Effects of Fire and Cutting on Vegetation Physical Properties and Herbivorous Foraging Behavior in the Grassland of Bardia National Park, Nepal

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ABSTRACT

Grasslands are critical ecosystems providing habitats and resources for wildlife. This study investigates the effects of grassland management practices, burning and cutting, on grass species composition and physical properties i.e., height and biomass in burned and cut grassland patches in the Bardia National Park (BNP). The study was carried out at Bagaura Phata of BNP. Vegetation assessment was carried out using point intercept method, with 1m² quadrant and vegetation samples were hand separated into different parts (green leaf, green stem, dry leaf and dry stem) to compare the physical properties between burnt and cut plots. Likewise, grazing intensity and pattern was quantified by visual inspection of grazing, pellet group count and direct observation. Species diversity index for herbivores was estimated using Shannon's diversity index. Our findings indicate significant differences in vegetation height between fire-treated and cutting-treated plots. Fire treatment significantly increased grass height, with a mean height of approximately 27.35 cm compared to 23.03 cm in cutting-treated plots. However, no significant disparities were observed in aboveground biomass between the two treatments. Additionally, distinct significant differences were found in the proportion of green leaf and dry leaf between fire-treated and cutting-treated plots, with the proportion of dry leaf being notably lower in fire-treated plots. Correlation analysis showed a negative relationship between grass height and grazing intensity, and between grass height and pellet group counts in both treatment types, indicating that grazing intensity decreases as vegetation height increases. No significant disparities were observed in grazing intensity between cutting and fire treatments. BNP contains more than 60 grass species of different families. There was no difference in the presence of individual grass species but difference between the plots receiving cutting and fire as a treatment- high presence of forbs species in the fire treatment. Desmostachya bipinnata, Narega prophyrocoma and Imperata cylindrica were dominant species in fire treatment plots whereas Vetivera zizanoides was dominant in cutting treatment plots. The study recommend for operations that a combination of burning and cutting to maintain biodiversity and optimize habitat conditions for various herbivores.

Keywords: *Biomass, grazing intensity, height, species composition*

INTRODUCTION

Terrestrial ecosystems dominated by herbaceous vegetation are defined as grassland. Grassland is sometimes defined as an area containing grass and other herbs, with no woody plants or with no more than 10% of the ground covered by these plants (Press *et al.*, 2014). Therefore, any herb-dominated vegetation, herb-dominated savanna or open forest grazed by ruminants, is considered grassland. The size of grasslands, 40.5% of the planet's surface area, excluding Greenland and Antarctica, indicates their significance on a worldwide scale (Suttie *et al.*, 2005). About 1.7 million ha, or about 11.5% of Nepal's total land resources are grasslands (Richard *et al.*, 2000). Grasslands in Nepal are mostly limited to four protected areas in the Terai (Koshi Tappu Wildlife Reserve, Shukla Phata National Park, Chitwan National Park and Bardiya National Park (Peet *et al.*, 1999; Richard, *et al.*, 2000).

Grasslands undoubtedly supply the nourishment for grazing animals and also have a number of crucial tasks, such as serving as biodiversity hotspots, water catchments, cultural and recreational areas, and as a carbon sink to reduce greenhouse gas emissions (Boval & Dixon, 2012). Tropical grasslands/ wooded grassland of Terai Nepal is dominated by perennial grasses especially of family graminoids, which are important habitat for globally threatened species including Swamp deer *(Cervus duvaucelii)*, Hispid hare *(Caprolagus hispidus)*, Bengal florican *(Houbaropsis bengalensis)*, Royal Bengal Tiger *(Panthera tigris tigris)*, Greater one-horned rhinoceros *(Rhinoceros unicornis)*, Asian Elephant *(Elephas maximus)* (Odden *et al.*, 2005; Steinheim *et al.*, 2005), and others mammals such as Wild water buffalo *(Bubalus bubalis)*, Hog deer *(Axis porcinus)* and Swamp deer *(Cervus duvaucelii),* Spotted deer *(Axis axis)* and seasonally for Blue bull *(Boselaphus tragocamelus)* (Wegge *et al.*, 2006). The structure and composition of grasslands are influenced by a variety of variables. The composition of grasslands is influenced by human and natural disturbances including geological, altitudinal, and climatic (Suttie *et al.*, 2005). Livestock grazing, control burning, cutting and other anthropogenic practices have a significant impact on the structure and composition of grasslands (Archibald, 2008).

Fire has been and continues to be an important disturbance in grassland evolution and management (Zedler, 2007). Low intensity burns enhance the availability, palatability, quality and quantity of grass and forest (Archibald *et al.*, 2005; Zedler, 2007). These burns remove dead materials with low nutrient values, while new growth high in protein, phosphorus and calcium becomes readily available. Fire plays a crucial role in recycling organic nutrients and prevents the growth of poor native invasive species, thereby increasing forage production (Archibald, 2008; Kitchen *et al.*, 2009). Additionally, fire significantly increases the biomass percentage of grasses, while reducing that of forbs (Kitchen *et al.*, 2009, Archibald, 2008). The major effects of grassland management on wildlife are indirect and pertain to changes in food and cover by increasing edge effect and number of brows, thereby improving conditions for deer and other wildlife (Wade & Lundsford, 1990). Therefore, to maximize the "edge effect" a mosaic of burnt and un-burnt areas are managed to promote a large and diverse wildlife population (Wade & Lundsford, 1990). A temporary increase in the numbers of Spotted deer *(Axis axis)* and Swamp deer was found after cutting and burning in an *Imperata cylindrica*-dominated grasslands (Moe & Wegge, 1997).

Cutting and burning are regular practices being carried out for the management of grassland in the Bardia National Park (Peet *et al.*, 1999), but it is difficult to trace when it began. Records from the Bardia National Park showed authorized grass cutting started in 1983, six years before the national park was established. Fire has also been used as a management tool; however, in the past uncontrolled burning was also described (Brown, 1997). Fire is generally set at the end of the dry season when grass cutting is completed and is only carried out by park authorities (Brown, 1997).

For archetypal predators like tiger to have a reliable food supply, robust populations of herbivores must be maintained by frequent management of grasslands. Controlled burning is considered the ideal method of managing grasslands, and research by Moe and Wegge (1997) found that grazers prefer burned plots over unburned ones. However, we do not know why herbivores favor freshly burned sites. Therefore, we questioned whether it was physical characteristics of the vegetation or other factors that attract herbivores in freshly burned sites. Despite existing research on the general ecological effects of management strategies in BNP, a critical gap remains in understanding how these strategies specifically impact the physical characteristics of plants and the subsequent grazing pattern of herbivores. This study investigated how burning and cutting practices in BNP influence key plant attributes like biomass, height, and composition. By quantifying these changes and measuring their impact on herbivore grazing patterns, we seek to understand how management strategies shape the plant-herbivore interaction dynamics within this ecosystem. This knowledge will not only fill a critical knowledge gap but also inform management practices and contribute to a broader understanding of plant-herbivore interactions in managed grasslands.

MATERIALS AND METHODS

Study area

Bardia National Park (2801 5'-28'40'N, 81°15'- 81°40'E) occupies 968 km^2 in the far west of the sub-tropical Terai region of Nepal. Bardia National Park (BNP) is located in the south-west of Nepal and is the largest protected area of the Terai, ranging from an altitude of 152 m to 1441 m above mean sea level. The weather is monsoonal and most precipitation occurs between June and September. While the top of the

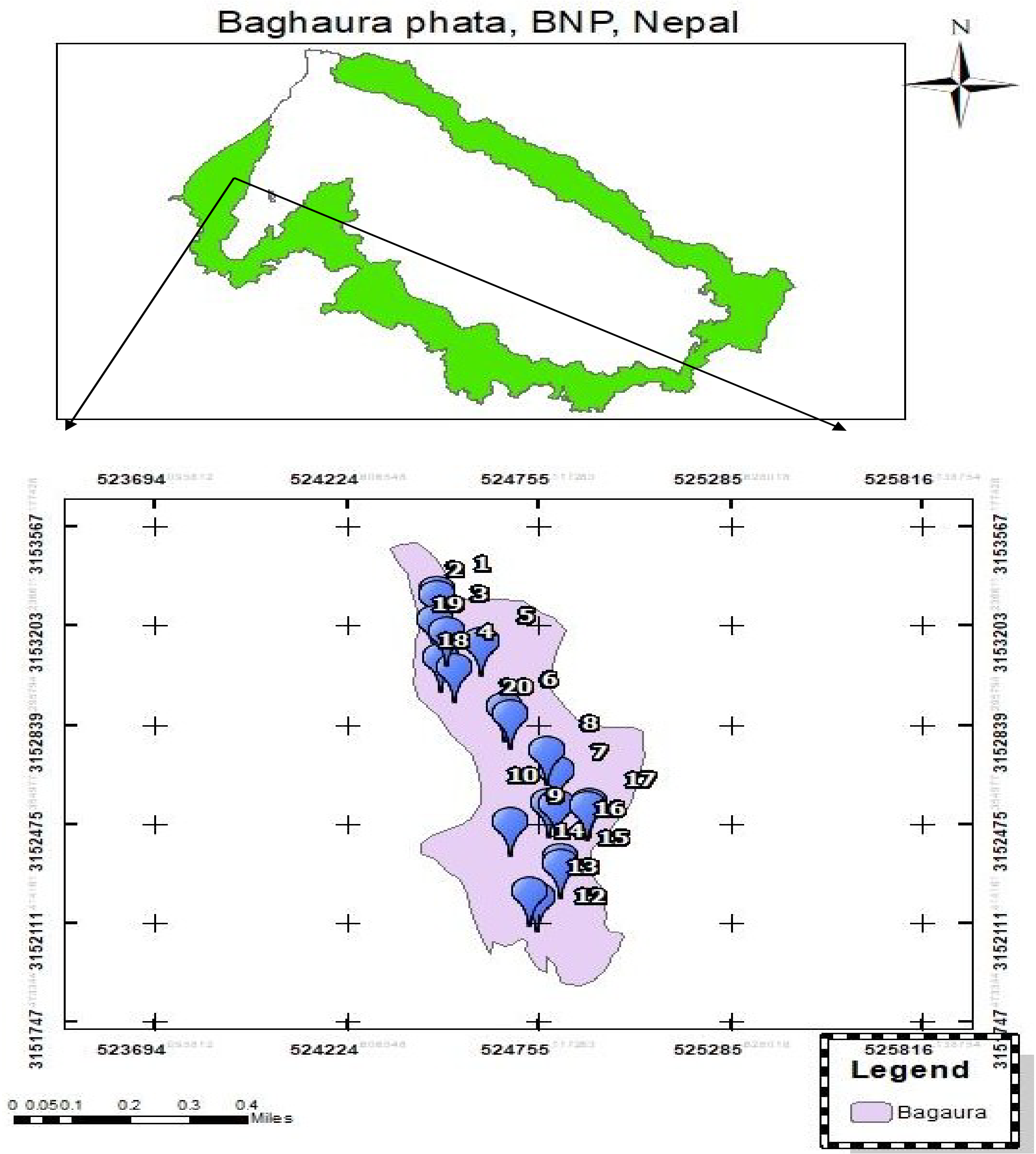

Figure 1: *Study area (Bagaura phata of BNP)*

Churia hills experiences mean annual rainfall of 2230 mm, the south of the park experiences mean annual rainfall of 1560 mm. A cool, dry season lasts from November to mid-February, followed by a hot, dry season until May. The daytime temperatures reach a peak in June at 45°C and fall as low as 10°C in January.

Approximately 70% of the park is dominated by sal *(Shorea robusta)* forest, the remainder being grassland, mixed hardwood forest and riverine forest. The grasslands are concentrated in the south-western corner of the park on the floodplain of the Karnali River. Fifty-four species of mammals occur, including tiger, greater one-horned rhinoceros, swamp deer *(Cervus duvauceli)* and Asian elephant *(Elephas maximus)*. The experiment was conducted in Bagaura phata at BNP (Figure 1), where different management treatments had been applied for a long time.

DATA COLLECTION

Species composition

The experiment was conducted in Bagaura phata at BNP (Figure 1), where different management treatments had been applied for a long time. 20 plots of size 60×60m which included 12- burnt plots and eight plots received cutting treatment. The experimental plots and methodologies used in this study were adapted from the study of Thapa *et al*. (2023a, 2023b). Thapa's research provided the foundation for our study design and data collection procedures (Thapa *et al.*, 2023a, 2023b).

A total of 16 quadrats (1m × 1m in size) were randomly laid down in each plot to have a maximum representation of the area within the plot. The quadrat was further divided into grids of 10×10 cm, hence contained 100 sampling points (Figure 2). Grass species from each sampling point were recorded from the quadrant. In each quadrat, we

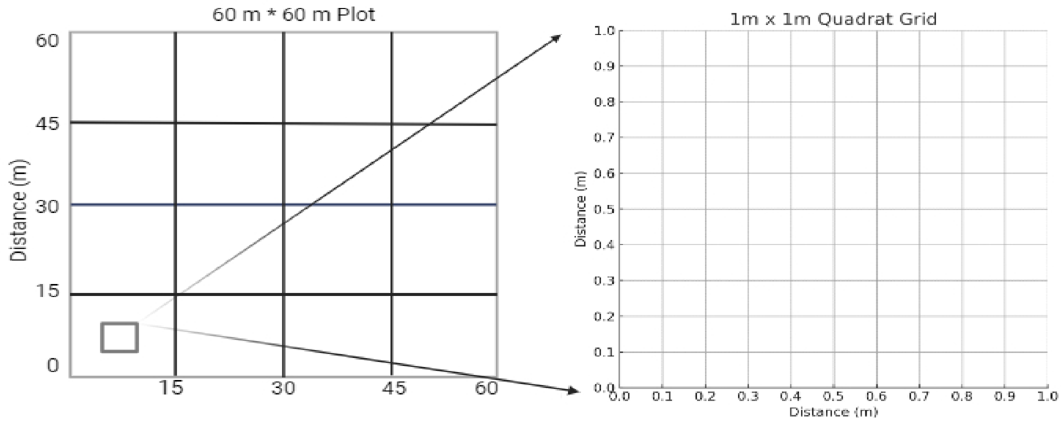

Figure 2: Experimental design showing, 60 m × 60 m plots and the 1m × 1m quadrants with 10 cm × 10 cm grids to measure species composition

employed the point intercept method with 100 sampling points to measure the species composition and dominance cover of various plant species (Goodall, 1952). All together 320 quadrats were laid down in the 20 (60 m×60 m) selected plots. We assessed species composition by listing all species and recording the frequency of hits for each and later calculating the density of each species in each plot. Based on these frequencies, we identified the dominant species in the grassland; the species with the highest number of hits was considered the dominant species.

Grass physical properties

Height: While measuring species composition, grass height was measured using a scale at three random points within each quadrat. To ensure randomness, we selected three plants from different grids within the quadrat. These plants were chosen based on their differing heights to capture a representative average grass height for each quadrat. So, a total of 16 quadrats

a

b

c

d

Figure 3: *Quadrant laid down to measure species composition (a); measuring grass height (b); aboveground biomass sample collection and (c) aboveground biomass sample drying at room temperature*

were randomly laid down in each plot (Goodall, 1952; Thapa *et al.*, 2021a). Altogether 3×16 = 48 grasses were measured from each plot.

Aboveground biomass

After measuring species composition, a grass sample from a 0.5 m x 0.5 m frame within a plot was clipped and measured for fresh weight. The 0.5 m x 0.5 m frame was randomly placed within the plot without considering its position relative to its sides to ensure unbiased and representative of the overall plot.

Leaf and stem proportion

Green leaves and green stems were separated from the collected grass samples and dried at room temperature (~30°C) until a constant weight was achieved. The samples were weighed every day to monitor the drying process. After approximately 7 days, when the samples reached a constant weight, the final dry weight of the green leaves, dead leaves and green stems and dead stems was recorded. The proportion of leaves and stem were calculated by dividing the weight of dry green leaves by the total dry biomass. Similarly, the leaf-to-stem ratio was calculated by dividing the weight of the leaves by the weight of the stems. The proportion of green leaves was calculated by dividing the dry weight of the green leaves by the total dry biomass. Similarly, the proportion of dead leaves was calculated by dividing the dry weight of the dead leaves by the total dry biomass the Additionally, the proportion of green stems and dead stems was calculated similarly by using their respective dry weights (Thapa *et al.*, 2021).

Grazing intensity and grazing pattern by herbivorous

We used pellet groups as a proxy and visual inspection of grazing intensity with 0-4 (0 = no grazing, 1= 25%. 2= 50%, 3= 75%, 4= 100%) range from low to high by visually estimating the extent of bite marks within a quadrat (Sankaran *et al.*, 2005; Thapa *et al.*, 2021b). This grazing intensity was measured within a 1 m×1 m quadrat and later this was used to determine utilization pattern and diversity index in the grassland. Fresh pellets were identified as those of herbivorous species (spotted deer, swamp deer and hog deer) based on morphology of pellet (Hermon & Peres, 2018; Skarin, 2009; Thapa *et al.*, 2022) and counted within 2 m x 2 m quadrats. The 2 m × 2 m areas were measured using a tape rather than using a physical frame, and these measurements were taken 16 times within each 60 m × 60 m plot, which contained 16 quadrats. This was done in a manner similar to the placement of the 1 m × 1 m quadrats, as illustrated in Figure 2. For each quadrat, if fresh pellets of a species were found, I recorded it as one individual of that species. This method assumes that the presence of fresh pellets in a quadrat is indicative of at least one animal of that species being present in that area recently. To estimate the number of animals, we summed the number of quadrats with fresh pellets for each species. For example, if hog deer pellets were found in 5 out of 16 quadrats, we estimated 5 hog deer in the 60 m x 60 m plot. This data, combined with direct animal observations (for large herbivores like elephants and wild boars), was used to calculate the diversity index of herbivores in the grassland.

Data analysis

Grass physical properties (height, aboveground biomass, proportion of green/dry leaf and stem) and grazing intensity by herbivorous were compared between burnt and cutting plots using the Welch Two Sample t-test. This test accounts for potential differences in variances between the groups.

Grazing pattern of herbivores: It was assessed by overall evaluation of grazing intensity and vegetation properties between burnt and cutting plots. Correlations between grass height (vegetation properties) and grazing intensity, and between grass height and pellet group were assessed using Pearson correlation coefficient (r). Lastly, species diversity index for herbivores was estimated using Shannon's diversity index. The Shannon diversity index (H) is a tool commonly used to characterize species diversity in a community. Shannon's index accounts for both abundance and evenness of the present species (Gorelick, 2006).

$$H = -\sum_{i=1}^{s} p_i \ln p_i \quad \ldots\ldots\ldots\ldots\ldots \text{Eq 1}$$

pi = The proportion of species i relative to the total number of species

ln = natural logarithm

The resulting product is summed across species, and multiplied by -1.

All statistical analyses were computed using the R-program, version 4.3.1

RESULTS

Species composition

There was no difference in the abundance of individual species between the plots receiving cutting and fire as treatments. Differences between the fire and cutting treatments resulted primarily from an increase in the species richness of forbs in the fire treatment. An increase in the dominance of *Desmostachya bipinnata*, *Narega prophyrocoma* and *Imperata cylindrica* was observed in the fire treatment whereas *Vetivera zizanoides* was dominant in cutting treatment. The major dominant species in the grassland, identified by their frequency of hits and density, are:

i. *Imperata cylindrical*
ii. *Vetivera zizanioides*
iii. *Desmostachya bipinnata*
iv. *Saccharum spontenum*
v. *Saccharum bengalenses*
vi. *Narega prophyrocoma*

Besides these 66 more grass species of different families were listed during the study (annex). The phata was dominated by grasses belonging to different families including Fabaceae, Poaceae, Cyperaceae, Lamiaceae and Asteraceae (Annex). *Vetivera zizaniodes* was highly preferred by grazers as indicated by high grazing intensity in the cut plots dominated by *Vetivera* than other areas.

Vegetation physical properties

We found noticeable difference in vegetation physical properties in terms of height, aboveground biomass, proportion of green leaf and stem, and dry leaf and stem as shown in Table (1) and Figure (4).

Based on our study, significant variations were observed in vegetation physical properties across fire and cutting treatments (Table 1). Specifically, fire treatment resulted in significantly taller grasses compared to cutting, highlighting its effectiveness in promoting greater vegetation growth within grassland ecosystems. Conversely, while biomass differences were noted between treatments, statistical analysis indicated no significant variation in fresh biomass. The proportion of green leaves showed a substantial difference, with cutting treatments exhibiting higher proportions compared to fire treatments. However, no significant difference was found in the proportion of green stems between treatments. Furthermore, the proportion of dry leaves and stems differed significantly between fire and cutting treatments, underscoring the varied ecological impacts of these management strategies.

Table 1: *Physical properties of vegetation under different treatments (fire and cutting)*

Vegetation properties	Treatments (mean, cm)		Welch Two Sample T-test			
	Fire	Cutting	t- value	df	p-value	95% Confidence Interval
Height	27.35	23.030	2.967	315.69	0.003	(1.454, 7.182)
Fresh biomass	131.559	156.471	-1.307	17.993	0.207	(-64.940, 15.116)
Green leaf proportion	0.450	0.620	-3.449	17.545	0.002	(-0.272, -0.065)
Dry leaf proportion	0.090	0.202	-2.359	17.37	0.030	(-0.212, -0.012)
Green stem proportion	0.116	0.101	0.421	17.602	0.678	(-0.061, 0.092)
Dry stem proportion	0.344	0.078	3.773	14.628	0.001	(0.115, 0.415)

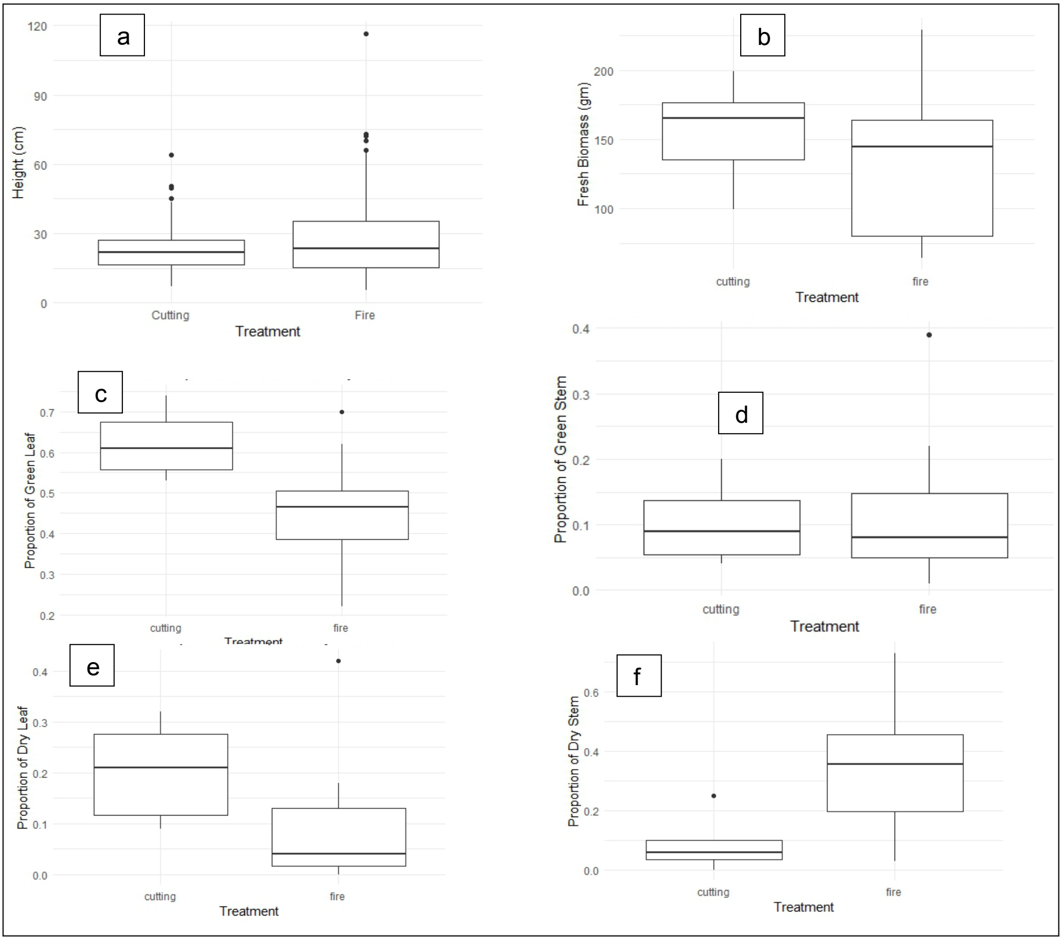

Figure 4: *Comparison between cutting and fire treatment for height (a), biomass (b), proportion of green leaves (c), proportion of green stem (d), proportion of dry leaves (e), proportion of dry stem (f).*

Grazing intensity and herbivorous grazing pattern in different treatment plots

The Welch Two Sample t-test was conducted to compare the average grazing intensity between the "Cutting" and "Fire" treatments. Results revealed no statistically significant difference in grazing intensity between the two treatments ($t = -0.54986$, $df = 282.61$, $p = 0.5828$). The 95% confidence interval for the difference in means ranged from -0.2987891 to 0.1683081, encompassing zero, suggesting no significant disparity between treatments. Mean grazing intensities were 1.960938 for "Cutting" and 2.026178 for "Fire." These findings imply comparable effects of "Cutting" and "Fire" treatments on grazing intensity. As higher density of pellet group of spotted deer was observed in burnt plots, the most abundant spotted deer in BNP was found in burnt plots compared to plots with cutting treatment.

The correlation calculated between grass height and grazing intensity in grazing lawns with both treatments resulted negative value i.e., r = -0.348 and -0.46 for cutting and fire, respectively (Figure 5), which means grazing intensity decreases with increased vegetation height. Similarly, we found a moderate negative relationship between average grass height and pellet group count ($r = -0.22$, $p < 0.05$) in the cutting treatment, and a similar negative relationship ($r = -0.17$, $p < 0.05$) in the fire treatment, indicating that as grass height increases, pellet group counts tend to decrease (Figure 6).

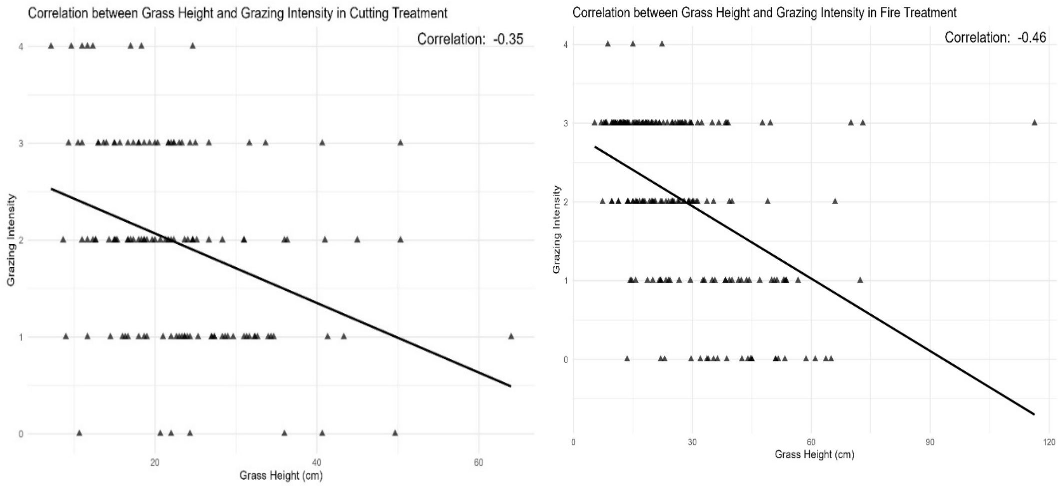

Figure 5: *Correlation between grass height and grazing intensity in cutting and fire treatment.*

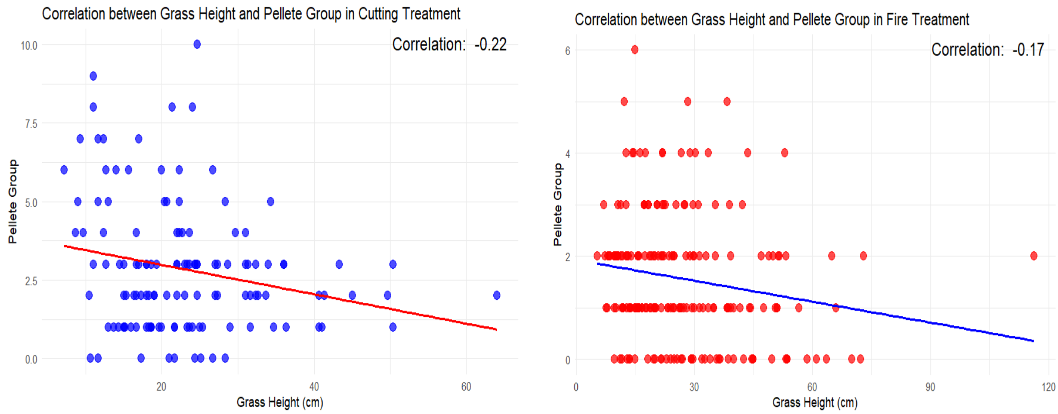

Figure 6: *Correlation between grass height and Pellet group in cutting and fire treatment.*

Grazers diversity index

Based on the presence-absence method for pellet counts and direct animal observations, we estimated the number of herbivores in the grassland. Fresh pellets of various herbivorous species were identified and recorded within each 2 m x 2 m quadrat. The Shannon diversity index was computed to assess species diversity in the Baghaura Phata of BNP, based on data collected through pellet count and direct observation. A total of 434 individuals were observed, comprising 24 elephants, 321 spotted deer, 72 sambars, 6 hog deer, and 11 wild boars. The calculated Shannon diversity index, indicative of species richness and evenness, yielded a value of 0.834.

DISCUSSION

Species composition

Grassland management practices within Bardia National Park demonstrably altered vegetation composition, as evidenced by differences in dominant species between fire and cutting treatments. This study supports previous findings by Peet *et al.* (1999) and expands upon them by identifying specific dominant species under each regime (fire: *Imperata cylindrica, Desmostachya bipinnata, Narega prophyrocoma;* cutting: *Vetivera zezonoides*) and quantifying the increase in forb diversity with fire. While five key grass species, *Imperata cylindrica, Saccharum spontaneum, Vetiveria zizanioides, Desmostachya bipinnata* and *Schizachyrium brevifolium* contribute significantly to overall cover in the study area which directly aligns with the finding from Peet *et al.* (1999). Over time, the recurrence and large magnitude of fires can lead to the gradual disappearance of grassland patches and species suitable for grazing animals (Archibald *et al.*, 2005). Moreover, large-scale fires at the landscape level may have negative consequences for small mammals, wildlife, and bird species that depend on grassland habitats (Peet *et al.*, 1999).

Vegetation physical properties

Our study revealed significant differences in vegetation height between fire-treated and cutting-treated plots, with fire treatment resulting in taller plants. However, no significant difference was observed in the aboveground biomass between the two treatment types. In contrast to the findings reported by (Sibanda *et al.*, 2017) our analysis did not reveal a significant difference in aboveground biomass between the two treatment types. Our study identified a higher proportion of green leaf biomass in plots subjected to cutting treatment, indicating a potential influence on the vegetation's physiological state. This observation suggests that the cutting treatment contributes to the maintenance of a higher proportion of green, photosynthetically active leaf material compared to fire treatment. It is plausible that the fire treatment could lead to the consumption of a substantial portion of available biomass, including green leaf material, as supported by insights from previous studies (Archibald, 2008; Kauffman *et al.*, 1994). Additionally, the statistically higher proportion of dry stem biomass in plots subjected to fire treatment aligns with the documented impact of fire on reducing the moisture content in plant tissues, favoring the accumulation of dry biomass (Archibald, 2008; Kauffman *et al.*, 1994). Similarly, the height growth was found significantly higher in burned plots compared to cut plots. This can be because dead materials, low in nutrient value, are removed while new growth high in protein, phosphorus and calcium becomes readily available as fire plays a dominant role in recycling the organic nutrients (Kauffman *et al.*, 1994; Thapa *et al.*, 2022).

Grazing intensity and herbivorous grazing pattern in different treatment plots

Our study found no significant difference in grazing intensity between fire-treated and cutting-treated plots, despite initial higher grazing in fire-treated plots, likely due to higher protein content in the early post-treatment period. Studies from the African savannas have reported that green leaf is considered of high-quality forage for herbivores and proportion of leaf over stem is a determinant for the selection of patches for grazing by the grazing herbivores (Archibald, 2008). Despite the observed higher proportion of green leaf in cutting treatments and increased dry stem content in fire treatments, indicating cutting treatments potentially provide favorable foraging conditions for herbivores, our study did not find a significant difference in grazing intensity between the two treatments. This discrepancy may be attributed to the relatively short duration of the study, spanning only four months post-treatment application. However, it is noteworthy that grazing intensity was initially higher in fire-treated plots compared to cutting-treated plots during the first few months, likely due to the higher protein content in burnt areas during the early post-treatment period which aligns with the findings of Drescher *et al.* (2006), Moe and Wegge (1997), Thapa *et al.* (2023a, 2023b). While the magnet effect of burned grasslands initially attracts grazers from unburned patches, this attraction may diminish over time due to a lower proportion of green leaf and a higher proportion of dry stem in fire plots (Archibald *et al.*, 2005; Thapa *et al.*, 2022; Wegge *et al.*, 2006). The significantly higher grass height observed in fire-treated plots may contribute to decreased grazing intensity and pellet count, grasses in fire-treated plots grow taller at a faster rate, rendering them less palatable to herbivores over time.

In both fire and cutting treatments, there is a negative correlation observed between grass height and grazing intensity and between grass height and pellet group, indicating that as grass height increases, grazing intensity decreases which is supported by the finding from (Archibald *et al.*, 2005; Thapa *et al.*, 2022) where grazers density being inversely related to vegetation height, notably decreasing when grass surpassed 10-15 cm. When grazing intensity decreases, the vegetation might attain its maximum height and maturity which are not preferred by the grazers which intern may convert into tall grassland patches (Karki *et al.*, 2000). Tall grassland patches created by fire treatment, despite having high biomass, are not utilized by herbivores due to their low nutrient concentration and patchy nature of grassland distribution further exacerbates this phenomenon, as herbivores disperse to other areas in search of more suitable forage within palatable height to meet their metabolic requirements (Archibald, 2008; Thapa *et al.*, 2023a, 2023b). Similarly, our findings suggest that while fire treatment initially enhances grassland quality, long-term management strategies should integrate spatial and temporal cutting practices along with fertilizer application to maintain optimal forage quality and herbivore utilization as suggested by (Thapa *et al.*, 2023a, 2023b). Also, our field study showed that mowed plots having *Vetivera zizaniodes* dominant were highly grazed than other areas, indicating *Vetivera zizaniodes* is highly preferred by grazers.

Park managers are managing grassland to produce quality forage for wild herbivores. Grazing land has the potential to significantly aid in sustaining or possibly increasing the population of wild ungulates that rely on grasslands, like chital (*Axis axis*), which are key prey for the endangered Royal Bengal Tiger (*Panthera tigris*) in Bardia National Park (Thapa *et al.*, 2021a). The study area is the highly used grassland in the core area of the park dominated by deer population. The tall grass prevalent in the study area offers abundant vegetation, yet of lower nutritional quality, which is less advantageous for smaller and medium-sized herbivores like deer. These herbivores, unlike larger roughage feeders observed, such as greater one-horned rhinoceros (*Rhinoceros unicornis*), and Asian elephants (*Elephas maximus*), have distinct forage requirements influenced by their body size and digestive physiology (Pradhan *et al.*, 2008; Thapa *et al.*, 2021b). One-horn rhinos exhibited a preference for grass over browsing throughout all seasons, consuming a higher ratio of grass to browse compared to elephants (Pradhan *et al.*, 2008). Both rhinos and elephants consume floodplain grass *Saccharum spontaneum* (Pradhan *et al.*, 2008), which is dominated in fire treatment. Considering these dynamics, objective park management should carefully consider when and which management practices to employ while managing grasslands. Simultaneous or alternating application of both fire and cutting treatments in different patches and seasons may result in continuous and moderate grazing, maintaining ecological and economic sustainability while preserving heterogeneity in plant and animal species composition.

This study highlights the temporal and spatial heterogeneity of disturbance, which increases variability in vegetation structure and subsequently affects higher trophic levels. The quantity, quality, and heterogeneity of resources and disturbances influence consumer diversity, plant productivity, composition, and diversity, ultimately affecting higher trophic levels. Therefore, implementing both fire and cutting treatments simultaneously or alternately can help maintain this heterogeneity, resulting in greater overall biodiversity and ecosystem resilience. Further long-term research is needed to investigate the nutritional and chemical makeup of grasses in different treatments to fully understand herbivorous grazing behavior and its implications for grassland management and ecosystem dynamics.

CONCLUSION

In conclusion, our study provides valuable insights into the effects of fire and cutting on vegetation physical properties and herbivorous foraging behavior in the grasslands of Bardia National Park, Nepal. Through comprehensive field observations and data analysis, we found significant differences between fire-treated and cutting-treated plots in terms of vegetation height, biomass, and composition. Fire treatment resulted in significantly taller grassland heights compared to cutting treatment, indicating a distinct impact on vegetation growth dynamics. However, we did not observe significant differences in aboveground biomass between the two treatments. Furthermore, fire treatment led to alterations in the proportion of green and dry leaf and stem, highlighting the ecological effects of prescribed burning on grassland vegetation. Despite these differences in vegetation properties, our study did not find significant disparities in grazing intensity between fire and cutting treatments. However, we observed a negative correlation between grass height and grazing intensity, suggesting that taller vegetation may deter herbivorous foraging behavior. The species composition analysis revealed shifts in dominant grass species between fire and cutting treatments, with an increase in forb diversity in fire-treated plots. These findings underscore the importance of considering both fire and cutting as management tools to maintain biodiversity and ecosystem resilience in grassland ecosystems. Overall, our study highlights the complex interactions between management practices, vegetation dynamics, and herbivore behavior in Bardia National Park. The insights gained from this research can inform sustainable grassland management strategies and contribute to the conservation of biodiversity in protected areas. Further long-term studies are warranted to assess the long-term effects of fire and cutting on vegetation dynamics and herbivore populations in grassland ecosystems.

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Annex: Grass species listed

Grass and forbs species observed and listed at Phata are:

SN	Grass or forbs species	Family	SN	Grass or forbs species	Family
1	*Hemartharia compressa*	Poaceae	34	*Desmidium gangeticum*	Fabaceae
2	*Arundo donax*	Poaceae	35	*Luzula multiflorum*	Juncaceae
3	*Axonopus compressus*	Poaceae	36	*Artimisia spp*	Asteraceae
4	*Blumea wightiana*	Asteraceae	37	*Flemingia macrophylla*	Fabaceae
5	*Brachiaria deflexa*	Poaceae	38	*Conyza bonariensis*	Asteraceae
6	*Cynodon dactylin*	Poaceae	39	*Conzya canadensia*	Asteraceae
7	*Rajia parviflora*	Poaceae	40	*Crotolaria medicagine*	Fabaceae
8	*Ageratum houstoniaum*	Asteraceae	41	*Cyperus brevifolius*	Cyperaceae
9	*Ageratum conyzoides*	Asteraceae	42	*Ageratum conyzoides*	Asteraceae
10	*Cynoglossum spp*	Boraginaceae	43	*Ageratum houstonianum*	Asteraceae
11	*Oxalis spp*	Oxalidaceae	44	*Alternanthera bettzickiana*	Amaranthaceae
12	*Euphorbia spp*	Euphorbiaceae	45	*Alternanthera paronychioides*	Amaranthaceae
13	*Pogostemon benghalensis*	Lamiaceae	46	*Alysicarpus species*	Fabaceae
14	*Circium wallich*	Asteraceae	47	*Acalypha indica*	Euphorbiaceae
15	*Clerodendrum spp*	Lamiaceae	48	*Achyranthes aspera*	Amaranthaceae
16	*Flemengia microfilia*	Fabaceae	49	*Aerva javanica (Burm.f.) Schult*	Amaranthaceae
17	*Ziziphus mauritiana*	Rhamnaceae	50	*Aeschynomene indica L.*	Fabaceae
18	*Occium spp*	Lamiaceae	51	*Alternanthera bettzickiana.*	Amaranthaceae
19	*Cyprus spp*	Cyperaceae	52	*Alysicarpus longifolius* *Alysicarpus bupleurifolius*	Fabaceae Fabaceae
20	*Desmodium spp*	Fabaceae	53	*Alysicarpus monilifer*	Fabaceae
21	*Eryngium foetidum*	Apiaceae	54	*Alysicarpus ovalifolius*	Fabaceae
22	*Caesulia axillaris rox*	Asteraceae	55	*Alysicarpus vaginalis*	Fabaceae
23	*Diplozium esculentum*	Dipteridaceae	56	*Anagallis arvensis*	Primulaceae
24	*Youngia japonica*	Asteraceae	57	*Argemone Mexican*	Papaveraceae
25	*Alternanthera sessilis*	Amaranthaceae	58	*Brachiaria erusiformis*	Poaceae
26	*Lepidagathis incura*	Acanthaceae	59	*Brachiaria ramose*	Poaceae
27	*Crotolaria species*	Fabaceae	60	*Brachiaria reptans*	Poaceae
28	*Desmodium multiflorum*	Fabaceae	61	*Cassia tora*	Fabaceae
29	*Brachiaria villosa*	Poaceae	62	*Conyza bonariensis*	Asteraceae
30	*Phyllanthus niruri*	Phyllanthaceae	63	*Cyperus brevifolius*	Cyperaceae
31	*Colebrookea oppositiafolia*	Lamiaceae	64	*Crotalaria medicaginea*	Fabaceae
32	*Ocimum basilicum*	Lamiaceae	65	*Cyperus difformis*	Cyperaceae
33	*Pogestemon bengalensis*	Lamiaceae	66	*Desmidium gangeticum*	Fabaceae