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Abstract: Current management paradigms suggest deferring grazing rangeland for two years post-fire to avoid additional stress on native grass species, but there is little research supporting these recommendations. This study was conducted within and adjacent to the burn area of a wildfire to evaluate the differences in diet quality, botanical composition, and foraging behavior of beef cattle on burned and unburned rangeland in the spring and fall of the year following a fire. Diet composition and masticate samples were collected during 20 min bite-count periods using six ruminally cannulated cows in burned and unburned sites in June and September. Diets differed between burned and unburned sites across seasons, but the differences were most apparent in June. Cattle grazed more selectively on burned sites in June, consuming a higher quality diet dominated by forbs. In September, cattle shifted to grass-dominated diets with fewer differences between burned and unburned sites. This indicates that the nutritional flush on post-fire rangelands may be minimized by the end of the first growing season post-fire. Additionally, in the first spring post-fire, cattle may shift grazing pressure away from vulnerable perennial native grass species to the early-seral forbs, commonly associated with the post-fire environment.

Keywords: beef cattle; botanical composition; diet quality; rangelands; wildfire

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1. Introduction

In recent years, there has been a significant increase in wildfires in the United States: from 1985 to 1989, an average of 1.2 million hectares burned annually; from 2016 to 2020, 3.2 million hectares burned annually [1]. Over that same period, the average annual federal spending on wildfire suppression rose from USD 728 million to USD 2.5 billion [2]. Historically, wildfire behavior has been positively associated with drought, average temperature, and earlier snowmelt [3]. With a projected 1.5 °C increase in global temperatures by 2050 [4], these trends are expected to continue, possibly leading to accelerated fire return intervals of under 20 years [5,6]. In comparison, return intervals between high severity fires for the past 10,000 years are estimated to have been between 100 and 300 years [7].

Largely characterized by native vegetation and erratic precipitation patterns, arid and semi-arid rangelands are susceptible to changes in vegetation and soil from ecological disturbances like wildfire and herbivory [8]. Of the 311.6 million hectares of rangeland in the United States, 35.5% are under management by federal agencies [9,10]. Additionally, public rangelands support 15.7 million livestock animal unit months (AUMs) annually, serving as a critical asset for the United States' livestock industry [9,10]. The federal recommendation for the post-fire management of most of these public lands is to defer grazing for two years after a fire [11]. The justification behind this recommendation is to allow perennial plant communities adequate recovery time post-fire. However, there has been little research to support or discount this recommendation. As livestock grazing is a primary management tool of these lands, its deferment has both ecological and economic consequences.

A rest period may seem intuitive to avoid the cumulative effects of fire and grazing, but literature suggests that plant response to fire differs among species and across ecological regions [12–16]. In the United States, rangelands vary greatly in plant species composition, fuel load potential, precipitation patterns, topography, and geology. This diversity makes it difficult to apply the current recommendation broadly.

One of the key perennial bunchgrasses for this study area is bluebunch wheatgrass. According to the literature, the natural recovery after a fire for bluebunch wheatgrass is typically two to three growing seasons [17,18], though Bunting and others [19] reported defoliation during the boot stage had no effect on bluebunch wheatgrass growth the following year. Jirik and Bunting [20] investigated the effects of post-fire defoliation on bluebunch wheatgrass and reported an effect during the growing season but found no differences in biomass production, basal area, tiller number, or plant mortality from fall defoliation.

Although somewhat limited, there is previous research into how wildfires alter foraging behavior, quality, and botanical composition of diets in herbivores [14,21–24]. In the Northern Great Basin, domestic sheep (*Ovis aries*) grazing post-fire rangelands were found to prefer early growing forbs, reducing subsequent forb production by up to 73% [14]. Fall grazing had little effect on range conditions, but Roselle et al. hypothesize that continued spring grazing may alter long-term range conditions [14]. This aligns with previous findings that sheep are relatively selective in their diets.

Conversely, cattle (*Bos taurus*) have been reported as being generalist grazers when compared to sheep and tend to prefer a grass diet. However, more recent work has shown that cattle are more selective during earlier phenological stages [25]. Vermeire et al. reported higher utilization of burned areas in pastures grazed by cattle from April to September but did not investigate differences within the grazing season [21].

Rangeland composition and structure can be altered over time by selective grazing [26]. In the intermountain west, fire alters cattle foraging behavior and site selection on a landscape scale [27–31]; however, there is little research that has evaluated the influence of fire on fine-scale foraging behavior or diet selection [32]. This information is important for managers to consider when implementing grazing strategies [33]. Therefore, the objectives of this study were to evaluate the impact of fire on diet quality, botanical composition, and foraging behavior on burned and unburned rangeland in the spring and fall in the year following fire. We hypothesized that (1) cattle diets would be higher quality on burned compared to unburned rangeland, and (2) this difference would be more apparent in the spring than in the fall.

2. Materials and Methods

2.1. Study Area and Design

The Bradley Creek fire began on 23 August 2020, southeast of Norris, MT, and burned 756 hectares of rangeland before it was contained on 27 August. The fire burned a portion of Montana State University's Red Bluff Research Ranch (45°35′ N, 111°38′ W). The cause of the Bradley Creek fire is unknown. During the fire, the mean air temperature was 20.6 °C, with maximum and minimum temperatures at 30.1 °C and 11.2 °C, respectively [34].

This study was conducted on the boundary of the burn at Red Bluff Research Ranch in a pasture that had not been grazed for two years prior to the wildfire. The elevation of the study area ranges from 1500 to 1550 m on a west-facing slope. Soil characteristics were similar across all sites. Mean annual precipitation for the study area is 426 mm [34]; however, the area only received 342 mm of precipitation during the 2021 water year (October 2020–September 2021, Figure 1). Dominant graminoids for the study area are bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] Á. Löve), Idaho fescue (*Festuca idahoensis* Elmer), needle-and-thread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth), and threadleaf sedge (*Carex filifolia* Nutt.). The most common forbs include milkvetch (*Astragalus* spp.), common dandelion (*Taraxacum officinale* Weber), western aster (*Symphyotrichum ascendens* [Lindl.] G.L. Nesom), Canada goldenrod (*Solidago canadensis* L.), and dotted gayfeather (*Liatris punctata* Hook.). Pre-fire, there were small populations of big sagebrush (*Artemesia tridentata* Nutt.) in the draws of the study area; however, all were consumed in the fire.

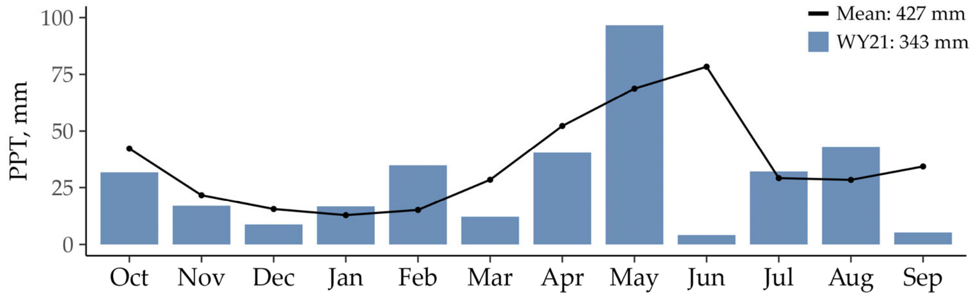

Figure 1. Precipitation (mm) for Red Bluff Research Ranch in water year 2021 compared to 30-year mean precipitation.

2.2. Diet Quality, Composition, and Foraging Behavior

Following the fire, we sampled four sites in the burned area and two sites in the adjacent unburned area in mid-June and mid-September of 2021 prior to any grazing. We adapted sampling methodology from Clark et al. [35] who used bite-count methodology [36–38] with ruminally cannulated cows to collect the diets consumed during the observed grazing bout. We collected diet samples at the sites using 6 four-year-old, ruminally cannulated, Angus-crossbred cows. For each site, all cows were ruminally evacuated before being allowed to freely graze for 20 min. Each cow was randomly assigned a technician who closely followed and recorded the number of bites of each species consumed during the grazing bout. The cows were accustomed to being in proximity with technicians, so their foraging behavior was not disturbed by observation. After each grazing bout, all rumen contents from the diet collection were removed and transported to the Oscar Thomas Nutrition Center in Bozeman, MT, where they were dried in a forced-air oven at 55 °C for 96 h, weighed, then ground to pass through a 1 mm screen in a Wiley mill.

Diet quality was determined through chemical analysis of the diet samples. Acid detergent fiber (ADF) and neutral detergent fiber (NDF) were determined using the Ankom 200 Fiber Analyzer (Ankom Co., Fairport, NY, USA) [39]. Crude protein (CP) content was determined at a commercial laboratory (Dairy One, Ithaca, NY, USA). Differences in diet quality were determined by differences in CP, NDF, and ADF, with greater CP content and lower fiber content being considered higher in quality.

Foraging behavior metrics included intake rate (grams consumed per minute), bite rate (bites per minute), and bite size (grams consumed per bite). Intake rate was calculated by dividing the total dry weight of the diet sample by the length of the grazing bout (20 min). Bite rate was calculated by dividing the total number of bites per grazing bout by the length of the grazing bout (20 min). Bite size was calculated by dividing the dry weight of the diet sample by the total number of bites.

2.3. Statistical Analysis

All data were analyzed in R 4.3.3 [40]. The effect of burn status (burned [B] vs. unburned [UB]) and season (June vs. September) on diet quality, diet composition, and foraging behavior were analyzed using a generalized linear mixed model corresponding to a completely randomized design. The model included a 2 × 2 factorial treatment arrangement of season of use, burn status, and their interaction as fixed effects and individual cow as a random effect [41,42]. All data were plotted and transformed if needed to satisfy assumptions of normality and homogeneity of variance. Individual animals were the experimental unit. Statistical significance was accepted at $p \leq 0.05$ and tendencies were considered at $0.05 < p \leq 0.10$. For the significant effects of burn status or season of use, the Tukey method was used to separate means [43].

3. Results

3.1. Diet Composition

Diet composition by plant growth form and the top 80% of species within each growth form are presented in Table 1. The differences in diet composition between burned and unburned sites were more pronounced in June than September. In June, diets at burned sites were dominated by forbs (79% composition; $p < 0.01$) whereas diets at unburned sites were dominated by graminoids (67% composition; $p < 0.01$). In September, there was no difference in diet composition by burn status, and graminoids comprised the majority of diets (89% composition; $p < 0.01$). Of the forb species, dandelion was the most variable in composition, ranging from 53% of diets in June at burned sites, 12% of diets in June at unburned sites, to being absent from all September diets ($p < 0.01$). The diet composition of most other forbs followed seasonal availability and shifted between seasons but not burn status. Within graminoid species, there were no differences in diet composition by burn status in June ($p > 0.16$). However, in September, Idaho fescue was a greater component of diets in unburned sites ($p < 0.01$), whereas bluebunch wheatgrass was a greater component of diets in burned sites ($p < 0.01$).

Table 1. Percent diet composition by plant growth form and the top 80% of species within each growth form of beef cattle diets on burned and unburned rangeland in June and September at the Red Bluff Research Ranch, southwestern Montana (data from 2021).

Forage Species	June		September		SEM [4]	*p*-Values [1]		
	B [2]	UB [3]	B	UB		F	S	F × S
Graminoids, %	**20.95 [a]**	**67.01 [b]**	**87.16 [c]**	**90.55 [c]**	**4.68**	**<0.01**	**<0.01**	**<0.01**
Carex filifolia	0.20	0.66	0.45	0.03	0.20	0.08	0.24	0.02
Festuca idahoensis	6.50 [a]	11.70 [a]	43.69 [b]	72.24 [c]	3.99	0.36	<0.01	<0.01
Hesperostipa comata	0.57 [a]	10.15 [ab]	22.94 [c]	13.33 [bc]	3.14	0.03	<0.01	<0.01
Pascopyrum smithii	3.15	0.57	5.65	2.32	1.51	0.23	0.16	0.81

Table 1. *Cont.*

Forage Species	June		September		SEM [4]	p-Values [1]		
	B [2]	UB [3]	B	UB		F	S	F × S
Pseudoroegneria spicata	2.27 [a]	4.27 [ab]	6.17 [b]	1.53 [a]	1.11	0.21	<0.01	<0.01
Forbs, %	**79.05 [a]**	**32.99 [b]**	**12.84 [c]**	**9.45 [c]**	**4.68**	**<0.01**	**<0.01**	**<0.01**
Astragalus spp.	21.45	15.94	0.22	0.39	4.74	0.42	<0.01	0.55
Echinacea purpurea	2.28	2.29	0.23	0	1.29	0.99	0.18	0.93
Solidago canadensis	0	0	5.11	2.96	1.21	0.99	<0.01	0.38
Symphyotrichum ascendens	0	0.05	6.25	3.03	1.89	0.99	<0.01	0.39
Taraxacum officinale	53.34 [a]	11.63 [b]	0 [b]	0 [b]	5.14	<0.01	<0.01	<0.01

[1] *p*-values for main effects and interaction between burn status (F) and season of use (S); [2] Burned sites; [3] Unburned sites; [4] Pooled standard error of the means presented; [a–c] Means within a row that lack common superscripts differ for burn status x season of use ($p \leq 0.05$).

3.2. Diet Quality

Diet quality is presented in Table 2. The ash content of diet samples was influenced by neither burn status ($p = 0.12$) nor season of use ($p = 0.57$). Crude protein tended to be influenced by the burn status × season interaction ($p = 0.06$). In June, CP was greater in burned than unburned sites ($p < 0.01$), whereas in September, CP did not differ between burn status ($p = 0.74$). Across burn status, CP was greater in June than September (20.8 vs. 12.2% CP, respectively; $p < 0.01$). Acid detergent fiber tended to be lower in June than in September (44.3 vs. 49.1% ADF, respectively; $p = 0.07$) but did not differ by burn status ($p = 0.23$). In contrast, NDF differed for the interaction between burn status and season ($p < 0.01$). In June, diets at burned sites were lower in NDF than unburned sites ($p < 0.01$). In September, there was no difference in burn status (79.0% NDF); however, both September burn status diets were greater in NDF than June burned diets ($p < 0.01$).

Table 2. Nutrient composition of beef cattle diets on burned and unburned rangeland in June and September at the Red Bluff Research Ranch, southwestern Montana (data from 2021).

Item	June		September		SEM [4]	p-Values [1]		
	B [2]	UB [3]	B	UB		F	S	F × S
Ash (%, DM)	17.2	15.1	16.6	15.9	0.93	0.12	0.57	0.47
CP [5] (% OM)	22.2 [a]	19.3 [b]	12.6 [c]	11.8 [c]	0.55	<0.01	<0.01	0.06
ADF [6] (% OM)	45.9	42.6	49.9	48.3	1.99	0.23	0.07	0.67
NDF [7] (% OM)	62.6 [a]	71.5 [b]	80.0 [c]	77.9 [bc]	2.06	<0.01	<0.01	<0.01

[1] *p*-values for main effects and interaction between burn status (F) and season of use (S); [2] burned sites; [3] unburned sites; [4] pooled standard error of the means presented; [5] crude protein; [6] acid detergent fiber; [7] neutral detergent fiber; [a–c] means within a row that lack common superscripts differ ($p \leq 0.05$).

3.3. Foraging Behavior

Cattle foraging behavior is presented in Table 3. Intake rate and bite rate were influenced by the burn status × season interaction ($p < 0.01$). In June, the intake rate in burned sites was lower than in unburned sites ($p < 0.01$). In September, intake rate was higher than in June burned ($p < 0.01$) but did not differ by burn status (27.6 $g \cdot min^{-1}$; $p = 0.68$). Bite rate was lower in June burned than September burned ($p < 0.01$) but did not differ within June ($p = 0.39$) and tended to differ in September ($p = 0.07$). Bite size tended to be influenced by the burn status × season interaction ($p = 0.08$). In June, bite size was smaller in burned sites ($p < 0.01$), whereas in September, bite size did not differ by burn status ($p = 0.72$).

Table 3. Intake rate ($g \cdot min^{-1}$), bite rate ($bite \cdot min^{-1}$), and bite size ($g \cdot bite^{-1}$) of beef cattle grazing burned and unburned sites in June and September at the Red Bluff Research Ranch, southwestern Montana (data from 2021).

Item	June		September		SEM [4]	p-Values [1]		
	B [2]	UB [3]	B	UB		F	S	F × S
Intake rate ($g \cdot min^{-1}$)	7.93 [a]	23.86 [b]	29.28 [b]	25.82 [b]	2.53	<0.01	<0.01	<0.01
Bite rate ($bite \cdot min^{-1}$)	8.23 [a]	15.83 [ab]	34.33 [c]	22.52 [bc]	3.47	0.11	<0.01	<0.01
Bite size ($g \cdot bite^{-1}$)	1.00 [a]	1.53 [b]	1.00 [a]	1.16 [ab]	0.11	<0.01	0.99	0.08

[1] p-values for main effects and interaction between burn status (F) and season of use (S); [2] burned sites; [3] unburned sites; [4] pooled standard error of the means presented; [a–c] means within a row that lack common superscripts differ ($p \leq 0.05$).

4. Discussion

Beef cattle diets differed between burned and unburned sites across seasons, but the differences were the greatest and most evident in the spring. Cattle preferred forbs on burned sites in the spring [14,25], shifting to a graminoid-based diet in the fall that was largely similar to the diets on unburned sites. Diet composition was reflected in diet quality where diets were higher quality on burned sites. We hypothesize that this was a result of differences in the species composition, quality, and availability of forage in the burned and unburned sites [25]. During the 2021 growing season, the study area was in a severe to exceptional drought [44], and in June, forbs appeared more succulent and abundant than native perennial bunchgrasses. The two primary forbs, dandelion and milkvetch, were present across the study site but were much less abundant on the unburned sites. These forbs were likely higher quality than the perennial bunchgrasses [45], and therefore, cattle selected heavily for them in burned sites (Table 1).

Key grass species (bluebunch wheatgrass, Idaho fescue, needle-and-thread) only comprised 9.34% of the average diets on burned sites whereas they comprised 26.12% of diets on the unburned sites. Lower utilization of key bunchgrass species during the most susceptible stage of plant growth could support low-density spring grazing after a wildfire. The implication from this study and the work performed by Jirik and Bunting [20] is that cattle may be able graze the spring after a wildfire without negatively impacting certain perennial bunchgrass species.

Foraging behavior also differed between treatments. Cattle had smaller bites on burned sites and, in the spring, had a lower intake rate than on unburned sites. In the fall, these differences were less apparent. This may indicate that cattle grazed more selectively on burned sites in the spring, selecting for forbs, allowing them to consume a higher quality diet. This may also be attributed to the greater available forage in the unburned areas due to the accumulation of standing dead material from previous years' growth. In September, cattle had a higher bite rate on unburned sites but had similar intake rates across sites. This may indicate that cattle were grazing less selectively and in the burned sites had to make up for smaller bites due to lower available forage with an increased bite rate. Paired with fall diet quality, these observations may indicate that the nutritional benefit to grazing recently burned rangeland is minimized at the end of the first growing season post-fire [14].

5. Conclusions

We observed that diet quality was improved for cattle grazing during the growing season immediately post-fire. This is likely a result of the high consumption of forbs in the burned areas, greater CP of new growth, as well as the lack of standing dead in the burned areas. Burn status also influenced foraging behavior. In the spring, cattle were able to consume higher quality diets with fewer bites. The botanical composition data also suggest that post-fire, there may be less impact on key bunchgrass species during spring grazing periods.

This experiment was conducted on the foothill rangelands of Southwestern Montana for the first year after a fire. Additional research would be beneficial to investigate the long-term implications of post-fire grazing on changes in botanical composition and plant communities. Additionally, rangelands are diverse, varying in plant composition, topography, geography, and precipitation patterns. Therefore, each rangeland ecosystem should be evaluated for unique responses.

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Institutional Review Board Statement: The animal study protocol was approved by the Agriculture Animal Care and Use Committee of Montana State University (#2020-AA15 on 11 June 2020).

Informed Consent Statement: Not Applicable.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

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