.0 ± 0.5a	7.2 ± 0.2a	5.2 ± 0.2b	17.1 ± 1.1a	11.9 ± 1.1b
Basal Diameter (cm)	July	5.2 ± 0.7a	6.1 ± 0.7a	6.8 ± 0.8a	6.6 ± 0.7a	17.5 ± 2.6a	5.4 ± 2.6b
Seedheads (number/plant)	July	0.8 ± 0.1a	1.6 ± 0.1b	1.2 ± 0.3a	0.6 ± 0.3a	2.0 ± 0.5a	0.1 ± 0.5b
Filled Florets (%)	July	60.6 ± 1.4a	34.4 ± 1.4b	61.0 ± 2.9a	27.4 ± 2.5b	55.6 ± 4.2a	16.5 ± 4.2b

[1]Means within rows, within grass species, followed by the same lowercase letter are not different (*P*>0.10).

than lightly grazed plants (*P*<0.01), averaging 27.4% and 61% filled florets on heavily and lightly grazed sites, respectively.

Rough Fescue

Leaf height of heavily grazed rough fescue plants was 33.9% (5.9 cm) and 30.4% (5.2 cm) shorter in June (*P*<0.01; Table 2) and July (*P*=0.01), respectively, than lightly grazed plants and basal diameter of plants on heavily grazed sites was 69.1% (12.1 cm) smaller (*P*=0.04) than plants on lightly grazed sites. The number of seedheads produced per plant and percent filled florets of rough fescue were lower on heavily grazed plants (*P*=0.03 and *P*<0.01, respectively) versus lightly grazed plants. Heavily grazed rough fescue plants averaged 95% fewer seedheads per plant and 70% fewer filled florets than lightly grazed plants.

Canopy Cover and Species Composition

Canopy cover and species composition of rough fescue were less on heavily grazed sites than on lightly grazed sites (*P*=0.01 and *P*=0.02, respectively; Table 3). Percent canopy cover of rough fescue was 0.6% on heavily grazed sites and 17.7% on lightly grazed sites and percent species composition of rough fescue was 2.7% and 38.1% on heavily and lightly grazed sites, respectively. Percent canopy cover and percent species composition did not differ between heavily and lightly grazed sites for bluebunch wheatgrass (*P*=0.64 and *P*=0.23, respectively) or Idaho fescue (*P*=0.17 and *P*=0.50, respectively).

Herbaceous Plant Yield

Herbaceous plant yield of graminoids or forbs was not different between heavily and lightly grazed sites in June (P=0.19 and P=0.80, respectively; Table 4) or July (P=0.11 and P= 0.55, respectively). Similarly, total herbaceous plant yield was not different between heavily and lightly grazed sites in June (P=0.15) or July (P=0.17).

Ground Cover

Ground cover of graminoids and forbs differed between heavily and lightly grazed sites (P=0.04), as did ground cover of dense clubmoss (P=0.04; Table 5). Ground cover of graminoids and forbs was 42% greater on heavily grazed sites than on lightly grazed sites and clubmoss was 99% greater on heavily versus lightly grazed sites. Ground cover of litter, gravel, rock and bare ground was not different between sites (P=0.20, P=0.43, P=0.85, and P=0.96, respectively). No difference in total ground cover between lightly and heavily grazed sites was observed (P=0.46).

Soil Properties

Soil bulk density was 15% greater on heavily grazed sites than lightly grazed sites at 2.0 g cm^{-3} and 1.7 g cm^{-3}, respectively (P=0.02; Table 6). Soil organic matter,

Table 3. Canopy cover and species composition of bluebunch wheatgrass, Idaho fescue, and rough fescue (±SEM) in July after long-term heavy or long-term light winter-spring grazing on foothill rangeland in west-central Montana.

Response Variable	Bluebunch Wheatgrass		Idaho Fescue		Rough Fescue	
	Light	Heavy	Light	Heavy	Light	Heavy
Canopy Cover (%)	3.1 ± 2.0a[1]	5.5 ± 2.0a	3.7 ± 0.9a	1.5 ± 0.9a	17.7 ± 4.2a	0.6 ± 4.2b
Species Composition (%)	7.0 ± 5.8a	18.9 ± 5.8a	8.4 ± 2.2a	5.6 ± 2.2a	38.1 ± 8.7a	2.7 ± 8.7b

[1]Means within rows, within grass species, followed by the same lowercase letter are not different (*P*>0.10).

Table 4. Graminoid, forb, and total herbaceous plant yield (±SEM) in July after long-term heavy or long-term light winter-spring grazing on foothill rangeland in west-central Montana.

Month	Graminoids		Forbs		Total Herbaceous	
	Light	Heavy	Light	Heavy	Light	Heavy
	(kg/ha)					
June	841.5 ± 120.9a[1]	589.4 ± 120.9a	314.6 ± 37.3a	301.0 ± 37.3a	1156.1 ± 113.6a	890.4 ± 113.6a
July	887.1 ± 108.7a	601.7 ± 108.7a	410.2 ± 57.0a	359.6 ± 57.0a	1297.2 ± 124.4a	1023.5 ± 124.4a

[1]Means within rows, within forage type, followed by the same lowercase letter are not different (*P*>0.10).

soil carbon, soil nitrogen, and the C:N ratio were not different (*P*=0.22, *P*=0.25, *P*=0.20, and *P*=0.92, respectively) between heavily and lightly grazed sites. Depth of the Ah horizon was 20% (2 cm) less on heavily grazed sites than on lightly grazed sites (*P*<0.01).

Table 5. Ground cover (±SEM) in July after long-term heavy or long-term light winter-spring grazing on foothill rangeland in west-central Montana.

Cover Type	Light	Heavy
	(%)	(%)
Graminoids and Forbs	50.7 ± 5.0a[1]	29.6 ± 5.0b
Clubmoss	0.2 ± 9.0a	31.2 ± 9.0b
Litter	32.9 ± 5.7a	21.1 ± 5.7a
Bare Ground	6.5 ± 4.1a	10.0 ± 4.1a
Gravel	6.3 ± 3.5a	1.8 ± 3.5a
Rock	14.4 ± 12.9a	14.1 ± 12.9a
Total	87.3 ± 6.5a	93.5 ± 6.5a

[1]Means within rows, within grazing intensity, followed by the same lowercase letter are not different (*P*>0.10).

Table 6. Soil properties (±SEM) in July after long-term heavy or long-term light winter-spring grazing on foothill rangeland in west-central Montana.

Soil Parameter	Light	Heavy
Bulk Density (g cm^{-3})	1.7 ± 0.1a[1]	2.0 ± 0.1b
Organic Matter (%)	4.3 ± 0.2a	3.9 ± 0.2a
Carbon (%)	3.6 ± 0.2a	3.2 ± 0.2a
Nitrogen (%)	0.3 ± 0.0a	0.3 ± 0.0a
C:N (%C : %N)	10.6 ± 0.2a	10.6 ± 0.2a
Ah Horizon (cm)	10.0 ± 0.0a	8.0 ± 0.0b

[1]Means within rows, within grazing intensity, followed by the same lowercase letter are not different (*P*>0.10).

CHAPTER 5

DISCUSSION AND CONCLUSIONS

Plant Vigor

Bluebunch Wheatgrass

Bluebunch wheatgrass plant vigor was somewhat lower on heavily grazed than lightly grazed sites, but it was not impacted as much as Idaho fescue or rough fescue. One probable reason is that elk on the SRWMA tend to grazed bluebunch wheatgrass more in winter than spring, whereas Idaho fescue and rough fescue are grazed more in spring and less in winter (Knight 1970).

Compared with lightly grazed plants, bluebunch wheatgrass leaf height in June was less on long-term heavily grazed sites. However, by July no difference was detected. On the same rough fescue/bluebunch wheatgrass habitat type, Brewer (2002) documented a 46% decrease in July leaf height when bluebunch wheatgrass plants were clipped to (3-cm stubble height) in May for 3 successive years. Leaf height was unaffected by heavy clipping in April.

Basal diameter of bluebunch wheatgrass was not reduced on long-term heavily grazed compared with long-term lightly grazed sites. I would expect leaf height to respond negatively to grazing before reduced basal diameters would occur and, as I previously stated, leaf height of bluebunch wheatgrass was not impacted by heavy grazing. In contrast to my results, clipping bluebunch wheatgrass heavily in winter and early summer caused an 8.5% decline in basal area in northeastern Oregon (Clark et al.

1998). However, moderate fall through spring sheep grazing increased bluebunch wheatgrass basal area by 22% compared with no grazing (Vogel and Van Dyne 1966).

Seedhead production was greater on heavily grazed sites than on lightly grazed sites in my study, however, the percent filled florets was lower on heavily grazed sites compared with lightly grazed sites. Lightly grazed bluebunch wheatgrass plants produced half as many seedheads as heavily grazed plants, while heavily grazed plants had one quarter fewer filled florets than long-term lightly grazed plants due to the cumulative effects of long-term grazing. In other studies, moderate grazing in late spring or early summer did not decrease the number of seedheads present on bluebunch wheatgrass plants (Clark et al. 2000; Brewer 2002), however, heavy clipping in mid-summer reduced flower stalk production and heavily clipped plants produced fewer fertile florets than lightly clipped plants (Heady 1950).

Idaho Fescue

Plant vigor of Idaho fescue was also somewhat lower on heavily grazed sites than on lightly grazed sites. Idaho fescue leaf height in June and July and percent filled florets were lower on heavily grazed sites, while basal diameter and number of seedheads were not.

Leaf height of Idaho fescue was shorter on long-term heavily grazed sites in June and July, but heavy grazing did not affect the basal diameter of Idaho fescue compared with lightly grazed sites. Similarly, Evanko and Peterson (1955) concluded that 50 years of heavy grazing reduced average leaf heights of Idaho fescue plants by 3.4 cm. However, Evanko and Peterson (1955) also found that long-term heavy, moderate, and light grazing in mid-summer through fall reduced overall basal area of Idaho fescue by an average of 42%, with long-term heavily grazed plants 3.4 cm^2 smaller than ungrazed controls. Idaho fescue may have been increasing in response to grazing on a site in southwestern Alberta, because under long-term heavy grazing, relative percent basal area of Idaho fescue plants was 50% greater than on areas receiving long-term light grazing (Johnston et al. 1971).

Idaho fescue plants in my study responded less dramatically with regard to seedhead production than those studied by Mueggler (1975). Heavy and severe clipping in mid-summer eliminated flower stalk production and, even after 5 years of rest, resulted in only 2/3 as many seedheads compared with unclipped plants. In my study, long-term heavily grazed plants had a smaller percent filled florets compared with lightly grazed plants, having 55% more filled florets than heavily grazed plants, which suggests that continued heavy grazing may eventually lead to reduced species composition if Idaho fescue continues to produce fewer filled florets. However, in the fescue grasslands of Alberta, long-term heavily grazed Idaho fescue plants produced 16% more germinable seeds than those that were long-term lightly grazed, which also suggests that Idaho fescue may have been an increaser on their study site (Willms and Quinton 1995).

Rough Fescue

Previous research suggested that rough fescue is sensitive to heavy grazing in spring, summer, or the combination of spring and fall (Johnston et al. 1971; McLean and Wikeem 1985b; Willms et al. 1985; Willm et al. 1988; Willms 1991), therefore it was not surprising that rough fescue was less vigorous on my heavily grazed study sites. Long-term heavily grazed rough fescue had lower average leaf length, basal diameter, number of seedheads, and percent filled florets compared with long-term lightly grazed plants.

Average leaf height of rough fescue that was heavily grazed in winter-spring was 32% lower than plants that were lightly grazed in winter-spring. My results support those of McLean and Wikeem (1985b), who concluded that heavy spring and fall clipping reduced average leaf length by 46% compared with unclipped plants. Basal diameter of heavily grazed rough fescue on my study sites was 70% smaller than lightly grazed plants, which is similar to Johnston et al. (1971) where 17 years of season-long grazing in summer reduced the relative percent basal area of rough fescue by 76%.

Compared with lightly grazed plants, the number of seedheads and percent filled florets was less on heavily grazed sites in my study. Similarly, only 3% of plains rough fescue plants that were heavily grazed in central Alberta produced seedheads (Best and Bork 2003). Also similar to my findings that long-term heavily grazed rough fescue plants produced 70% fewer filled florets, Willms and Quinton (1995) concluded that 37 years of heavy grazing from mid-May to early November nearly eliminated production of germinable seeds, indicated by a 96% reduction in germinable rough fescue seeds in the seedbank of long-term heavily and long-term lightly grazed areas.

Canopy Cover and Species Composition

Rough fescue is the dominant grass species within the potential natural plant community of the rough fescue/bluebunch wheatgrass habitat type (Mueggler and Stewart 1980). On heavily grazed sites in my study, rough fescue was grazed at high enough levels for many consecutive years that the percent canopy cover and percent composition of rough fescue within the plant community declined by 97% and 93%, respectively, compared with lightly grazed sites. Percent canopy cover and percent species composition of bluebunch wheatgrass and Idaho fescue, however, were not lower on long-term heavily grazed sites.

A similar near-pristine site in the same habitat type was located near my lightly grazed sites and sampled in the mid-1970s (Mueggler and Stewart 1980). Comparisons of canopy cover between this site and my study sites suggest that rough fescue did not tolerate long-term heavy grazing in winter-spring. My heavily grazed sites and the near-pristine site had <1% and 21% canopy cover of rough fescue, respectively. Long-term light grazing in winter-spring, however, sustained rough fescue in proportions found within the potential natural community (i.e., 18% and 21% canopy cover in the lightly grazed sites and near-pristine sites, respectively). Bluebunch wheatgrass canopy cover was less on my heavily or lightly grazed than on the near-pristine site (i.e., 4% and 14% canopy cover of bluebunch wheatgrass, respectively). Idaho fescue canopy cover was largely unaffected by long-term grazing in winter-spring, with my grazed sites averaging only 3% canopy cover and the near-pristine site having none.

Rough fescue on foothill rangeland was previously known as buffalo bunchgrass (USFS 1937; Johnston and MacDonald 1967) because it was the primary winter forage for bison (*Bison bison bison*) in this habitat (Fryxell 1928; Johnston and MacDonald 1967; Dormaar and Willms 1990). Rough fescue evolved with long-term heavy winter bison grazing, which brought forth the misconception that rough fescue was tolerant to heavy grazing in other seasons (Johnston and MacDonald 1967). However, research has shown that rough fescue is not tolerant to heavy grazing in spring, summer, and early fall (Johnston et al. 1971; McLean and Wikeem 1985b; Willms et al. 1985; Willms et al. 1988; Willms 1991). My results indicate that rough fescue is also sensitive to heavy winter-spring grazing when it occurs over many successive years.

Similar to my results, increasing grazing intensity from light to heavy in areas grazed for 32 years in summer nearly eliminated rough fescue, reducing it by 79% compared with light grazing (Willms et al. 1985). However, contrary to my results, Willms et al. (1985) also found that Idaho fescue composition increased by 58% in heavily grazed areas compared with lightly grazed areas (Willms et al. 1985), while I found no change in Idaho fescue canopy cover or composition between heavily and lightly grazed sites. Also contrary to my findings, 50 years of heavy grazing from mid-May to mid-November caused bluebunch wheatgrass canopy cover to decline by 42% and Idaho fescue canopy cover to decline by 33% compared with lightly grazed areas (Evanko and Peterson 1955).

Herbaceous Plant Yield

Herbage yield of graminoids, forbs, and total herbage yield were not limited by heavy long-term winter-spring grazing in June or July compared with light long-term winter-spring grazing. These findings were surprising, given the dramatic decrease in plant vigor, canopy cover, and species composition of rough fescue, the dominant herbage producer in this habitat type, in response to heavy grazing. Total herbaceous yield of graminoids and forbs was reduced by 16.7% when grazed lightly or moderately for 3-4 years during and prior to the boot stage (Vogel and Van Dyne 1966). Grasses on my study site were either dormant or in the vegetative stage while elk grazed and grazing during this stage is typically not damaging to plant yield (Lacey et al. 1994). However, 4 years of elk grazing during winter-spring (grazing intensity unreported) had no impact on herbaceous biomass in upland grass/shrub sites compared with 4-year exclosures in an elk winter range in Rocky Mountain National Park, Colorado, but 35 years of elk grazing on similar upland grass/shrub sites reduced herbaceous biomass by 32% compared with 35-year exclosures (Schoenecker et al. 2004). Similar to my results, Anderson and Frank (2003) were unable to detect differences in herbaceous biomass after 40 years of long-term heavy winter-spring grazing, which was attributed to altered plant demography and morphology that increased allocation of production. The heavily grazed sites in my study had a higher composition of increaser graminoids (e.g., prairie junegrass) that contributed to herbage yield of graminoids and total herbage yield, and compensated for the loss in plant vigor, canopy cover, and species composition of rough fescue.

Ground Cover

Total percent ground cover was not less on heavily grazed sites than lightly grazed sites, however, percent ground cover of graminoids and forbs was less on heavily grazed sites and ground cover of dense clubmoss was greater on heavily grazed sites. I attribute these differences to the reduced plant vigor and diminished composition of the dominant grass species, rough fescue, due to heavy grazing which allowed clubmoss to gain a competitive advantage and fill in spaces where bare ground or stressed graminoids may have once occupied. Further, dense clubmoss also limits water availability to other plant species and likely deterred seedling establishment and limited water availability to mature plants already enduring drought conditions (Dolan and Taylor 1972; Lacey et al. 1995; USDA Forest Service 2005).

On heavily grazed sites where dense clubmoss comprised 31% ground cover, compared with less than 1% on lightly grazed sites and percent ground cover of graminoids and forbs was only 30% compared with 51% on lightly grazed sites. Dense clubmoss is considered an aggressive invader on soils that maintain adequate moisture in the top 5 cm of soil or under drought conditions with grazing (Dolan and Taylor 1972; Lacey et al. 1995; USDA Forest Service 2005). Historical records indicate the presence of dense clubmoss on the SRWMA (MT FWP 1967-1987) and its increased ground cover is attributed to heavy grazing and reduced plant vigor and species composition of rough fescue within this habitat type and may have been exacerbated on the heavily grazed sites by a 7-year drought prior to the study.

Percent ground cover of litter was not affected by long-term heavy grazing in my study, which is in contrast to Evanko and Peterson's (1955) findings that percent ground cover of litter was reduced and amount of bare ground increased in response to long-term heavy grazing in mid-summer through fall compared with ungrazed exclosures. On foothill fescue grasslands in Alberta, cover of litter on lightly grazed sites was 92% higher than on severely grazed sites after 30 years of grazing in mid-May to mid-November (Willms et al. 1988).

Soil Properties

Bulk density was the only soil property that was different on long-term heavily grazed sites compared with long-term lightly grazed sites. My results support those of Binkley et al. (2003) who concluded that bulk density increased under heavy grazing by elk on foothill rangeland. Dormaar and Willms (1998) also reported increased bulk densities on foothill fescue grassland soils that were heavily grazed in spring-summer-fall for 44 years.

Soil carbon and nitrogen in areas with long-term grazing have been shown to vary greatly with soil type and grazing intensity (Manley et al. 1995; Dormaar and Willms 1998; Binkley et al. 2003). Similar to my results, no differences were detected in percent soil nitrogen due to grazing intensities ranging from light to very heavy following 17 years of spring-summer-fall grazing on foothill fescue grassland soils in southwestern Alberta (Johnston et al. 1971), and no differences in percent soil nitrogen or soil carbon were detected due to long-term heavy elk grazing in winter-spring in Colorado (Binkley et al. 2003).

No difference in percent soil organic matter was measured between long-term lightly and long-term heavily grazed sites in my study. Similarly, percent soil organic matter was not reduced by long-term spring-summer-fall grazing on fescue grasslands in southwestern Alberta (Johnston et al. 1971). On my study sites, the depth of the Ah horizon was lower on heavily grazed sites, similar to Dormaar and Willms (1998) on a foothill grassland site in southwestern Alberta where depth of the Ah horizon was 30% less in areas that were grazed heavily versus lightly for 44 years from mid-May through

November. The differences in the Ah horizon between heavily and lightly grazed sites in Dormaar and Willms (1998) and my study may be attributed to the increased bulk density observed with long-term heavy grazing.

Conclusions

Plant vigor, canopy cover, and species composition of rough fescue were all lower on heavily grazed sites. Idaho fescue and bluebunch wheatgrass were less vigorous on long-term heavily grazed sites, but plant vigor was not as low as rough fescue, and no differences were found in canopy cover or species composition of Idaho fescue or bluebunch wheatgrass. Vigor of bluebunch wheatgrass was the least adversely affected of the dominant grass species on this site. Reduced basal diameter of rough fescue, the dominant graminoid species in this habitat type, largely accounted for the differences observed in ground cover of graminoids and forbs between heavily and lightly grazed sites. Increased bulk density observed on long-term heavily grazed sites further exacerbates the effects of heavy grazing on plants by compacting soils, thus affecting water acquisition and plant growth. My results demonstrate that in the rough fescue/bluebunch wheatgrass habitat type on foothill rangeland in Montana, rough fescue cannot tolerate many successive years of grazing in winter-spring, but long-term light grazing in winter-spring can sustain rough fescue. Heavy or light long-term grazing in winter-spring decreased the abundance of bluebunch wheatgrass but had minimal impact on Idaho fescue.

CHAPTER 6

MANAGEMENT IMPLICATIONS

My results support the premise that rough fescue the rough fescue/bluebunch wheatgrass habitat type cannot tolerate many successive years of heavy grazing in winter-spring, even with rest in late spring, summer, and early fall. However plant vigor, canopy cover, and species composition of rough fescue can be sustained with many successive years of light winter-spring grazing in this habitat type. To sustain bluebunch wheatgrass, my results indicate that grazing must be less frequent. More research is needed to identify appropriate winter-spring grazing frequencies for bluebunch wheatgrass in this habitat type. Idaho fescue in this habitat type can tolerate many successive years of heavy grazing in winter-spring.

Land managers should monitor canopy cover, species composition, and plant vigor of key bunchgrass species closely on foothill rangeland grazed moderately and heavily in winter-spring by elk, particularly if domestic livestock will graze in the same areas in summer. Brewer (2002) recommended that bluebunch wheatgrass plants in the rough fescue/bluebunch wheatgrass habitat type grazed heavily in May not be grazed by domestic livestock until late summer to maintain plant vigor and yield or that elk should be encouraged to use other areas during May to accommodate livestock grazing earlier in summer. Reducing livestock stocking rates in early summer or reducing elk stocking rates in spring may also allow earlier summer grazing in this habitat type by domestic livestock.

With regard to the SRWMA, better grazing distribution of elk during winter-spring is needed to maintain or restore species composition and vigor of rough fescue, and vigor of bluebunch wheatgrass and Idaho fescue. Traffic bordering the lightly grazed portion of the SRWMA is the greatest deterrent to elk grazing in that area. Currently, this road is closed half way up the south edge of the SRWMA from mid-November to mid-May. Therefore, closing the county road at a location further from the SRWMA may improve elk distribution and encourage grazing in this area. Forage in areas that have been lightly grazed consists of large amounts of decadent plant material. Prescribed burning (Jourdonnais and Bedunah 1990) or fertilizing (Long 1989) could be used to improve palatability of grasses, increase the attractiveness of forage on these sites, and encourage elk to forage more within this portion of the SRWMA. Additionally, prescribed livestock grazing, which is currently being used on the Mount Haggin Wildlife Mangement Areas (Frisina 1992), the Wall Creek Wildlife Management Area (Alt et al. 1992), and the Fleecer Wildlife Management Area (Frisina and Morin 1991) could also be used to condition forage and improve elk distribution. Increasing the attractiveness of the forage present, in conjunction with closing the road further from the SRWMA, would likely encourage elk to utilize the lightly grazed portions of the SRWMA, which would reduce the grazing pressure on the heavily grazed portions.

Creating disturbance in heavily grazed areas in winter-spring may also encourage elk to move into areas that historically have been lightly grazed. Because the SRWMA is closed to the public during winter-spring, creating disturbance in heavily grazed areas during this time may be less feasible than reducing disturbance on the county road in the lightly grazed area. Reducing elk stocking rates by decreasing elk numbers also may help reduce the grazing intensity in the heavily grazed portion.

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