Mesic Meadow Responses to Variation in Grazing Management Practices: Balancing Sage-Grouse Resources with Livestock Production

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Authorization to Submit Thesis

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Abstract

Mesic meadows across the arid western United States play an integral role in providing water and forage resources for wildlife and domesticated livestock. Greater sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse), a species of conservation concern, depend upon mesic meadows because they support key forb species of high nutritional importance to juveniles during late-brood rearing. Additionally, mesic meadows provide valuable forage and water resources to domesticated livestock, especially as summer progresses and adjacent upland vegetation begins to desiccate. Due to the limited geographic extent (< 3%) of mesic systems at the landscape scale, identifying management techniques that provide grazing opportunity and balance the resource needs of greater sage-grouse is essential. Thus, the first chapter of this thesis sought to evaluate how variation in the season (Early: early-June Late: early-August) and intensity (Control: 0%, Moderate: 30-40%, High: 70-80% relative use) of short-duration livestock grazing in mesic meadows influence cover and biomass percentages of sage-grouse high importance forbs (HIF), pre-grazing to post-grazing change in soil moisture, and noxious weed cover immediately before and after grazing and following a rest period for pasture regrowth. Neither short-duration grazing treatments nor ungrazed control treatments resulted in a decline in HIF cover of biomass percentages. Alternatively, both early-season and high-intensity grazing treatments independently increased HIF cover during pre-grazing sample periods from 2019 to 2020. We did not detect any changes in HIF metrics during the post-grazing sample period. Again, HIF metrics remained similar within treatments between years during the regrowth sampling period; however, the regrowth percent of biomass comprised of HIF was greater in early-season treatments than late-season treatments in 2020. Pre-grazing to regrowth sampling declines in soil moisture were greater in 2019 than 2020, and early-season grazing treatments experienced larger declines in soil moisture than late-season grazing treatments. Noxious weed cover did not change in response to short-duration grazing or ungrazed control treatments. The second chapter of this thesis evaluated the effects of grazing season and intensity from a livestock performance and forage availability and quality perspective. Early-season grazing improved crude protein (CP) and decreased acid detergent fiber (ADF) and neutral detergent fiber (NDF) from 2019 to 2020. Compared to all other treatments, early-season grazing at a high-intensity produced forages with the greatest CP and lowest NDF during regrowth sampling in late

September. Average daily gains (ADG) of yearling heifers varied by year, but variation was minimal and not associated with grazing season or intensity. Differences in forage and ADG responses depended upon year, likely due to greater spring and annual precipitation in 2019 compared to 2020. Developing feasible grazing management strategies that can sustain or enhance mesic resources relied upon by sage-grouse is vital to the conservation of the species. Further, balancing forage quantity and quality responses and livestock performance is essential for the management of mesic systems that support livestock and wildlife. This study provides evidence for the use of grazing as a tool to help achieve wildlife, forage, and livestock management objectives in mesic meadows.

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Dedication

I cannot thoroughly express my gratitude for the passion instilled within me by my parents to pose questions about, seek answers to, and explore all aspects of the natural world. They have provided tremendous support, outside perspectives, and challenged my way of thinking throughout my career to help me develop as a person and professional in order to reach my goals and aspirations. I will be forever grateful for the support and the path this guidance has directed me to follow.

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Chapter One: Is short-duration cattle grazing an effective tool to manage forbs important to sage-grouse and soil moisture in mesic meadows?

Abstract

Mesic meadows provide valuable water and forage resources for wildlife and domesticated livestock in the arid western United States. Greater sage-grouse (*Centrocercus urophasianus*), a species of conservation concern, rely upon these habitats because they support key forb species and succulent vegetation of high importance to juveniles during late-brood rearing. Because mesic meadows comprise only a small fraction of the landscape, identifying grazing strategies compatible with the maintenance and production of mesic resources is vital to balancing livestock production with sage-grouse habitat. Therefore, we evaluated the relationships between short-duration grazing treatments and habitat components in mesic meadows important to sage-grouse. In 2019 and 2020, we established short-duration grazing treatments that varied by season (Early: early-June; Late: early-August) and intensity (control: 0%, moderate: 30-40%, high: 70-80% relative use). We monitored trends in cover and biomass percentages of high importance forbs (HIF), soil moisture declines, and the change in weed cover immediately before and after grazing and again after pasture regrowth. Short-duration grazing treatments did not reduce HIF cover or biomass. Early-season and high-intensity grazing subsequently increased HIF cover during the pre-grazing sample period from 2019 to 2020. Post-grazing HIF cover and biomass percentages remained similar across all treatments. Regrowth measurements of HIF biomass percentages were greater in early-season grazing treatments than late-season grazing treatments in 2020. Decline in soil moisture from pre-grazing to regrowth sample periods was greater in early-season treatments than late-season treatments but was not associated with grazing intensity. The cover of weeds did not change under short-duration treatments. This study emphasizes the potential of early-season high-intensity grazing to increase HIF cover and biomass for brood-rearing sage-grouse over short time intervals.

Introduction

Understanding ecological responses of mesic meadows to livestock grazing in rangelands is essential to the management of these unique systems and their associated resources. Mesic meadows, the transitional zones between wet and dry ecosystems (Svejcar 1997, Stringham and Repp 2010), typically comprise less than 3% of the total landscape in the arid western United States (Donnelly et al. 2016). Variation in adjacent topography directs surface and subsurface water flow patterns to mesic areas, resulting in elevated soil moisture (Naiman and Décamps 1997; Patten 1998). This underlying hydrology influences soils and vegetation communities, creating stark contrasts between adjacent uplands (Elmore and Bestcha 1987; Castelli et al. 2000). During summer months in arid landscapes, mesic meadows can produce and sustain green forage while adjacent upland vegetation production slows and plants desiccate (Gillen et al. 1985; Parsons et al. 2003). This difference in production, coupled with increased water availability, provides abundant resources that attract wildlife and livestock to mesic meadows (Swanson et al. 2015).

Greater sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse), a species of conservation concern, are drawn to mesic habitats during late-season brood-rearing because these areas can support more abundant and diverse communities of essential dietary forbs relative to upland habitats (Drut et al. 1994; Klebenow 1968; Wallestad 1971; Schroeder et al. 2004). This group of dietary forbs (hereafter, preferred forbs) serves as an important source of protein, which aids in the growth and survival of juvenile and adult sage-grouse (Johnson and Boyce 1991; Drut et al. 1994). Based on the utility and value of specific forbs to sage-grouse, such as when and which portions of the plant are available, palatable, and nutritive, preferred forbs can be further classified into categories of moderate or high importance (Luna et al. 2018). Many factors influence sage-grouse population dynamics, including the availability and production of mesic habitats and wetland complexes that harbor important food items during late-brood rearing (Atamian et al. 2010; Blomberg et al. 2012). For instance, Casazza et al. (2011) documented greater brood success among female sage-grouse that used habitat closer to wet meadow edges with greater plant and forb species diversity. Due to the reliance of sage-grouse on these portions of the landscape, conservation and restoration of mesic meadow habitats for sage-grouse are critical to the species' recovery (Atamian et al. 2010; Donnelly et al. 2016). However, characteristics of mesic areas such as greater forage and water availability make these limited portions of the landscape critical to many other species as well (Belsky et al. 1999), including domesticated livestock (Kauffman and Krueger 1984).

In the western United States, livestock grazing occurs on over 300 million acres of federal land and 200 million acres of private land (Armour et al. 1994). Within lands occupied by domesticated livestock, grazing does not occur uniformly (Bailey et al. 1996; Bailey 2005). Landscape resources and features such as water (Bailey 2005), higher quality vegetation (Zengeya et al. 2012), and flatter topography (Bailey et al. 1996) can influence livestock distributions and use of available forage. These traits serve as the defining characteristics of mesic habitats, often translating into the congregation of livestock within these areas (Kauffman and Krueger 1984). This congregation of animals and associated heavy grazing pressure can result in changes to the structure and composition of mesic meadow vegetation (Bullock et al. 2001; Boyd et al. 2014) and soils (Naeth et al. 1991), which may influence the ability of mesic meadows to provide wildlife habitat (Krausman et al. 2009). The complexities of grazing management systems require controlled experiments to document how variation in the application of grazing affects mesic habitats that support vital preferred forb communities for sage-grouse during late-brood rearing (Beck and Mitchell 2000; Pennington et al. 2016).

Adjusting the season, intensity, and duration of grazing provides land and livestock managers the opportunity to use grazing as a management tool (Howery et al. 2000; Swanson et al. 2015; Bailey et al. 2019). When appropriately applied, livestock grazing can alter species composition and the productivity of herbaceous plant communities to meet managers' objectives (Rosenthal et al. 2012; Boyd et al. 2014). Such manipulations in grazing strategy may benefit sage-grouse when preferred forbs, such as common dandelion (*Taraxacum officinale*), become more abundant in response to grazing (Tueller 1962; Klebenow and Gray 1968; S. Drut et al. 1994). Alternatively, improperly managed grazing and other land management practices can degrade sage-grouse habitat (Beck and Mitchell 2000). Because livestock grazing can benefit or degrade wildlife habitat depending upon factors inherent to both current and past management and associated environmental conditions (Krausman et al. 2009), grazing can elicit site-specific responses (Hayes and Holl 2003a; Oles et al. 2017), which are essential to address in the context of an experiment.

When determining the influence of grazing on sage-grouse habitat, a complicating factor is the interaction of grazing with pasture conditions and environmental variables such as existing plant community composition or soil moisture. For instance, non-native perennial forage grasses, introduced to improve forage quality for livestock, can displace other plant species and prevent future recolonization (Kulmatiski 2006; Averett et al. 2020), potentially replacing important sage-grouse food resources and affecting the outcome of grazing. Alternatively, overgrazing can result in soil compaction and lead to decreases in water holding capacity (Villamil et al. 2001; Zhao et al. 2011), which could influence the ability of sites to produce and sustain succulent forbs important to sage-grouse. Further, soil moisture can depend on the interaction among environmental variables, such as temperature, precipitation, and grazing treatments (Weber and Gokhale 2011). Lastly, other characteristics such as abundant herbaceous litter can increase soil moisture (Weber and Gokhale 2011), and subsequently increase plant biomass production (Deutsch et al. 2010). Because plant communities and soil moisture are associated with characteristics of livestock grazing management such as season (Naeth et al. 1991; Davis et al. 2014) and intensity (Naeth et al. 1991; Papanikolaou et al. 2011; Souther et al. 2019), specific information is needed to determine how livestock grazing can be best implemented to maintain or enhance mesic meadow resources crucial to sage-grouse.

Our objective was to determine how variation in the season and intensity of livestock grazing influences forbs preferred by sage-grouse and soil moisture within mesic meadow habitats used for late-season brood-rearing. We hypothesized that the responses of foliar cover and herbaceous biomass of preferred forbs would vary with grazing management because differences in season and intensity of grazing would disproportionately reduce competitive forage grasses, creating opportunities for preferred forbs to establish. We hypothesized that soil moisture depletion rates would vary as a function of grazing management because the season and intensity of grazing would create dissimilarity in litter accumulation and herbaceous cover among pastures, resulting in differential moisture loss among treatments. In addition to evaluating effects on preferred forbs and soil moisture, we evaluated responses to grazing treatments from noxious weeds to address concerns about potentially increasing the abundance of undesirable plants with altered grazing management.

We established pastures and applied short-duration experimental grazing trials to evaluate responses of preferred forbs, soil moisture, and noxious weeds to address our hypotheses.

Methods

Location

We conducted our study at the Rinker Rock Creek Ranch (RRCR), a biological field station operated by the University of Idaho on the northern periphery of the Snake River Plain in Blaine County, Idaho. Ecoregions across the ranch include Idaho Batholith and Snake River Plain (McGrath et al. 2002). Across the ranch, elevation ranged from 1,475-1,860 m. Over the past 30 years, mean annual precipitation ranged from 30.5-40.6 cm; 30-year average temperatures fluctuated from -10.5° C in December to 31.1° C in July and August (PRISM Group and Oregon State University 2020). Common land uses include cattle grazing, mountain biking, hunting, and horseback riding.

Mesic meadows and adjacent uplands across RRCR are categorized as priority habitat for sage-grouse (Makela and Major 2012). Sampling took place in mesic meadows around the lower reaches of Rock Creek, a second-order perennial stream, and Little Rock Creek, a first-order ephemeral stream (Fig. 1). These meadows were dominated by poorly drained Bruneel and Marshdale-Bruneel loams and well-drained Simonton loam, which are characteristic of a flood plain and fan remnants, respectively (USDA and NRCS 2021). Elevation across the meadows from south to north ranged from 1,470 to 1,485 m. Historically, these meadows were used for hay production and livestock grazing. Meadow foxtail (*Alopecurus pratensis*), an introduced perennial forage grass, was the dominant grass species spanning the entirety of our study pastures. Other less abundant grasses included smooth brome (*Bromus inermis*) and Kentucky bluegrass (*Poa pratensis*). Woody plant species were willows (*Salix* spp.); however, Woods' rose (*Rosa woodsia*) and mountain big sagebrush (*Artemisia tridentata*) had encroached upon the meadow in isolated areas. Common forbs of high importance to sage-grouse included common dandelion (*Taraxacum officinale*), yellow salsify (*Tragopogon dubius*), and clover (*Trifolium* spp.) (Luna et al. 2018). Other preferred forbs present across the site but not considered of high importance included povertyweed (*Iva axillaris*), shaggy fleabane (*Erigeron pumilus*), and camas (*Camassia* spp.). We encountered noxious weeds (hereafter, weeds) including field bindweed (*Convolvulus arvensis*), diffuse knapweed (*Centaurea diffusa*), and Canada thistle (*Cirsium arvense*) throughout our study pastures (Prather et al. 2018).

Experimental Design

We used a completely random design to evaluate short-duration (16 days) grazing effects on responses of HIF cover (%) and biomass proportions (%), weed cover (%), and decline in soil moisture (%). Pastures were established for short-duration grazing (approximately 1.7 ha each) from May to August at RRCR and stocked with yearling heifers (Fig. 1). Grazing occurred during two consecutive years (2019 and 2020), which we incorporated into the designs of all models. We designed treatments using a 2×3 factorial describing levels of season (early or late) and intensity (control, moderate, or high). During the regrowth sampling period, treatments were designed as a 2×2 factorial plus control to account for control pastures serving as controls for both early- and late-season observations. Heifers (n = 75 in 2019; n = 73 in 2020) were stocked into six pastures for early-season (June 4-20, 2019; June 2-18, 2020) and six pastures for late-season grazing (July 30 – August 15, 2019; July 28 – August 13, 2020). Stocking rate for each pasture was calculated two days prior to grazing each year using grass biomass measurements to estimate total grass availability per pasture and cattle body weight to estimate daily intake using methods described by Ellison et al. (2021). Pastures (n = 3 pastures per treatment) were grazed at moderate (30-40% relative utilization; $\bar{x}$ = 5.7 heifers in 2019, $\bar{x}$ = 5.3 heifers in 2020) or high (70-80% relative utilization; $\bar{x}$ = 18.5 heifers in 2019, $\bar{x}$ = 14.2 heifers in 2020) intensities (Frost et al. 1994). To ensure that we achieved target values of relative use, we collected grazing utilization measurements using stubble height methods following the removal of livestock from our experimental pastures (USDA and USDOI 1999). We also included control pastures (n = 3) that were fenced but remained ungrazed by cattle throughout the study (n = 15 total pastures; Fig. 1). A single watering location was made available along Rock Creek within each pasture.

Vegetation Sampling

All pastures were sampled using 50-m transects distributed across each pasture using a stratified random sampling approach; strata were different vegetation cover types. To determine the appropriate number of transects required to accurately capture community composition, we created species accumulations curves using transects as the sampling unit (Moreno and Halffter 2001). Species accumulation curves resulted in n = 4 transects per pasture.

We sampled plant foliar cover and biomass three times per year for pastures treated with short-duration grazing. First, transects were sampled prior to grazing initiation (≤ seven days; hereafter, pre-grazing sampling period) to understand baseline plant community composition and structure. Second, to evaluate the responses of plant communities to grazing, we sampled the same transects again within seven days of heifers being removed from pastures (post-grazing sampling period). Third, to assess changes in plant communities following regrowth within the same growing season, transects were sampled again in late September (regrowth sampling period).

We collected foliar cover data along each transect using line-point intercept (LPI), measurements of plant height, herbaceous litter depth, and clippings for biomass estimation (Mackinnon et al. 2011; Stiver et al. 2015; Herrick et al. 2016). Across all sampling methods, forbs were identified to genus where possible for categorization of preference by sage-grouse as moderate or high importance (Luna et al. 2018). We collected LPI and vegetation height measurements at 1-m intervals (n = 50 measurements per transect). Plant species were recorded in the order of interception from the top canopy layer to soil surface (Herrick et al. 2016). Individual plant heights were collected for the tallest grass or grass-like, forb, and woody plant species within a 15 cm radius of each LPI interval along the transect (n = 50 height measurements per transect; Herrick et al. 2016). We recorded height measurements as the distance between the soil surface and the maximum natural height of the plant (Stiver et al. 2015). We collected herbaceous litter depth at the 10-, 20-, 30-, 40-, and 50-m marks of transects. To determine litter depth, we measured from the soil surface to the top of an accumulated litter profile.

Effects of grazing on aboveground biomass were measured by mechanically clipping and collecting vegetation within 100-cm^2 plots placed approximately 0.5 m from each transect tape to avoid clipping vegetation sampled during other measurements. Clipping took place at the 10-, 20-, 30-, 40-, and 50- m marks of transects during the pre-early season, post-early season, pre-late season, post-late season, and regrowth sampling periods, respectively. Biomass was clipped to ground level and stored in paper bags if the plant from which biomass was being collect was alive and rooted within the plot, separating forbs from other herbaceous material. Samples were weighed to the nearest gram to determine wet weight using a digital scale. After attaining wet weight values, samples were oven-dried in a desiccator at 65.6° C for 48 hours, then reweighed to determine dry weight (g). We calculated biomass dry matter (%) for each pasture by dividing the dry weight by the wet weight and multiplying by 100. Total pasture production was estimated by converting dry matter production within plots to pounds per acre, then extrapolating to the pasture scale.

Soil Moisture Sampling

Pastures were subjected to periodic flood irrigation depending upon water availability; however, the lateral extent and temporal influence of this irrigation was minimal and therefore not quantified except as included in measures of soil moisture. We estimated soil moisture using two different methods to account for temporal and spatial heterogeneity within pastures. To collect coarse information from all pastures through time, we used sensors (Decagon: 5TM and EC-20 probes; METER group: Teros 10 soil moisture sensors) and data loggers (Decagon EM-50 and EM-5 loggers) deployed before livestock grazing began. Sensors collected measurements every 24-hours until regrowth sampling was complete in September. In short-duration grazing pastures, we measured soil moisture (%) at a single location (n = 1 measurement per pasture). We placed sensors at a 10 cm soil depth between 130- and 150-m directly east or west of the main channel of Rock Creek (Stringham and Repp 2010). Placement varied to ensure sensor locations were uniform with respect to soil type and vegetation communities (Sample et al. 2016). Additionally, to describe spatial variation in soil moisture within each pasture we also measured moisture (%) at 10 cm soil depth coinciding with the 10-m and 40-m marks of each transect (n = 8 measurements per pasture) during each sampling period using soil moisture probes (DSMM500 Precision Digital Soil Moisture meter with probe).

Statistical Analysis

For all analyses, we applied linear mixed-effects models (LMMs) using the package lme4 in R (Bates et al. 2015). We evaluated the influence of fixed effects and interactions on dependent variables using a Type III analysis of variance (ANOVA). We adjusted error degrees of freedom using the Satterthwaite method. To judge model fit, we evaluated diagnostic plots of residuals versus fitted values and quantile-quantile plots to ensure adherence to assumptions of homogeneity of variance and normality, respectively. To identify where differences occurred within significant effects, we applied contrasts only between levels of explanatory variables relevant to our underlying hypotheses. We conducted all contrasts using the package emmeans in R (Lenth 2021). We applied a Bonferroni adjustment to control for Type II error when conducting multiple comparisons. Statistical significance was evaluated at $P \leq 0.05$. Estimates reported here represent least-squared means plus or minus one standard error derived from LMMs.

Foliar Cover

To evaluate how the season and intensity of short-duration grazing affected cover (%) of high importance forbs (HIF) and weeds in short-duration pastures, transect response values were averaged to the pasture level during pre-grazing, post-grazing, and regrowth sampling periods in each year. Statistical analysis of cover for moderate importance forbs was precluded due to low response levels and sparse information. The remaining cover data were arcsine square root transformed to meet assumptions of normality (e.g., Schulz and Leininger 1990, Rhodes et al. 2010, Souther et al. 2019). Models incorporated the 2x3 factorial treatment structure for season (early or late) and intensity (control, moderate, or high) and accounted for year (2019, 2020) in designs. Years, treatment effects, and their two- and three-way interactions were assumed as fixed effects, while pasture was considered a random effect. Pre- and Post-grazing data were modeled separately. For the regrowth measurement period, the control pastures were common for both the early- and late-season observations. In this case, the regrowth data was modeled assuming a 2×2 factorial plus control treatment structure. Foliar cover, herbaceous litter depth and yearly soil moisture before livestock grazing (hereafter, initial soil moisture) were evaluated as potential covariates in each model.

Biomass of High Importance Forbs

We modeled HIF biomass (% of total biomass) following the same LMMs described above to evaluate the effects of short-duration grazing treatments on forbs of high importance to sage-grouse. When necessary, these data were log-transformed (log(x+1)) to meet assumptions of normality. We evaluated herbaceous litter depth and initial soil moisture as candidate covariates in these models.

Soil Moisture

Linear mixed-effects models were used to evaluate the response of soil moisture decline based on volume (%) between pre-grazing and regrowth sampling periods within short-duration grazing treatments. We calculated soil moisture decline as the difference between pre-grazing and regrowth measurements at the pasture scale during 2019 and 2020. We included year, season, and intensity in addition to their three-way and two-way interactions as fixed effects (Table 1), while pasture was considered as a random effect. The difference in litter depth between pre-grazing and regrowth samples was evaluated as a potential covariate.

Results

Foliar Cover

Before grazing, there was a year by season (P = 0.003) and year by intensity (P = 0.001) interaction on HIF cover. Pre-grazing cover of HIF increased (P = 0.02) from 5.00 ± 2.14% before the application of any short-duration grazing in 2019 to 8.44 ± 2.14% following one year of grazing in 2020 across early-season grazing treatments (Fig. 2). Alternatively, HIF cover was similar (P = 0.49) before grazing during the late season in 2019 (5.72 ± 2.14%) and following one year of grazing in 2020 (4.06 ± 2.14%; Fig. 2). Cover of HIF before grazing did not change (P = 1.00) between 2019 (1.50 ± 3.59%) and 2020 (0.67 ± 3.59%) in ungrazed controls (Fig. 3). Likewise, pre-grazing cover of HIF was similar (P = 0.83) under moderate-intensity grazing in 2019 (8.92 ± 2.62%) and 2020 (6.67 ± 2.62%; Fig. 3). Pre-grazing HIF cover increased (P = 0.004) under high-intensity grazing from 5.67 ± 2.62% in 2019 to 11.42 ± 2.62% in 2020 (Fig. 3). Weed cover before grazing was similar between years and did not respond to short-duration grazing treatments (Figs. 2-3). There was no evidence for HIF or weed cover covariate adjustment by foliar cover (P = 0.95, P = 0.43, respectively), herbaceous litter depth (P = 0.18, P = 0.58, respectively) or initial soil moisture (P = 0.40, P = 0.13; respectively) on HIF cover during pre-grazing sampling.

After grazing, there was no evidence (P = 0.28) of a year by season interaction on HIF cover. There was a year by intensity interaction (P = 0.02) on post-grazing HIF forb cover; however, adjusted custom contrasts did not detect any differences (P > 0.05) in cover across grazing intensities between years. Cover of HIF remained similar (*P* = 0.39) following grazing across treatments in the early season during 2019 (4.28 ± 1.31%) and 2020 (3.11 ± 1.31%; Fig. 2). Similarly, HIF cover following late-season grazing was similar (*P* = 1.00) between 2019 (2.28 ± 1.31%) and 2020 (2.17 ± 1.31%; Fig. 2). Cover of HIF remained similar (*P* = 1.00) in ungrazed controls following grazing between 2019 (1.25 ± 2.20%) and 2020 (0.42 ± 2.20%; Fig. 3). After grazing, HIF cover in 2019 (1.25 ± 2.20%) was similar (*P* = 1.00) to cover in 2020 (0.42 ± 2.20%) in ungrazed controls (Fig. 3). Moderate-intensity grazing also retained similar (*P* = 0.11) HIF cover following grazing in 2019 (5.58 ± 1.61%) and 2020 (3.25 ± 1.61%; Fig. 3). Finally, HIF cover under high-intensity grazing was similar (*P* = 1.00) between 2019 (3.00 ± 1.61%) and 2020 (3.25 ± 1.61%; Fig. 3). Post-grazing effects of year by season (*P* = 0.68) and year by intensity (*P* = 0.39) on weed cover were not evident (Figs. 2-3). Neither HIF nor noxious weed cover was found to vary as a function of covariates for foliar cover (*P* = 0.95, *P* = 0.17, respectively) herbaceous litter depth (*P* = 0.91, *P* = 0.28, respectively), or initial soil moisture (*P* = 0.42, *P* = 0.15, respectively) during the post-grazing sampling period.

During the regrowth sampling period, there was no evidence of year by season (*P* = 0.16), year by intensity (*P* = 0.08), or season by intensity (*P* = 0.24) interactions on HIF cover. Despite a numeric increase, regrowth cover of HIF was similar (*P* = 0.08) between 2019 (3.58 ± 1.72%) and 2020 (7.19 ± 1.72%) in early-season treatments (Fig. 2). Regrowth cover of HIF was also similar (*P* = 1.00) among late-season treatments between 2019 (2.08 ± 1.72%) and 2020 (2.83 ± 1.72%; Fig. 2). In comparison, regrowth cover of HIF was similar during 2019 (*P* = 1.00) and 2020 (*P* = 0.38) in early-season (2019: 3.58 ± 1.72%; 2020: 7.19 ± 1.72%) and late-season (2019: 2.08 ± 1.72%; 2020: 2.83 ± 1.72%) treatments. When evaluating whether grazing intensity elicited changes in HIF cover at regrowth, estimates of high-intensity grazing reflected only a numerical (*P* = 0.11) increase between 2019 (3.25 ± 1.72%) and 2020 (7.28 ± 1.72%; Fig. 3). Moderate-intensity grazing treatments also maintained similar (*P* = 1.00) amounts of regrowth HIF cover in 2019 (2.42 ± 1.72%) and 2020 (2.75 ± 1.72%; Fig. 3). Additionally, there were no differences (*P* = 1.00) in regrowth HIF cover in 2019 (1.00 ± 2.44%) or 2020 (0.33 ± 2.44%) in ungrazed controls (Fig. 2-3). No differences in regrowth HIF cover were detected between high- and moderate-intensity treatments during 2019 (*P* = 1.00) or 2020 (*P* = 0.77; Fig. 3). Cover of HIF after regrowth in high-intensity treatments was also similar to ungrazed controls during 2019 (P = 1.00) and 2020 (P = 0.33; Fig. 3). Lastly, there were no differences in HIF cover after regrowth between moderate-intensity and ungrazed control treatments during either 2019 (P = 1.00) or 2020 (P = 1.00; Fig. 3). Regrowth weed cover was greater (P = 0.05) in 2019 (1.01 ± 0.56%) than 2020 (0.51 ± 0.39%) across treatments (Figs. 2-3); however, there was no evidence for year by season (P = 0.45), year by intensity (P = 0.48), or season by intensity (P = 0.79) interactions on weed cover. Again, neither HIF nor noxious weed cover were influenced by covariates of foliar cover (P = 0.54, P = 0.78, respectively), herbaceous litter depth (P = 0.67, P = 0.71, respectively) or initial soil moisture (P = 0.42, P = 0.83, respectively) during regrowth sampling.

Biomass

Before grazing, there was a year by season interaction (P = 0.006) on the percentage of HIF biomass; however, adjusted custom contrasts did not detect differences between biomass percentages within seasons across years (Table 2). There were no changes in HIF biomass percentages associated with grazing intensity (P = 0.21) or the interaction between year and intensity (P = 0.81) during the pre-grazing sampling period. The percent of HIF biomass was similar (P = 0.38) in early-season treatments before grazing in 2019 (0.258 ± 0.256%) and 2020 (1.130 ± 1.122%; Table 2). Pre-grazing HIF biomass percentages were also similar (P = 0.06) in late-season treatments during 2019 (0.101 ± 0.100%) and 2020 (0.011 ± 0.010%; Table 2). Adjustments in the percent of pre-grazing HIF biomass were not necessary for potential covariates of foliar cover (P = 0.81), herbaceous litter depth (P = 0.79), or initial soil moisture (P = 0.86).

Based on observation of residuals, we censored data during post-grazing analysis of HIF biomass percent when a low number (n = 3 observations) of extreme values (> 1.5 standard deviations above mean) in early-season high- and moderate-intensity treatments clearly drove estimated relationships between total vegetation cover and the percent of HIF biomass. Post-grazing HIF biomass percentage depended upon year (P < 0.001) and season (P = 0.04). The percent of post-grazing HIF biomass was greater (P < 0.001) in 2019 (0.059 ± 0.035%) than 2020 (0.003 ± 0.002%) across all short-duration grazing treatments (Table 2). Additionally, the percent of HIF biomass was greater (P = 0.04) following early-season treatments (0.035 ± 0.025%) than following late-season treatments (0.005 ± 0.003%) across years (Table 2). No adjustments for potential covariates of foliar cover (P = 0.37), herbaceous litter depth (P = 0.65), or initial soil moisture (P = 0.45) were necessary.

Following regrowth, there was a year by season interaction (P = 0.03) on HIF biomass percentage. The regrowth percentage of HIF biomass remained similar (P = 0.07) from 2019 (0.034 ± 0.050%) to 2020 (1.290 ± 1.860%) in early-season treatments (Table 2). Late-season HIF biomass also remained similar (P = 1.00) during regrowth sampling periods in 2019 (0.008 ± 0.011%) to 2020 (0.003 ± 0.004%; Table 2). In 2019, HIF biomass percentages were similar (P = 1.00) between early-season and late-season treatments (Table 2). However, regrowth HIF biomass percentages were greater (P = 0.04) in early-season treatments than late-season treatments during 2020 (Table 2). Adjustment for potential covariates including foliar cover (P = 0.62), herbaceous litter depth (P = 0.42), or initial soil moisture (P = 0.23) were not required for regrowth HIF biomass percentages.

Soil Moisture

In 2019, pre-grazing soil moisture ranged 20.3-50.0 m^3/m^3 in early-season treatments, whereas pre-grazing soil moisture in late-season treatments ranged 6.1-23.0 m^3/m^3. In 2020, pre-grazing soil moisture in early-season treatments ranged 13.4 to 44.8 m^3/m^3, while pre-grazing soil moisture in late-season treatments ranged 4.1 to 15.1 m^3/m^3. Pre-grazing to regrowth declines in soil moisture varied by year (P = 0.001) and season of grazing (P < 0.001); however, declines were not dependent upon grazing intensity (P = 0.60) or the interaction between year and intensity (P = 0.78; Table 3). Soil moisture declines from pre-grazing to regrowth sampling periods was greater (P = 0.001) in 2019 (-11.53 ± 1.24%) than 2020 (-5.51 ± 1.24; Table 3). As expected, early-season treatments (-14.93 ± 1.31) experienced greater (P < 0.001) declines pre-grazing to regrowth declines in soil moisture than late-season treatments (-2.12 ± 1.31; Table 3). Lastly, there was no evidence for adjusting soil moisture declines by change in herbaceous litter depth (P = 0.13).

Discussion

Short-duration grazing that provisions adequate periods for vegetation regrowth serve as viable means for maintaining functioning condition and minimizing adverse effects of livestock grazing in mesic areas (Dalldorf et al. 2013; Swanson et al. 2015). Results from this study suggest that short-duration grazing applications in mesic meadows can also serve as a helpful management tool to maintain or enhance sage-grouse food resources. Despite some variation in the responses of cover and biomass percentage of HIF, likely attributed to differences associated with the evaluated measurements (Chiarucci et al. 1999), patterns were similar for both variables, suggesting we observed increased abundance of HIF and not simply trade-offs between cover and biomass. Despite low values of HIF cover and biomass immediately after all grazing treatments, early-season grazing facilitated improvements in the cover and biomass percentages of HIF across years. We attribute this pattern to the ability of early-season grazing to improve HIF resources by delaying their maturation and allowing adequate regrowth opportunity compared to late-season treatments (Vavra 2005). Additionally, early-season grazing can curtail the yield of competitive forage grasses like meadow foxtail (Wenick et al. 2008), which might otherwise displace less competitive forbs important to sage-grouse. Competition from established plants is a primary driver of individual plant success and plant community composition in productive habitats (Geho et al. 2007). For instance, the establishment and persistence of dandelion, a primary component of the HIF community at our study site, requires disturbance regimes capable of mitigating competition exerted by tall grass communities (Mølgaard 1977; Supek et al. 2017; Gaisler et al. 2019). Because meadow foxtail is an early maturing species (Wenick et al. 2008), late-season grazing was unable to suppress individuals before they reached maturity, produced seed, and entered a state of semi-dormancy due to low moisture conditions (Schoth 1945). Therefore, disturbance caused by early-season grazing and the associated suppression of meadow foxtail likely explains improvements in HIF metrics in pastures subjected to early-season grazing treatments. In contrast, no changes were detected between late-season grazing treatments or ungrazed controls.

Although season of short-duration grazing was identified as a more consistent factor affecting HIF cover and biomass, intensity of short-duration grazing also influenced pre-grazing HIF cover. Under this context, increases in HIF responses are likely attributed to decreased height of competitive vegetation throughout the growing season, which is a mediating factor in the richness and cover of forb groups such as native and exotic annuals (Hayes and Holl 2003b). Further, dandelion and other smaller, less-competitive plants have responded positively to increases in grazing intensity in pastures dominated by perennial grasses (Harker et al. 2000) and systems dominated by tall, rhizomatous grasses (Jones et al. 2010). In contrast to measurements collected before grazing, we did not detect differences among any treatments in HIF cover or biomass immediately after grazing. This is likely a function of increased height of meadow foxtail in control treatments inhibiting the growth of understory forbs and removal of palatable HIF, such as clover, in grazed treatments. During the regrowth sampling period, early-season grazing treatments had greater percentages of HIF biomass than late-season grazing treatments in 2020; however, there were no changes in HIF cover or biomass among treatments from 2019 to 2020. One partial explanation for the lack of variation following a regrowth period is that it is an artifact of our sampling design. Because measurements on HIF cover and biomass during the regrowth sampling period may have fallen outside of a viable phenological window conducive for detection, early senescing forbs may have been difficult to detect. Alternatively, observed differences before grazing may have been small enough to be lost following grazing and the regrowth period. Regardless, early-season and high-intensity grazing improved HIF metrics within mesic meadows, particularly when evaluating changes from 2019 to 2020. Finally, it should be noted that although statistical differences were observed between HIF cover and biomass percentages among treatments, effect sizes were generally small in the scope of total pasture composition. However, forbs were generally rare in our pastures at the beginning of our experiment, and we interpret increases in HIF metrics, although small, as evidence that early-season short-duration grazing can help improve dietary resources of sage-grouse.

Livestock grazing can degrade sage-grouse habitat through the introduction of alien weeds (Young and Longland 1996; Beck and Mitchell 2000). However, this degradation is often the result of over- or improperly managed grazing (DiTomaso 2000). In our study, short-duration grazing treatments did not elicit a response in cover of weeds. Although not a primary objective of this study, livestock grazing can be implemented in a manner that does not affect (Davis et al. 2018) or even reduces (De Bruijn and Bork 2006) the abundance of the weeds detected within our study sites. However, the short nature of this two-year study limits our ability to attest to long term trends in the cover of weeds with respect to short-duration grazing treatments. Instead, our results provide evidence that short-duration grazing can be applied in a manner conducive to late-brood rearing dietary resources for sage-grouse without promoting the cover of weeds, which would compromise pasture condition in the short term.

Declines in soil moisture from before grazing to regrowth sampling periods were greater in 2019 than 2020 and, as expected, were greater in early-season treatments than late-season treatments. We attribute both observations to differences in pre-grazing soil moisture, which aligns with the findings of other studies that describe decreases in moisture metrics, such as plant available water, as spring transitions into summer months (Mitchell et al. 2017). However, contrary to our hypothesis, the intensity of short-duration grazing did not influence soil moisture declines from before grazing to regrowth sampling. Generally, increasing grazing intensity has been linked with lower water content and storage capacity in the top layer of soils because trampling reduces porosity, inhibiting the ability of soils to store water (Villamil et al. 2001). Further, heavier grazing intensities can promote greater evaporation rates at the soil surface by removing protective vegetation when compared to light or moderate grazing intensities (Zhao et al. 2011). However, grazing can also decrease the leaf area index of plants compared to ungrazed controls, which can lead to a lower cumulative level of evapotranspiration (Bremer et al. 2001). In our experiment, it is possible that a combination of factors such as increased plant transpiration in ungrazed controls and evaporation rates occurring at the soil surface in grazed treatments resulted in similar patterns of soil moisture loss at the evaluated 10-cm depth (Yan et al. 2018).

Mesic resources have been identified as a critical component to sage-grouse brood rearing success (Wallestad 1971; Atamian et al. 2010; Donnelly et al. 2016), and sage-grouse have shown an affinity for meadows grazed by livestock over ungrazed meadows (Evans 1986). Our study provides evidence for the efficacy of short-duration livestock grazing to promote HIF resources in mesic meadow pastures. Consistent with our hypothesis, cover and biomass percentages of HIF did not respond similarly across all short-duration grazing treatments. In particular, early-season grazing was a constant component of short-duration grazing treatments that elicited a positive response in HIF cover and biomass percentages when competing with dominant forage grasses. The findings of this study add to a growing body of literature documenting the ability of livestock grazing to be implemented as a tool to help reach specific vegetation management objectives (Howery et al. 2000; Frost and Launchbaugh 2003; Bailey et al. 2019).

Implications

Despite low initial measurements of HIF cover and biomass percentages, our results suggest that short-duration livestock grazing during the early summer can sustain or enhance forbs preferred by sage-grouse in mesic meadows dominated by competitive forage grasses. Late summer grazing did not improve HIF cover or biomass percentages in the short term, but importantly did not reduce HIF metrics relative to pastures with no cattle grazing, suggesting that short-duration grazing later in the summer may not be detrimental to HIF communities. Although not as consistent as early-season grazing, high-intensity grazing may also prompt positive responses in HIF communities. Changes in soil moisture and weed cover were not attributed to short-duration grazing, suggesting it is compatible with the overall functioning of mesic meadows. With consideration of initial pasture conditions and environmental variables, short-duration grazing can be a valuable tool to help enhance dietary resources of sage-grouse without compromising pasture condition over short time intervals.

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Tables

Table 1.1. Fixed effects and interactions for linear mixed-effects models used to evaluate the effects of short-duration grazing treatments on response variables of high importance sage-grouse preferred forb foliar cover and biomass, foliar cover of noxious weeds, and soil moisture declines. Treatments consisted of timing (early-season [early June] and late-season [early August]) and intensity [control (0%), moderate (30-40%), and high (70-80%) relative use by livestock] variables. Measurements were collected during the pre- and post-grazing and regrowth sampling periods in mesic meadow pastures during 2019 and 2020 at Rinker Rock Creek Ranch in Blaine County, Idaho.

Year	Season	Intensity	Interactions
2019	Early	Control	Year × Season
2020	Late	Moderate	Year × Intensity
		High	Season × Intensity
			Year × Season × Intensity

Table 1.2. Least-squares means ± standard error[1] of the percent (%) of total herbaceous biomass composed of preferred forbs of high importance to greater sage-grouse (*Centrocercus urophasianus*) during the pre-grazing (< 7 days) and post-grazing (< 7 days) sampling periods in the early-season (early June) and late-season (early August) as well as the regrowth sampling period (late September) in 2019 and 2020 at the Rinker Rock Creek Ranch in Blaine County, Idaho[2].

					Year × Season			
	Year (Y)		Season (S)		2019		2020	
Sample Period	2019	2020	Early	Late	Early	Late	Early	Late
Pre-Grazing: Percent of HIF Biomass[2]	0.161 ± 0.125	0.109 ± 0.084	0.540 ± 0.490	0.033 ± 0.029	0.258 ± 0.256	0.101 ± 0.100	1.130 ± 1.122	0.011 ± 0.010
	Y: *p*-value 0.51		S: *p*-value 0.02		Y × S: *p*-value 0.006			
Post-Grazing: Percent of HIF Biomass[2]	0.059 ± 0.035	0.003 ± 0.002	0.035 ± 0.025	0.005 ± 0.003	0.156 ± 0.122	0.022 ± 0.017	0.008 ± 0.008	0.001 ± 0.001
	Y: *p*-value < 0.001		S: *p*-value 0.04		Y × S: *p*-value 0.96			
Regrowth Sampling: Percent of HIF Biomass[2]	0.024 ± 0.022	0.043 ± 0.039	0.211 ± 0.271	0.005 ± 0.006	0.034 ± 0.050	0.008 ± 0.011	1.290 ± 1.860	0.003 ± 0.004
	Y: *p*-value 0.48		S: *p*-value 0.07*		Y × S: *p*-value 0.03*			

[1]Standard error was estimated using the delta method.
[2] Pastures were grazed for 16 days in 2019 and 2020.
[3]Contrasts were conducted within each sampling period.
**P*-values representing effects during the regrowth sampling period do not account for controls due to model structure.

Table 1.3. Least-squares means estimates ± standard error for change in volumetric water content (%) between early-season (early June) and late-season (early August) pre-grazing sample periods and the regrowth sampling period (late September) in mesic meadow pastures during 2019 and 2020 at the Rinker Rock Creek Ranch in Blaine County, Idaho[1].

	Year (Y)		Season (S)	
	2019	2020	Early	Late
Change in Volumetric Water Content (m^3/m^3)	-11.53 ± 1.24	-5.51 ± 1.24	-14.93 ± 1.31	-2.12 ± 1.31
	Y: *p*-value 0.001		S: *p*-value < 0.001	

[1]Pastures were grazed for 16 days in 2019 and 2020.

Figures

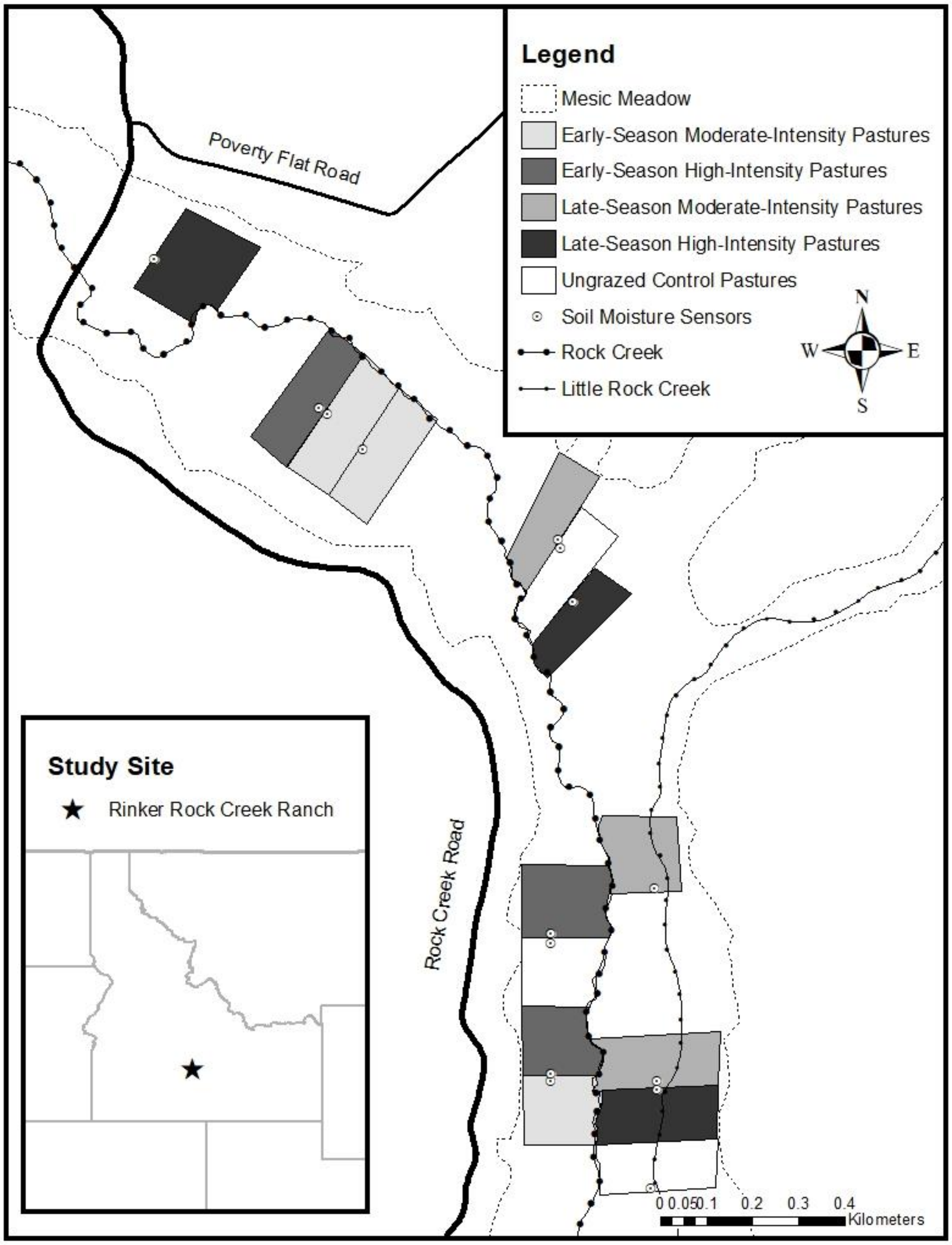

Figure 1.1. Distribution of experimental grazing pastures established at the Rinker Rock Creek Ranch (RRCR) in Blaine County, south-central Idaho. Pastures were stocked with yearling heifers to achieve control (ungrazed: 0%), moderate (30-40%), or high (70-80%) relative use of available forage during 16-day trials in either the early-season (early June) or late-season (Early August).

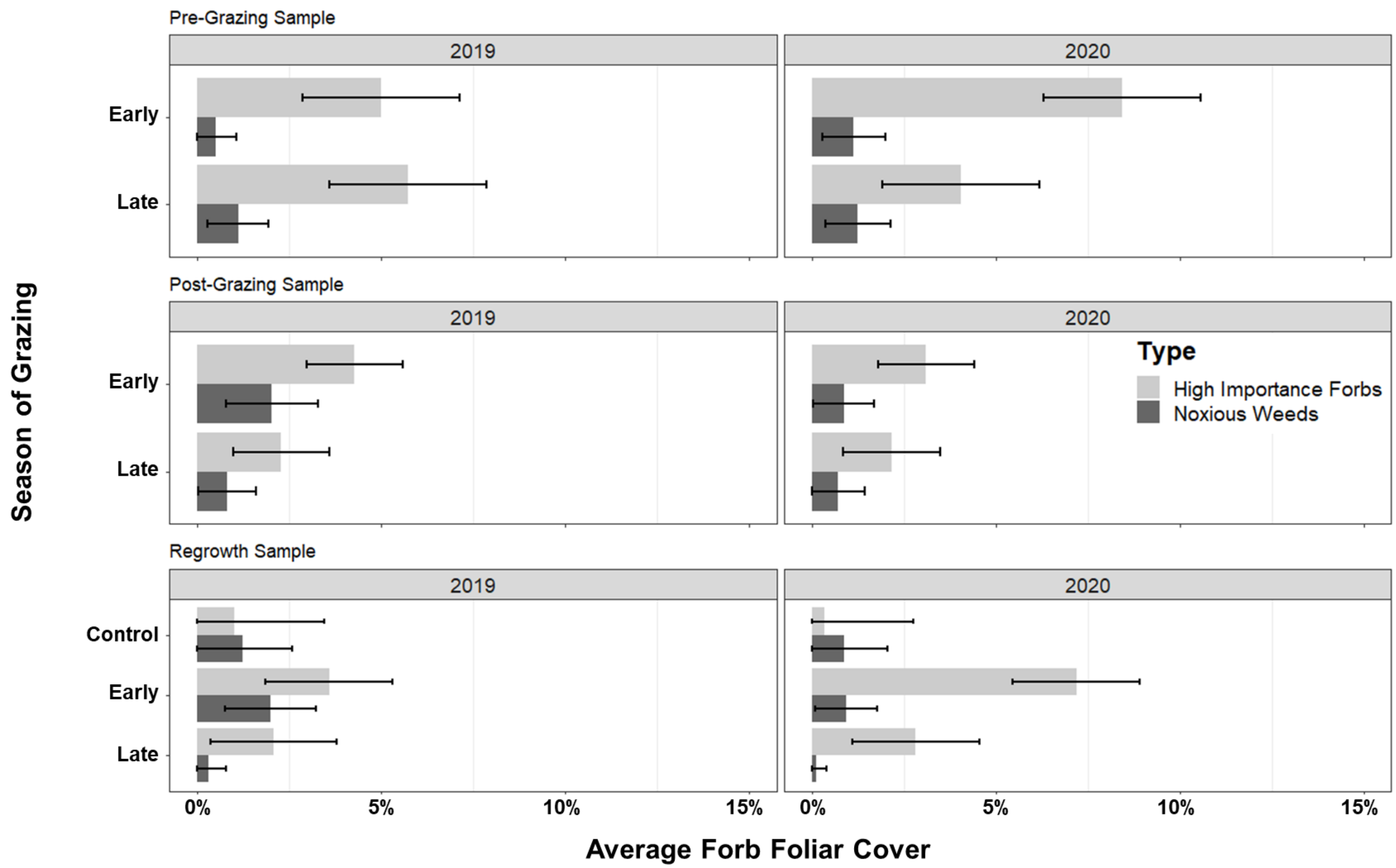

Figure 1.2. Least-squares means ± standard error of foliar cover (%) for preferred forbs of high importance to greater sage-grouse (*Centrocercus urophasianus*) and noxious weeds [cumulatively, field bindweed (*Convolvulus arvensis*), diffuse knapweed (*Centaurea diffusa*), and thistle (*Cirsium* spp.)] by grazing season during the pre-grazing (< 7 days), post-grazing (< 7 days), and regrowth (late September) sampling periods in early-season (early June) and late-season (early August) short-duration grazing treatments during 2019 and 2020 at the Rinker Rock Creek Ranch in Blaine County, Idaho.

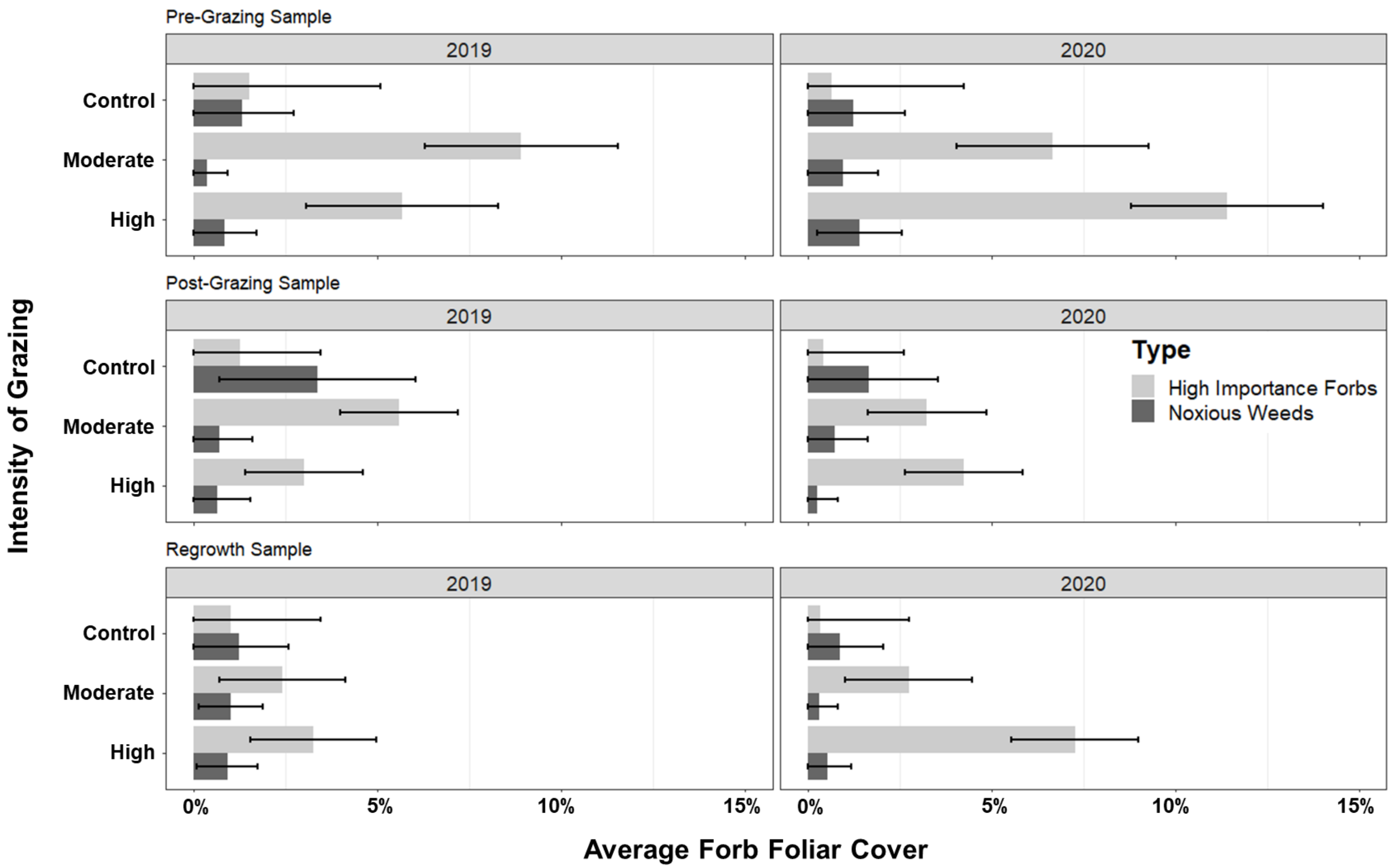

Figure 1.3. Least-squares means ± standard error of foliar cover (%) for preferred forbs of high importance to greater sage-grouse (*Centrocercus urophasianus*) and noxious weeds [cumulatively, field bindweed (*Convolvulus arvensis*), diffuse knapweed (*Centaurea diffusa*), and thistle (*Cirsium* spp.)] by grazing intensity during the pre-grazing (< 7 days), post-grazing (< 7 days) sampling periods), and regrowth (late September) over early-season (early June) and late-season (early August) short-duration grazing treatments during 2019 and 2020 at the Rinker Rock Creek Ranch in Blaine County, Idaho..

Chapter 2: Changes in forage quality and average daily gains of cattle in a short-duration gazing experiment in south-central Idaho

Abstract

Managers tasked with balancing livestock production and wildlife habitat in mesic meadows face a unique set of challenges. In the arid western United States, these challenges are compounded because mesic areas comprise only a small portion of the overall landscape yet provide vital forage and water resources to livestock and wildlife and are essential to underlying ecosystem integrity and function. Our objectives were to compare the effects of short-duration grazing treatments that varied by season and intensity of use on forage quantity and nutrient quality of pasture and the average daily gains (ADG) of yearling cattle. We established pastures (n = 15 total pastures) in mesic meadows at the University of Idaho Rinker Rock Creek Ranch in south-central Idaho and stocked them with yearling heifers during 2019 and 2020. Heifers grazed six pastures in June (early-season; 16 days) and six pastures in August (late-season; 16 days) at moderate (30-40%) and high (70-80%) relative utilization levels (n = 3 pastures per treatment). Three pastures were not grazed and were used as controls. Forage quality was collected and analyzed at pre-grazing, post-grazing, and after a period of regrowth in late September. Early-season grazing increased crude protein (CP) and decreased acid detergent fiber (ADF) and neutral detergent fiber (NDF) from 2019 to 2020. Contrasted against all other treatments, early-season grazing at a high-intensity produced forages with the highest CP and lowest NDF during regrowth sampling in late September. Average daily gains (ADG) of yearling heifers were greater during the first year of the trial than the second year. Differences in ADG were not associated with grazing season or intensity, despite apparent numeric differences. Forage and ADG responses varied between years, likely due to differences in spring and annual precipitation. This study demonstrates the effectiveness of early-season grazing at a high-intensity for improving forage quality and increasing ADG of livestock in mesic meadows.

Introduction

Livestock grazing in mesic or riparian areas poses a unique set of challenges to rangeland managers because of the importance of these habitats to floral and faunal communities and underlying ecosystem integrity and function. In the western United States, these challenges are compounded by a paucity (< 3%) of mesic systems at the landscape scale (Kauffman and Krueger 1984; Donnelly et al. 2016). Unmanaged livestock grazing can degrade the function and associated resources of an ecosystem (Belsky et al. 1999). However, research documenting the adverse effects of livestock grazing often focuses on historic overgrazing, which is not always reflective of modern management (Borman 2005; Davies et al. 2014). Today, a growing body of literature provides evidence for the utility of livestock grazing to sustain or enhance aspects of ecological function when adequately managed (Frost and Launchbaugh 2003; Rosenthal et al. 2012; Oles et al. 2017).

In conjunction with climatic conditions, manipulations of grazing parameters such as season of use or grazing intensity can facilitate change in ecosystem characteristics such as plant community composition or soil exposure (Roath and Krueger 1982; Davis 2014; Souther 2019). When manipulations are applied to grazing treatments to achieve a desired management objective, we refer to this specific application as targeted grazing (Bailey et al. 2019). Managers may implement targeted grazing to improve habitat quality for wildlife (Krausman et al. 2009), increase plant diversity (Rosenthal et al. 2012), or improve forage quality (Clark et al. 2000; Vavra 2005). Because mesic meadows support vital forage resources for both wildlife and livestock, applying targeted grazing strategies to enhance the quantity and nutritional quality of forages could provide better foraging opportunities and more valuable forage resources later in the year.

Forage production may be stimulated under varying levels of grazing pressure when an adequate opportunity for regrowth is allotted (McNaughton 1979; McNaughton 1983; Donkor et al. 2002). Further, managed grazing can improve the nutritional quality of available forages (Vavra 2005; Bailey et al. 2019). For instance, simulated grazing during spring at moderate utilization prompted increases in crude protein, calcium, and phosphorus of bluebunch wheatgrass (*Pseudoroegneria spicata*) in the fall when compared with unclipped plants (Pitt 1986). Further, late-spring grazing by sheep improved crude protein content of bluebunch wheatgrass and Idaho fescue (*Festuca idahoensis*) compared to ungrazed plots (1.0% and 1.3%, respectively) in November on Rocky Mountain elk (*Cervus elaphus nelsoni*) winter range in northeastern Oregon (Clark et al. 2000). In Nevada, livestock grazing between June and July on mesic meadows stimulated regrowth and delayed senescence of palatable forbs, resulting in greater use of grazed pastures than ungrazed pastures by greater sage-grouse (*Centrocercus urophasianus*; Evans 1986). When deliberately applied and executed, manipulations of grazing season and intensity can provide a valuable means for enhancing wildlife habitat and dietary resources; however, such manipulations may not serve as an optimal strategy for livestock production (Holechek et al. 1982).

Livestock performance and production are a product of the relationship between grazing management, forage productivity, and forage quality. Comparisons among grazing management strategies given available pasture and forage resources help determine optimal animal gain and production outcomes (e.g., Heitschmidt et al. 1982; Jung et al. 1985). Further, livestock production and forage quality responses are often evaluated under the context of grazing to determine how to maximize the utility of available forages (e.g., Wenick et al. 2008). Forage quality is positively correlated with crude protein and total digestible nutrients, which indicate nitrogen content and energy and forage digestibility, respectively (Ball et al. 2001). Alternatively, forage quality is negatively correlated with acid detergent fiber and neutral detergent fiber, indicators of fiber content and digestibility and forage intake potential, respectively (Ball et al. 2001). In tandem, grazing management and forage responses interact with one another and facilitate livestock performance, thereby determining the effectiveness of the management strategies for livestock production purposes. For example, increases in alfalfa composition of forages under rotational grazing resulted in higher digestibility levels and greater crude protein contents throughout the grazing season compared to continuous grazing (Walton et al. 1981). This change in forage quality resulted in greater weight gains of cattle under rotational management than continuous management (Walton et al. 1981). Like wildlife, livestock prefer portions of the landscape that yield the resources necessary to support maximum individual performance, otherwise known as optimal habitat (Bailey 2005). In arid landscapes, livestock are attracted to sources of water (Pringle and Landsberg 2004), higher vegetation quality (Zengeya et al.

2012), and less rugged topography (Bailey et al. 1996). Because these are also descriptors of mesic meadows, it is essential to understand how livestock performance, forage quantity, and forage quality respond to various grazing applications, and further, to determine the influence of these responses on resources important to wildlife.

The objective of this experiment was to evaluate how manipulations in the season and intensity of short-duration grazing influenced the quantity and quality of forages and average daily gain (ADG) of crossbred (Hereford × Angus) yearling heifers in mesic meadows. We hypothesized that forage quantity would decrease as a function of increasing grazing pressure. Further, we hypothesized that forage quality would be a function of grazing season and intensity because differences in these short-duration grazing parameters would facilitate variation in the phenological stages and regrowth progression of forages (Clark et al. 2000). Therefore, we predicted that heifers would have access to higher quality forages during early-season grazing than during late-season grazing. Also, we expected that optimal forage quality in the fall would be most pronounced in pastures grazed during the early season at greater intensities. Lastly, we hypothesized that ADG of yearling heifers would not vary significantly among treatments due to the limited amount of time available to individuals to select the most palatable vegetation. We predicted that ADG would be slightly greater in early-season treatments than late-season treatments due to differences in the quality of available forage during these seasons (Waldie et al. 1983; Ball et al. 2001) and that heifers, grazing under moderate intensities, would have greater gains than heifers under high intensities.

Methods

Location

The Rinker Rock Creek Ranch (RRCR) is a research station managed by the University of Idaho and located approximately 15 km southwest of Bellevue, Idaho, in Blaine County. Elevation on the ranch ranges 1,475-1,860 m. Historically, precipitation (1981-2010) ranged from 30.5-40.6 cm, and temperatures (1981-2010) ranged from -10.5° C in December to 31.1° C in July and August (PRISM Group and Oregon State University 2020). To determine the effects of variation in short-duration grazing treatments, we established experimental grazing pastures in mesic meadows on the southern border of RRCR (43° 20’ 57.51” N, 114° 22’ 49.31” W).

The mesic meadows used in this experiment were historically planted for hay production and livestock grazing. During this trial, forage grass communities were dominated by non-native meadow foxtail (*Alopecurus pratensis*). Less abundant grasses included smooth brome (*Bromus inermis*) and Kentucky bluegrass (*Poa pratensis*). Common dandelion (*Taraxacum officinale*), yellow salsify (*Tragopogon dubius*), clover (*Trifolium* spp.), and willowherbs (*Epilobium* spp.) were the most abundant forbs throughout the meadow. Willows (*Salix* spp.) dominated the riparian corridor along Rock Creek, but Woods’ rose (*Rosa woodsii*) and mountain big sagebrush (*Artemisia tridentata*) were also present at low densities (< 2% cover of entire meadow).

Experimental Design

We used a completely random design to evaluate the effects of short-duration (16 days) grazing on responses of forage quantity, quality, and livestock gains. Short-duration grazing took place from May to August. Grazing treatments occurred in the same short-duration pastures (n = 15), approximately 1.7 ha each, during 2019 and 2020. Year was incorporated into the design of all models. Treatments were designed as a 2×3 factorial reflecting levels of season (early or late) and intensity (control, moderate, high). To evaluate differences in responses during regrowth sampling periods, treatments were designed as a 2×2 factorial plus control because controls were common for both the early- and late-season observations. Two seasonal grazing treatments were created by stocking yearling heifers into six pastures early (n = 148; average beginning body weight; hereafter, BW = 359 ± 2.86 kg; June 4-20, 2019; June 2-18, 2020) and six pastures late (n = 113; average beginning BW = 396 ± 3.57 kg; July 30 – August 15, 2019; July 28 – August 13, 2020) during the grazing season. During both early- and late-grazing seasons, yearling heifers were stratified by BW and randomly stocked into three pastures to achieve moderate (30-40% relative utilization; $\bar{x}$ = 6 heifers per pasture in 2019, average beginning BW = 391 ± 4.24 kg; $\bar{x}$ = 5 heifers per pasture in 2020, average beginning BW = 352 ± 5.05 kg) or three pastures to achieve high (70-80% relative utilization; $\bar{x}$ = 18 heifers per pasture in 2019, average beginning BW = 394 ± 3.89 kg; $\bar{x}$ = 14 heifers per pasture in 2020, average beginning BW = 353 ± 3.54 kg) stocking rates. We restocked the same heifers used in early-season treatments for the late-season treatments. We reassigned individual heifers to the same grazing intensity pastures during both early and late seasons. Three pastures provided controls without cattle grazing (n = 3 pastures per treatment; n = 15 total pastures). We calculated stocking rates to achieve the desired grazing utilization level using dry weight (g) biomass production extrapolated to the pasture scale (Ellison et a. 2021). In each pasture, we monitored relative use of yearly forage production during and after trials using a modified utilization gauge with curves developed for the most common grasses across the meadow (Aldon and Francis 1984; USDA and USDOI 1996).

Livestock

The University of Idaho Institutional Animal Care and Use Committee (IACUC) approved all procedures conducted as part of this study (#IACUC 2019-8; #IACUC 2020-08). In 2019, we stocked crossbred (Hereford × Angus) yearling heifers (n = 75; average beginning BW = 377.4 ± 5.3 kg) from the University of Idaho Nancy M. Cummings Research, Extension, and Education Center in short-duration grazing pastures. In 2020, we stocked crossbred (Hereford × Angus) yearling heifers (n = 73; 341 ± 4.4 kg initial BW) supplied by Prescott Cattle for use in the experiment. During both years of investigation, we weighed heifers using a portable livestock scale and scale-head. Heifers were weighed two consecutive days before and after grazing. We calculated final pre- and post-grazing weights as the average between weights collected during consecutive weigh days. Once pre-trial BWs were collected, heifers were stratified by BW and randomly assigned to pastures ensuring that average pre-grazing BW was similar across pastures.

Forage Biomass and Nutrient Analysis

Vegetation transects stratified by dominant vegetation cover type were established in short-duration grazing pastures. Along transects, we collected vegetation biomass three times; before (< 7 days) and after (< 7 days) livestock grazing and following a period of regrowth (late September) at four locations per pasture. In ungrazed control pastures, we collected biomass before (< 7 days) and after (< 7 days) grazing during early- and late-season periods and again in late September. We collected biomass in plots measuring 1 square meter paired with vegetation transects. We clipped biomass in plots to ground level at the 10-, 20-, 30-, 40-, or 50- m marks of transects coinciding with pre-early season, post-early season, pre-late season, post-late season, and regrowth sampling periods, respectively.

We changed locations of biomass plots between sampling periods to avoid potential effects from previous clipping events. When collecting biomass, we only clipped and collected current-years growth to prevent skewing the current year's production results with the previous year's residual biomass. Once clipped, we sorted vegetative biomass by functional group (grass and grass-like plants, and forbs) into paper bags for weight, percent dry matter (DM), and nutrient analyses.

We determined the wet weight of biomass samples by weighing biomass bags to the nearest gram using a digital scale. We then oven-dried samples in a desiccator at 65.6° C for 48 hours and then reweighed samples following drying to obtain dry weight (g) measurements. To determine the biomass DM of each sample, we divided dry weight measurements by wet weight measurements and multiplied values by 100. Once we obtained DM values, we ground individual forage samples once through a two mm screen and then through a one mm screen using a forage cutting mill. Samples were bagged and shipped to Ward Laboratories, Inc. in Kearney, NE, to determine crude protein (%; CP), acid detergent fiber (%; ADF), neutral detergent fiber (%; NDF), and total digestible nutrients (%; TDN) on a DM basis (Ward Laboratories Inc. 2021).

Soil Moisture

We collected soil moisture (m^3/m^3) information from the first week of grazing trials during both years of the study as an explanatory covariate when comparing differences in herbaceous biomass, CP, ADF, and NDF. We placed soil moisture sensors (Decagon: 5TM and EC-20 probes; METER group: Teros 10 soil moisture sensors) and data loggers (Decagon EM-50 and EM-5 loggers) that recorded soil moisture every 24 hours at a single location in each pasture to collect coarse temporal information throughout the grazing season. Measurements were averaged by week to provide soil moisture measurements throughout grazing trials in both 2019 and 2020.

Statistical Analysis

We used linear mixed-effects models (LMMs) from the package lme4 in R for all analyses (Bates et al. 2015). We used a Type III analysis of variance (ANOVA) to evaluate the influence of fixed effects and interactions on response variables. We adjusted error degrees of freedom by applying the Satterthwaite method. We assessed diagnostic plots of residuals versus fitted values and quantile-quantile plots to ensure models satisfied the assumptions of homogeneity of variance and normality. We deemed explanatory variables and differences between them statistically significant at $P \leq 0.05$. When we observed a statistically significant effect, we evaluated differences among levels of explanatory variables relevant to our underlying hypotheses using the package emmeans in R (Length 2021). We applied a Bonferroni adjustment when evaluating multiple comparisons to limit Type II error. Estimates are reported as least-squared means plus or minus one standard error derived from the LMMs.

Forage Biomass and Nutrient Analysis

To determine how varying season and intensity of short-duration grazing treatments influenced quantity and quality of forages, we applied LMMs to the response values of forage DM, herbaceous biomass (kg ha^{-1} DM; herafter, forage biomass), CP, ADF, and NDF aggregated by mean to the pasture level during pre-grazing, post-grazing, and regrowth sampling periods. We evaluated the main effects of year, season of grazing, and grazing intensity, including the three-way interaction among these variables and all possible two-way interactions on forage nutrient responses during pre-grazing and post-grazing sampling periods. When modeling nutrient values of forages collected during the regrowth sampling period, we constructed models as a 2×2 factorial plus control because the same pastures served as controls during early and late seasons. These models assessed the fixed effects of year, season of grazing, grazing intensity, the three-way interaction among all main effects, and all possible two-way interactions through single and multiple degree of freedom contrasts. We included pasture as a random effect in all models to account for variation between pastures.

Average Daily Gains of Livestock

Models to evaluate how average daily gains (ADG) of livestock responded to short-duration grazing treatments included the fixed main effects of year, season of grazing, intensity of grazing, and the three-way and all possible two-way interactions. Grazing season and intensity were established as a 2×2 factorial to represent early- and late-season applications at both moderate- and high-intensities of grazing. We included pasture as a random effect in all models to account for intrinsic differences associated with each pasture. Finally, we evaluated the effect of pre-grazing bodyweight measured as the initial weight of each individual recorded prior to stocking as a potential covariate. Estimates of ADG are reported as kg day^{-1} plus or minus standard error.

Results

Spring and annual precipitation varied between years. In 2019, annual precipitation (77.3 cm) was above average, but in 2020 was average (35.81 cm) in Camas County, Idaho, at 1,750 m elevation and approximately 37 km northwest from our study area (Fig 1; USDA and NRCS 2021).

Dry Matter

There was a year by season interaction ($P < 0.001$) before grazing, an intensity ($P = 0.01$) and year by season interaction ($P = 0.04$) after grazing, and a season by intensity interaction following regrowth ($P = 0.04$) on forage DM (Table 1). Before grazing, forage DM was lower in early- ($P = 0.004$) and late-season ($P < 0.001$) grazing during 2019 than 2020 (Table 1). As expected, DM was also lower before early-season grazing than late-season grazing in 2019 ($P = 0.001$) and 2020 ($P < 0.001$; Table 1). Forage DM was greater ($P = 0.01$) after grazing occurred in high-intensity pastures than in controls, but no differences in DM were observed between high- and moderate-intensities ($P = 0.20$) or between moderate-intensity and controls ($P = 0.22$; Table 1). After grazing, DM was similar ($P = 0.28$) between 2019 and 2020 in the early season; however, DM in the late season was lower ($P < 0.001$) during 2019 than 2020 (Table 1). Again, DM was lower following early-season grazing than late-season grazing in 2019 ($P < 0.001$) and 2020 ($P < 0.001$; Table 1). Finally, under early-season high-intensity grazing regrowth DM was numerically lower ($P = 0.06$) than under late-season high-intensity grazing, but comparisons between all season and intensity combinations indicated there were no differences in regrowth DM (Table 1).

Forage Biomass

Biomass depended upon year by season ($P < 0.001$) and year by intensity ($P = 0.03$) interactions before grazing, the interaction between year and intensity ($P = 0.05$) after grazing, and varied by year ($P < 0.001$) following regrowth (Table 2). Biomass estimates were greater before grazing in 2019 than 2020 during both early- ($P = 0.03$) and late-seasons ($P < 0.001$; Table 2). Similarly, biomass estimates from before grazing decreased from 2019 to 2020 across control (*P* < 0.001), moderate- (*P* = 0.02), and high- (*P* < 0.001) intensities (Table 2). Biomass estimates following grazing were greater during 2019 and 2020 under control (*P* < 0.001) and moderate (*P* = 0.01) intensities (Table 2). Estimates of biomass following grazing under high intensities were similar (*P* = 0.22) between years (Table 2). In 2019, biomass was similar (*P* = 1.00) under high- and moderate-intensities, but greatest in ungrazed controls (*P* = 0.002, *P* = 0.05, respectively) after grazing. In 2020, biomass estimates following grazing were similar between high- and moderate-intensities (*P* = 1.00), but these estimates were also considered similar to ungrazed controls (*P* = 0.74, *P* = 1.00, respectively; Table 2). During regrowth sampling periods, biomass estimates were again greater (*P* < 0.001) in 2019 than 2020 (Table 2). Regrowth estimates of forage biomass were similar between control and moderate-intensities (*P* = 0.78), control and high-intensities (*P* = 0.11), and moderate- and high-intensities (*P* = 0.48) when averaged across years. During pre-grazing (*P* = 0.21), post-grazing (*P* = 0.94), and regrowth (*P* = 0.19) sampling periods, we found no evidence to support inclusion of initial soil moisture as a potential covariate on forage biomass.

Crude Protein

There was a year by season (*P* = 0.03) interaction before grazing, main effects of year (*P* = 0.002) and season (*P* < 0.001) after grazing, and a main effect of year (*P* = 0.002) and interaction between season and intensity (*P* ≤ 0.01) after regrowth on forage CP (Table 3). Before grazing, CP was greater during the early season than late season in 2019 (*P* < 0.001) and 2020 (*P* < 0.001; Table 3). Crude protein increased (*P* = 0.03) before early-season grazing from 2019 to 2020, whereas CP contents were similar (*P* = 1.00) before late-season grazing between years (Table 3). After grazing, CP increased (*P* < 0.002) from 2019 to 2020 when averaged across all short-duration grazing treatments (Table 3). Again, CP was greater (*P* < 0.001) following early-season grazing than following late-season grazing (Table 3). Crude protein was less responsive to grazing intensity (*P* = 0.08) than to grazing season during post-grazing sampling; however, we did observe numerical declines in CP with increasing grazing intensity. Lastly, regrowth CP was greater (*P* = 0.002) in 2020 than 2019 across treatments (Table 3). Across years, CP during the regrowth period was greatest in early-season high-intensity treatments when compared to early-season moderate-intensity (*P* < 0.001), late-season moderate-intensity (*P* < 0.001), late-season high-intensity (*P* <

0.001), and control (P < 0.001) treatments (Table 3). Aside from early-season high-intensity, CP was similar (P > 0.05) across all other treatments during the regrowth period. Crude protein was not adjusted for variation in initial soil moisture during pre-grazing (P = 0.55), post-grazing (P = 0.06), or regrowth (P = 0.28) sampling periods.

Acid Detergent Fiber

There was a year by season (P = 0.02) interaction before grazing, main effects of year (P = 0.002) and season (P < 0.001) after grazing, and a main effect of year (P = 0.03) following regrowth on forage ADF (Table 4). Before grazing, ADF did not change from 2019 to 2020 under early- (P = 0.12) or late-season (P = 0.76) grazing (Table 4). As expected, ADF values were lower before early-season grazing than late-season grazing in 2019 (P < 0.001) and 2020 (P < 0.001; Table 4). After grazing, ADF was greater (P = 0.002) in 2019 than 2020 when averaged across all treatments (Table 4). Further, ADF was higher (P < 0.001) following late-season grazing than early-season grazing (Table 4). Regrowth ADF measurements decreased (P = 0.03) from 2019 to 2020 across all treatments (Table 4). Although not as pronounced as differences before or after grazing, regrowth ADF was numerically lower (P = 0.07) when early-season grazing was applied rather than late-season grazing (Table 4). Regrowth ADF was similar among all levels of grazing intensity (P = 0.48). Again, it was not necessary to include initial soil moisture as a potential covariate for forage ADF during pre-grazing (P = 0.26), post-grazing (P = 0.22), or regrowth (P = 0.31) sampling periods.

Neutral Detergent Fiber

Neutral detergent fiber varied by season (P < 0.001) before grazing, season (P < 0.001) and intensity (P = 0.004) after grazing, and by year (P = 0.01) and the interaction between season and intensity (P < 0.001) after regrowth (Table 5). Neutral detergent fiber before (P < 0.001) and after (P < 0.001) grazing was lower in the early season compared to late season (Table 5). Increases in grazing intensity resulted in numerically higher NDF estimates after grazing (Table 5). Neutral detergent fiber after grazing was greater under high-intensity grazing than moderate-intensity (P = 0.02) or ungrazed controls (P = 0.005; Table 5). During the regrowth sampling period, NDF was lower (P = 0.01) in 2020 than in 2019 across all treatments (Table 5). Further, NDF was lower under early-season high-intensity grazing than early-season moderate-intensity (P = 0.04), late-season moderate-intensity (*P* = 0.01), late-season high-intensity (*P* < 0.001), and ungrazed controls (*P* = 0.01; Table 5). Differences in forage NDF were not adjusted for initial soil moisture during pre-grazing (*P* = 0.54), post-grazing (*P* = 0.15), or regrowth (*P* = 0.98) sampling periods.

Total Digestible Nutrients

There was a year by season (*P* = 0.02) interaction before grazing, year (*P* = 0.002) and season (*P* < 0.001) main effects after grazing, and year (*P* = 0.03) effect following regrowth on forage TDN (Table 6). Before grazing, forage TDN was greater in the early season than late season in 2019 (*P* < 0.001) and 2020 (*P* < 0.001; Table 6). After grazing, TDN was lower (*P* = 0.002) across all short-duration grazing treatments in 2019 than 2020 (Table 6). Measurements of TDN were greater (*P* < 0.001) following early-season grazing than following late-season grazing when averaged over years and grazing intensities (Table 6). Regrowth TDN increased (*P* = 0.03) between 2019 and 2020 across all treatments (Table 6). Forage TDN was numerically greater (*P* = 0.07) in early-season treatments than late-season treatments after regrowth; however, there were no statistical differences between grazing seasons. Initial soil moisture was not included as a covariate in TDN models during pre-grazing (*P* = 0.26), post-grazing (*P* = 0.22), or regrowth (*P* = 0.31) sampling periods.

Average Daily Gains of Livestock

Average daily gains (ADG) of livestock were greater (*P* ≤ 0.01) in 2019 (0.85 ± 0.05 kg day^{-1}) than 2020 (0.60 ± 0.06 kg day^{-1}) across all short-duration grazing treatments (Fig. 2). Further, the ADG of yearling heifers were numerically greater (*P* = 0.08) in the early-season (0.81 ± 0.06 kg day^{-1}) compared to the late-season (0.64 ± 0.07 kg day^{-1}; Fig. 2). Yearling heifers achieved numerically greater (*P* = 0.12) gains under moderate-intensities (0.80 ± 0.07 kg day^{-1}) compared to high-intensities (0.65 ± 0.06 kg day^{-1}; Fig. 2). Pre-grazing body weight did not explain (*P* = 0.84) any of the observed variation in ADG of heifers.

Discussion

Mesic systems provide abundant forage and water resources shared by wildlife and livestock (Krausman et al. 2009; Swanson et al. 2015). In our study, we observed that forage DM and forage biomass varied in response to grazing season and intensity; however, overall

DM was lower and biomass greater in 2019 than 2020, likely due to greater precipitation in 2019. In a defoliation experiment of smooth brome and Kentucky bluegrass, increased defoliation intensity decreased shoot DM compared to non-defoliated plants (Donkor et al. 2002). Similarly, we observed lower regrowth DM under high-intensity grazing during the early season. Increases in grazing intensity during the late season were likely unable to replicate these patterns because defoliation occurred after meadow foxtail had entered a state of semi-dormancy in which growth was halted or minimal in response to low moisture conditions (Schoth 1945). Forage production is positively associated with increases in spring, early summer, and annual precipitation (Smoliak 1956; Lauenroth and Sala 1992; Derner et al. 2008b). With adequate precipitation, grazed sites can produce greater total forage biomass than ungrazed sites (Patton et al. 2007). When averaged across years, regrowth biomass was similar across ungrazed, moderate-, and high-intensity grazing treatments, despite numeric decreases with increasing grazing intensity. When allowed adequate rest periods following grazing, meadow foxtail (Wenick et al. 2008) and other rhizomatous grasses (Broadbent et al. 2019) can recover and produce additional biomass. This recovery could explain why biomass estimates increased between post-grazing and regrowth sampling periods under moderate- and high-intensity grazing.

Early-season grazing facilitated increases in forage CP and numerical increases in regrowth TDN in conjunction with reciprocal declines in ADF and NDF from 2019 to 2020. In general, CP and TDN decline while fiber components increase during forage maturation (Ball et al. 2001; Arzani et al. 2004). Therefore, phenological stage at time of grazing can influence forage quality responses. For instance, increases in CP and decreases in ADF of regrowth bluebunch wheatgrass have occurred when clipping takes place early during phenological progression, such as the boot, emergence, flowering, or seed formation stages (Pitt 1986). During early-season grazing, dominant forage grasses were transitioning from boot to flowering stages. In contrast, grasses had developed seed and were in seed shatter stages at the onset of late-season grazing. Changes in phenological stage likely explain differences in forage quality between grazing seasons. Alternatively, when defoliation occurs during later phenological stages, improvements in quality compromise the health and reproduction potential of the plant (McLean and Wikeem 1985; Pitt 1986). Further, higher intensity grazing can also suppress plant development and prolong time spent in vegetative stages depending upon the phenological stage of forages during defoliation (Clark et al. 2000; Pavlů et al. 2006). High levels of defoliation can result in plant regrowth from axillary buds (Mueller and Richards 1986; Yuan et al. 2020). Under this scenario, plant development is delayed, resulting in senescence at an earlier phenological stage (Clark et al. 200), thereby increasing forage quality. Further, plantations grazed by sheep in Oregon's Coast Range from May to September showed generally greater amounts of green, succulent vegetation the following year than ungrazed plantations (Rhodes and Sharrow 1990), which likely explains our observed improvements in forage quality under early-season grazing between years. High-intensity sheep grazing in the Netherlands also increased CP compared to forages grazed at lighter intensities (Bakker et al. 1984). Because forage nutritional responses depend upon phenological stage and grazing intensity, regrowth CP was highest and NDF lowest under early-season high-intensity grazing compared to all other treatments.

Average daily gains of crossbred yearling heifers varied by year, but differences between grazing seasons and intensities were not statistically significant, supporting our hypothesis. Differences in ADG between 2019 and 2020 likely result from variation in forage biomass available before and after grazing, which we attribute to differences in spring and annual precipitation between years. Grazing season gains of yearling beef cattle have shown strong hyperbolic increases with increasing spring precipitation during a long-term experiment in Wyoming (Derner et al. 2008a). Although ADG was similar between early- and late-seasons, interpreting the cause of numeric differences in gain is important from a production standpoint, especially when considering the same animals were used for grazing during both seasons, suggesting that variation in forages and not differences in livestock contributed to these observations. As forages mature, leaf-to-stem ratios decline, which corresponds with decreases in CP and increases in fiber contents (Ball et al. 2001; Arzani et al. 2004). Throughout most stages of grass development, leaves have higher CP and lower ADF than stems (Baron et al. 2000). Therefore, early-season grazing allowed heifers access to higher quality forages with greater leaf-to-stem ratios than late-season grazing. Further, on riparian areas in northeastern Oregon, forages had lower DM, greater CP, and lower ADF and NDF during early summer grazing periods than late summer periods (Parsons et al. 2003). In the present study, during a single 16-day trial, an individual heifer gained approximately 2.72 kg more during the early season than an individual grazing during the late season. Further, ADG were numerically greater under moderate- than high-intensities. When evaluating performance across thirty-two combined grazing days from June to August, this translates to a 4.80 kg advantage per individual under moderate- compared to high-intensity grazing. However, this difference comes with the caveat that higher-intensity grazing supported more individual heifers than moderate-intensity grazing. When extrapolated to total production across 32 grazing days during early- and late-seasons, this difference in stocking equated to a 140.54 kg ha^{-1} and 85.91 kg ha^{-1} advantage in 2019 and 2020, respectively, under high-intensity grazing. Therefore, improvements in individual performance under moderate-intensity grazing did not overcome total production from high-intensity grazing. This finding is consistent with other long-term studies that have documented improvements in ADG with decreases in grazing intensity in the mixed-grass prairie of Wyoming (Manley et al. 1997; Derner et al. 2008a). Slightly greater gains under moderate-intensity grazing were likely a function of decreased competition for high-quality forages among heifers.

Because forage quantity and quality are responsive to grazing management (Pavlů et al. 2005; Wenick et al. 2008), grazing strategies that optimize these parameters can be implemented to produce greater quality forages for livestock and wildlife. In mesic meadow communities dominated by non-native forage grasses, short-duration grazing during the early season at a high intensity improved regrowth qualities of forages in mesic meadow pastures over the short term, despite precipitation differences from 2019 to 2020. However, statistically similar biomass estimates in 2019 and 2020 across grazing intensities do not reflect the numerically low estimates of regrowth biomass under high-intensity grazing, which is important given the shared dependence of wildlife on forage resources in mesic systems. Forage responses to precipitation are well documented (Lauenroth and Sala 1992; Derner et al. 2008a), and this study provides further support for the importance of factoring environmental conditions into grazing management plans. The ADG of yearling heifers did not vary depending upon season or intensity of short-duration grazing. Due to the tendency of grazing to elicit site-specific responses in mesic systems (Oles et al. 2017), the most effective grazing treatment in this study may not produce similar outcomes if initial pasture conditions are not comparable. Grazing management should be tailored to meet management objectives and needs of both wildlife and livestock.

Implications

In mesic meadow communities dominated by non-native forage grasses, nutritional quality of forages can be enhanced through variations in the season and intensity of short-duration grazing. Early summer (early June) grazing at high intensities can delay the phenological progression of forages, subsequently enhancing future forage quality into the fall (late September) and possibly following year. If grazing occurs late in the summer (early August), forage quality is unlikely to respond because grasses such as meadow foxtail have already matured and entered into a state of dormancy. Increasing grazing intensity can result in lower forage biomass; however, this is highly contingent upon environmental factors such as spring and annual precipitation. Differences in the average daily gains of livestock between treatments will be small yet may be of economic importance in livestock production. However, because the nutritional quality of forages decreases with increasing maturity, grazing early in the summer will provide livestock with access to higher quality forage than grazing later in the summer. Further, increases in grazing intensity will result in slightly lower individual gains, but does provide greater total livestock production per hectare.

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Tables

Table 2.1. Least-squares means ± standard error of forage dry matter collected (< 7 days) during pre-grazing and post-grazing sampling periods associated with early-season (early June) and late-season (early August) grazing seasons and during the regrowth sampling period (late September) in 2019 and 2020 at the Rinker Rock Creek Ranch in south-central Idaho[1].

						Year × Season				Season × Intensity					
	Year (Y)		Intensity (I)			2019		2020		Early			Late		
Forage Dry Matter (%)	2019	2020	CON[2]	MOD[2]	HIGH[2]	Early	Late	Early	Late	CON[2]	MOD[2]	HIGH[2]	CON[2]	MOD[2]	HIGH[2]
Pre-Grazing	33.10 ± 1.61	54.40 ± 1.61	43.20 ± 1.97	43.20 ± 1.97	44.80 ± 1.97	24.80 ± 2.27	41.40 ± 2.27	36.70 ± 2.27	72.00 ± 2.27	29.30 ± 2.79	31.40 ± 2.79	31.60 ± 2.79	57.00 ± 2.79	31.40 ± 2.79	58.00 ± 2.79
	Y: *p*-value < 0.001		I: *p*-value 0.80			Y × S: *p*-value < 0.001				Y × I: *p*-value 0.76					
Post-Grazing	51.10 ± 2.00	63.70 ± 2.00	49.80 ± 2.94	57.60 ± 2.58	64.90 ± 2.58	36.90 ± 2.75	65.30 ± 2.75	43.80 ± 2.75	83.70 ± 2.75	33.70 ± 3.65	40.10 ± 3.65	47.40 ± 3.65	66.00 ± 3.65	75.20 ± 3.65	82.30 ± 3.65
	Y: *p*-value < 0.001		I: *p*-value = 0.01			Y × S: *p*-value 0.04				Y × I: *p*-value 0.89					
Regrowth Sampling	76.50 ± 2.12	84.80 ± 2.12	79.80 ± 3.56	83.60 ± 2.52	78.20 ± 2.52	71.00 ± 3.35	84.40 ± 3.35	80.60 ± 3.35	87.50 ± 3.35	79.80 ± 3.56[†]	82.10 ± 3.56	69.40 ± 3.56	79.80 ± 3.56[†]	85.00 ± 3.56	86.90 ± 3.56
	Y: *p*-value 0.01		I: *p*-value 0.16			Y × S: *p*-value 0.32*				Y × I: *p*-value 0.04					

[1]Pastures were grazed for 16 days in 2019 and 2020

[2]Grazing Intensity: CON (control; ungrazed), MOD (moderate; 30-40% relative use), HIGH (high; 70-80% relative use).

***P*-values representing effects during the regrowth sampling period only reflect non-control treatments.

[†]Regrowth estimates of forage dry matter are the same for early-season and late-season treatments.

Table 2.2. Least-squares means ± standard error of forage biomass dry basis collected (< 7 days) during pre-grazing and post-grazing sampling periods associated with early-season (early June) and late-season (early August) grazing seasons and during the regrowth sampling period (late September) in 2019 and 2020 at the Rinker Rock Creek Ranch in south-central Idaho[1].

			Year × Season				Year × Intensity					
	Year (Y)		2019		2020		2019			2020		
Forage Biomass (kg ha^{-1} DM)	2019	2020	Early	Late	Early	Late	CON[2]	MOD[2]	HIGH[2]	CON[2]	MOD[2]	HIGH[2]
Pre-Grazing	2,809 ± 193	1,513 ± 193	1,701 ± 244	3,917 ± 244	1,157 ± 244	1,870 ± 244	3,147 ± 396	2,405 ± 299	2,875 ± 299	1,677 ± 396	1,608 ± 299	1,255 ± 299
	Y: *p*-value < 0.001		Y × S: *p*-value < 0.001				Y × I: *p*-value 0.03					
Post-Grazing	2,721 ± 227	898 ± 227	2,392 ± 304	3,050 ± 304	704 ± 304	1,091 ± 304	4,240 ± 431	2,394 ± 373	1,529 ± 373	1,512 ± 431	725 ± 373	455 ± 373
	Y: *p*-value < 0.001		Y × S: *p*-value 0.59				Y × I: *p*-value 0.05					
Regrowth Sampling	2,486 ± 195	712 ± 195	1,819 ± 309	2,558 ± 309	477 ± 309	858 ± 309	3,680 ± 436	2,581 ± 309	1,796 ± 309	890 ± 436	858 ± 309	477 ± 309
	Y: *p*-value < 0.001		Y × S: *p*-value 0.18*				Y × I: *p*-value 0.35*					

[1]Pastures were grazed for 16 days in 2019 and 2020

[2]Grazing Intensity: CON (control; ungrazed), MOD (moderate; 30-40% relative use), HIGH (high; 70-80% relative use).

***P*-values representing effects during the regrowth sampling period only reflect non-control treatments.

Table 2.3. Least-squares means ± standard error of the crude protein dry basis collected (< 7 days) during pre-grazing and post-grazing sampling periods associated with early-season (early June) and late-season (early August) grazing seasons and during the regrowth sampling period (late September) in 2019 and 2020 at the Rinker Rock Creek Ranch in south-central Idaho[1].

					Year × Season				Season × Intensity					
	Year (Y)		Season (S)		2019		2020		Early			Late		
Crude Protein (%)	2019	2020	Early	Late	Early	Late	Early	Late	CON[2]	MOD[2]	HIGH[2]	CON[2]	MOD[2]	HIGH[2]
Pre-Grazing	9.10 ± 0.27	9.64 ± 0.27	12.41 ± 0.31	6.33 ± 0.31	11.86 ± 0.35	6.33 ± 0.35	12.96 ± 0.35	6.32 ± 0.35	11.50 ± 0.54	12.43 ± 0.54	13.30 ± 0.54	6.37 ± 0.54	6.59 ± 0.54	6.03 ± 0.54
	Y: *p*-value 0.04		S: *p*-value < 0.001		Y × S: *p*-value 0.03				Y × I: *p*-value 0.08					
Post-Grazing	6.16 ± 0.24	7.34 ± 0.24	8.71 ± 0.24	4.79 ± 0.24	7.79 ± 0.34	4.54 ± 0.34	9.64 ± 0.34	5.03 ± 0.34	9.15 ± 0.41	8.82 ± 0.41	8.16 ± 0.41	5.26 ± 0.41	4.78 ± 0.41	4.32 ± 0.41
	Y: *p*-value 0.002		S: *p*-value < 0.001		Y × S: *p*-value 0.06				Y × I: *p*-value 0.96					
Regrowth Sampling	4.57 ± 0.14	5.47 ± 0.14	5.99 ± 0.18	4.42 ± 0.18	5.76 ± 0.22	3.85 ± 0.22	6.22 ± 0.22	4.98 ± 0.22	4.28 ± 0.26†	4.79 ± 0.26	7.19 ± 0.26	4.28 ± 0.26†	4.71 ± 0.26	4.12 ± 0.26
	Y: *p*-value < 0.001		S: *p*-value 0.001*		Y × S: *p*-value 0.09*				Y × I: *p*-value < 0.001					

[1]Pastures were grazed for 16 days in 2019 and 2020

[2]Grazing Intensity: CON (control; ungrazed), MOD (moderate; 30-40% relative use), HIGH (high; 70-80% relative use).

***P*-values representing effects during the regrowth sampling period only reflect non-control treatments.

†Regrowth estimates of forage CP are the same for early-season and late-season treatments.

Table 2.4. Least-squares means ± standard error of the acid detergent fiber dry basis collected (< 7 days) during pre-grazing and post-grazing sampling periods associated with early-season (early June) and late-season (early August) grazing seasons and during the regrowth sampling period (late September) in 2019 and 2020 at the Rinker Rock Creek Ranch in south-central Idaho[1].

					Year × Season			
	Year (Y)		Season (S)		2019		2020	
Acid Detergent Fiber (%)	2019	2020	Early	Late	Early	Late	Early	Late
Pre-Grazing	38.60 ± 0.48	39.00 ± 0.48	35.30 ± 0.49[a]	42.30 ± 0.49[b]	34.20 ± 0.68	43.00 ± 0.68	36.40 ± 0.68	41.70 ± 0.68
	Y: *p*-value 0.49		S: *p*-value < 0.001		Y × S: *p*-value 0.02			
Post-Grazing	44.40 ± 0.61	41.40 ± 0.61	40.50 ± 0.61	45.40 ± 0.61	42.70 ± 0.87	46.10 ± 0.87	38.20 ± 0.87	44.60 ± 0.87
	Y: *p*-value 0.002		S: *p*-value < 0.001		Y × S: *p*-value 0.11			
Regrowth Sampling	48.60 ± 0.65	46.50 ± 0.65	46.50 ± 0.73	48.50 ± 0.73	47.00 ± 1.03	50.50 ± 1.03	46.00 ± 1.03	46.50 ± 1.03
	Y: *p*-value 0.03		S: *p*-value 0.07*		Y × S: *p*-value 0.17*			

[1]Pastures were grazed for 16 days in 2019 and 2020

***P*-values representing effects during the regrowth sampling period only reflect non-control treatments.

Table 2.5. Least-squares means ± standard error of the neutral detergent fiber dry basis collected (< 7 days) during pre-grazing and post-grazing sampling periods associated with early-season (early June) and late-season (early August) grazing seasons and during the regrowth sampling period (late September) in 2019 and 2020 at the Rinker Rock Creek Ranch in south-central Idaho[1].

								Season × Intensity					
	Year (Y)		Season (S)		Intensity (I)			Early			Late		
Neutral Detergent Fiber (%)	2019	2020	Early	Late	CON[2]	MOD[2]	HIGH[2]	CON[2]	MOD[2]	HIGH[2]	CON[2]	MOD[2]	HIGH[2]
Pre-Grazing	60.90 ± 0.91	60.90 ± 0.91	58.30 ± 0.96	63.40 ± 0.96	61.10 ± 1.34	60.50 ± 1.17	61.00 ± 1.17	60.50 ± 1.66	56.90 ± 1.66	57.60 ± 1.66	61.70 ± 1.66	64.00 ± 1.66	64.50 ± 1.66
	Y: *p*-value 0.97		S: *p*-value < 0.001		I: *p*-value 0.91			S × I: *p*-value 0.10					
Post-Grazing	67.10 ± 0.82	65.20 ± 0.82	63.50 ± 0.84	68.80 ± 0.84	63.20 ± 1.10	65.40 ± 1.03	69.90 ± 1.03	59.70 ± 1.46	61.80 ± 1.46	69.00 ± 1.46	66.70 ± 1.46	69.00± 1.46	70.7 ± 1.46
	Y: *p*-value 0.09		S: *p*-value < 0.001		I: *p*-value 0.004			S × I: *p*-value 0.13					
Regrowth Sampling	71.60 ± 0.82	68.50 ± 0.82	65.50 ± 1.08	73.90 ± 1.08	71.30 ± 1.52	68.40 ± 1.08	70.90 ± 1.08	71.30 ± 1.52[†]	69.60 ± 1.52	61.40 ± 1.52	71.30 ± 1.52[†]	72.30 ± 1.52	75.40 ± 1.52
	Y: *p*-value 0.006		S: *p*-value < 0.001		I: *p*-value 0.13			S × I: *p*-value < 0.001					

[1]Pastures were grazed for 16 days in 2019 and 2020

[2]Grazing Intensity: CON (control; ungrazed), MOD (moderate; 30-40% relative use), HIGH (high; 70-80% relative use).

*****_P_-values representing effects during the regrowth sampling period only reflect non-control treatments.

[†]Regrowth estimates of forage NDF are the same for early-season and late-season treatments.

Table 2.6. Least-squares means ± standard error of the total digestible nutrients dry basis collected (< 7 days) during pre-grazing and post-grazing sampling periods associated with early-season (early June) and late-season (early August) grazing seasons and during the regrowth sampling period (late September) in 2019 and 2020 at the Rinker Rock Creek Ranch in south-central Idaho[1].

					Year × Season			
	Year (Y)		Season (S)		2019		2020	
Total Digestible Nutrients (%)	2019	2020	Early	Late	Early	Late	Early	Late
Pre-Grazing	58.60 ± 0.55	58.00 ± 0.55	62.30 ± 0.56	54.30 ± 0.56	63.60 ± 0.77	53.60 ± 0.77	61.10 ± 0.77	55.00 ± 0.77
	Y: *p*-value 0.49		S: *p*-value < 0.001		Y × S: *p*-value 0.02			
Post-Grazing	51.90 ± 0.70	55.30 ± 0.70	56.40 ± 0.70	50.80 ± 0.70	53.80 ± 0.99	49.90 ± 0.99	59.00 ± 0.99	51.70 ± 0.99
	Y: *p*-value 0.002		S: *p*-value < 0.001		Y × S: *p*-value 0.11			
Regrowth Sampling	47.10 ± 0.74	49.50 ± 0.74	49.50 ± 0.83	47.30 ± 0.83	48.90 ± 1.17	45.00 ± 1.17	50.10 ± 1.17	49.60 ± 1.17
	Y: *p*-value 0.03		S: *p*-value 0.07*		Y × S: *p*-value 0.17*			

[1]Pastures were grazed for 16 days in 2019 and 2020

*****_P_-values representing effects during the regrowth sampling period only reflect non-control treatments.

Figures

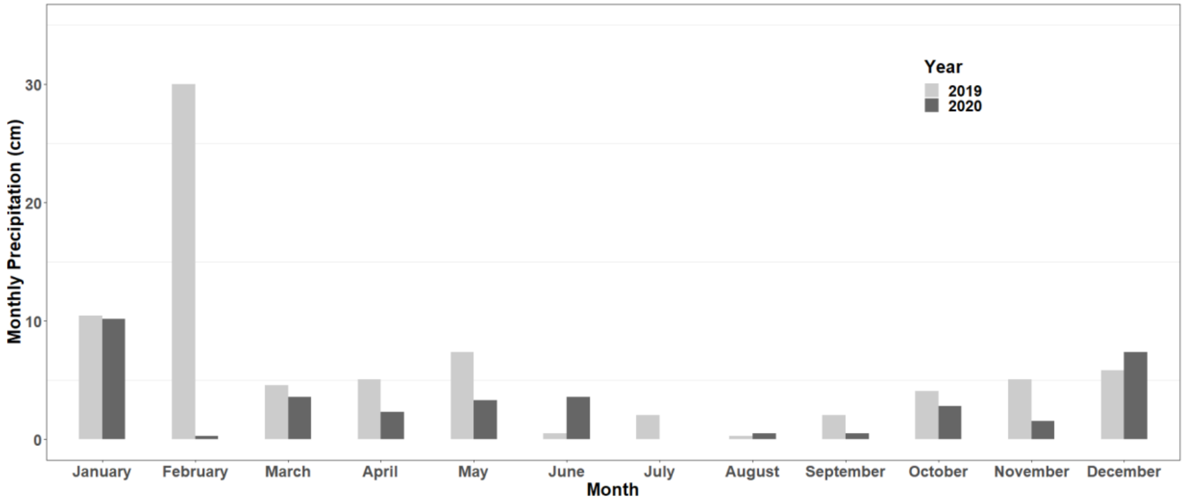

Figure 2.1. Monthly precipitation during 2019 and 2020. Data were collected from the U.S. Department of Agriculture and Natural Resources Conservations Service Soldier R. S. Idaho SNOTEL site in south-central Idaho (USDA and NRCS 2021).

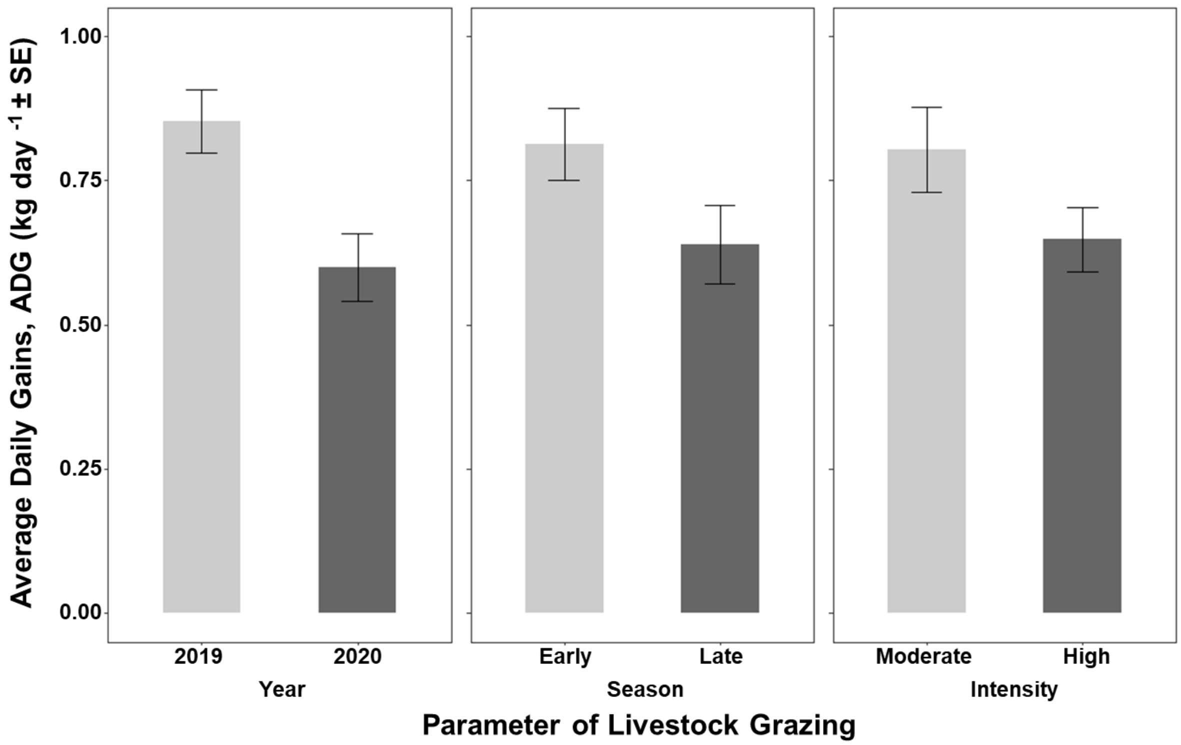

Figure 2.2. Least-squares means ± standard error of average daily gains per individual yearling heifer (Angus × Hereford crossbred) by year, season (Early: early June; Late: early August), and intensity (Moderate: 30-40% relative use; High: 70-80% relative use) of short-duration grazing treatments at the Rinker Rock Creek Ranch in south-central Idaho.