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**Research Article**

# IMPACTS OF LIVESTOCK GRAZING ON VEGETATION AND SOIL IN LOWLAND GRASSLAND ECOSYSTEM OF NEPAL

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## ABSTRACT

Livestock grazing is one of the largest sectors for land use globally, and contrasting impacts (negative, neutral, and positive) of livestock grazing on vegetation and soil have been observed. In Koshi Tappu Wildlife Reserve (KTWR), livestock grazing is one of the major problems but has been feebly addressed in previous research. This study, therefore, aims to determine the impacts of livestock grazing on vegetation and soil quality in grasslands of core and buffer zones of KTWR. Less grazing intensity was observed at the core zone compared to the buffer zone. Livestock grazing was observed with negative impacts on the richness and diversity of the plant species causing changes in the community assemblages. Invasive plant species richness, however, was found higher in the low grazed areas. Differences in soil pH, phosphorus, and potassium content between high and low grazed areas were not observed. In contrast, soil electrical conductivity, bulk density, and nitrogen content were significantly higher in the high grazed areas. Controlled grazing is recommended at buffer zone grasslands of KTWR to enhance plant diversity and nutrient availability. The core areas of the reserve should be managed for reducing the abundance and distribution of invasive alien plant species.

**Keywords**: Grazing, plant diversity, plant richness, soil characteristics

## INTRODUCTION

Livestock rearing has been an integral part of human civilization (Mayer *et al.*, 2006). It is a largest sector for land use globally (Herrero & Thornton, 2013). Excessive grazing is identified as one of the key disturbances leading to grasslands degradation and soil carbon loss (Jeddi & Chaieb, 2010). Change in vegetation due to the grazing beyond carrying capacity alters plants composition which could cause reduction in species richness and diversity (Rigi & Fakhire, 2014). The magnitude and direction of the effects of herbivores on plant communities are variable and influenced by grazing management (Vesk & Westoby, 2001). Furthermore, grazing intensity has the potential to modify soil structure, function and capacity to store soil organic carbon (SOC) and could significantly change grassland C stocks (Cui *et al.*, 2005). As SOC has a major influence on soil physical structure and a range of ecosystem services (e.g., nutrient retention, water storage, pollutant attenuation), its reduction could lead to reduced soil fertility and consequently, land degradation (Rounsevell *et al.*, 1999). Overgrazing severely reduces grassland productivity, vegetation cover, and the proportion of forage grasses (Wang *et al.*, 2016), which increases the risk of soil erosion and desertification (Zhou *et al.*, 2010).

Livestock grazing is affecting grassland and forest ecosystems of Nepal (Thapa *et al.*, 2016; Aryal *et al.*, 2015; ICIMOD, 2014; Bhattarai & Kindlmann, 2012; Pokharel, 2005). DFRS (2015) showed that nearly two-thirds of the total forest area in Nepal is affected by livestock grazing. Despite having enormous grazing pressure in the ecosystems, the underlying impacts of livestock grazing on the ecosystems, especially in the grasslands of Nepal are feebly known (Bhattarai & Kindlmann, 2012). Moreover, though there are few studies concentrated in hilly and mountainous regions, quantification of the impacts of grazing in lowland protected grasslands are very limited. This study is based on the hypothesis that the uncontrolled livestock grazing decreases vegetation diversity and richness and reduces the soil nutrient availability in Koshi Tappu Wildlife Reserve (KTWR). This study, therefore, aims to determine the impacts of livestock grazing on vegetation and soil quality of lowland protected area, i.e., KTWR of eastern Nepal, where livestock grazing has become major issue in biodiversity conservation.

## MATERIALS AND METHODS

### Study Area

The KTWR is the first Ramsar site and the only wildlife reserve in Nepal. It lies at the bank of Sapta Koshi River bordering Sunsari, Saptari and Udayapur districts of eastern Nepal (Fig. 1), covering an area of 175 $km^2$ and additional buffer zone of 173.5 $km^2$. The reserve is characterized by sandy and silty soils with patches of scrub and mixed deciduous riverine forest scattered on the high ground. It has a subtropical climate and the topography ranges from 75–100 m asl. The KTWR was gazetted in 1976 mainly to conserve habitat for the remaining population of Wild Water Buffalo (*Bubalus arnee*). The other grazers in KTWR include Blue bull (*Boselaphus tragocamelus*), Hog deer (*Axis porcinus*) and Spotted deer (*Axis axis*) (KTWR, 2018). Grassland is the dominant land cover of the reserve largely determined by frequent shifting of Koshi River course that constitutes approximately 53% followed by forest (10%), riverbank and river (37%) (KTWR, 2018). The grassland at KTWR is dominated by *Calopogonium* sp., *Nephrolepis* sp., *Lantana* sp., *Cyperus* sp., *Phragmites* sp., *Carex* sp., *Sagina* sp., *Eurya* sp., *Cynodon* sp., *Vetiveria* sp., *Stellaria* sp., *Sambucus* sp., *Polygonum* sp., *Rumex* sp. and others (ICIMOD, 2014). Livestock rearing is one of the major economic activities in KTWR (ICIMOD, 2014). Large numbers of domestic bovines are also seen in the core area of the reserve.

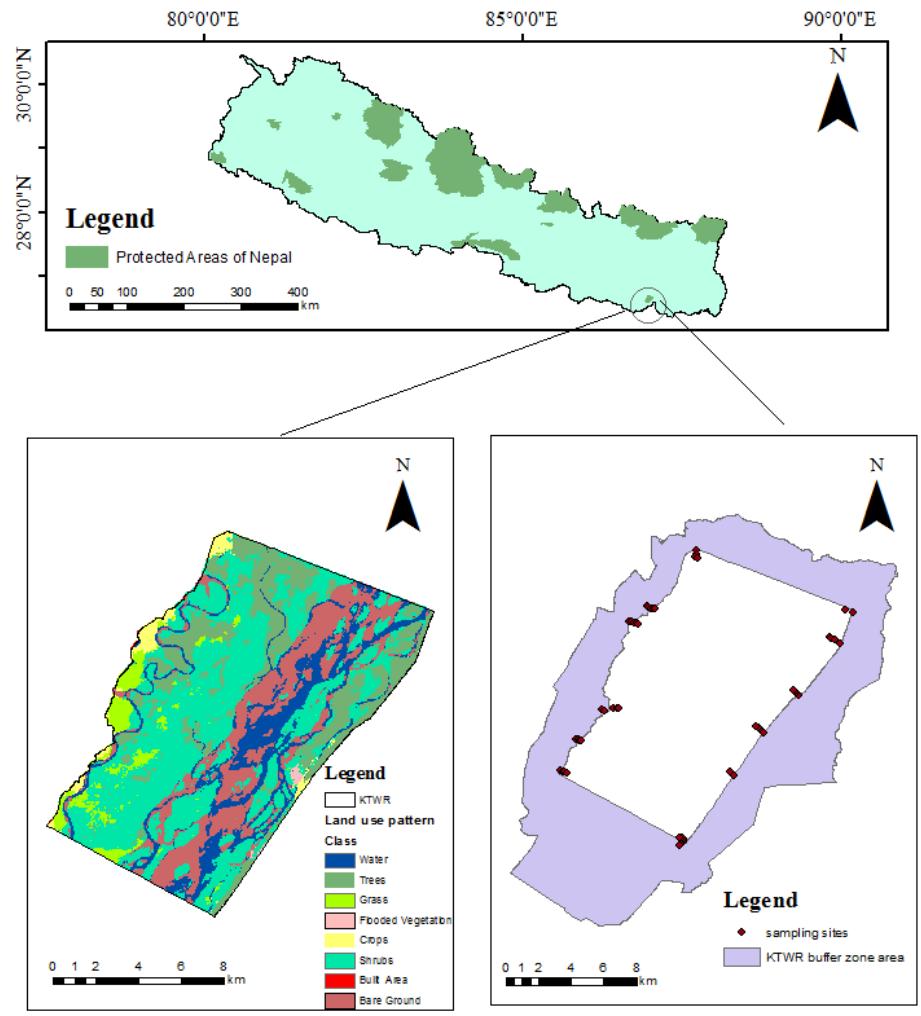



**Figure 1. Location map of the study area**

**Data Collection**

Field study was carried during pre-monsoon season, 2019. Two core-buffer border lines of KTWR as main transects (one at Sunsari area: eastern border, and other at Saptari-Udaypur area: western border) were considered for the study. Each border line was 17 km long. At each of the transects, systematic sampling was carried by making sub transects of 1 km perpendicular to the 17 km transect (500 m outward buffer zone and 500 m inward the core area from the line) at each 3 km. The sampling plots were arranged alternately in 100 m intervals**.** However, in some places due to conversion of buffer zone area into agricultural land by the local people, sampling was done from the feasible sites only. Similarly, in some sites, sampling was not possible due to Koshi River resulting in unequal numbers (among 49, 32 plots in core and 17 plots in buffer zone) of sampling plots.

Total 49 plots were studied in which 32 were from core zone and 17 from buffer zone. GPS location of each sampling quadrat was noted with the help of Garmin eTrex GPS. Vegetation sampling was done by using 20 m × 25 m quadrat. Trees (DBH > 10 cm) were counted within the quadrat of 20 m × 25 m. Saplings (DBH 5-10 cm) and shrubs were counted from nested 5 m × 5 m quadrats at two diagonal corners of the 20 m × 25 m quadrat. Similarly, seedlings (DBH < 5 cm) and herbs were counted (colony was counted for clonal plants) from the 1 m × 1 m quadrats at two diagonal corners of the 20 m × 25 m plot. Unidentified plant species plants were collected by preparing herbarium and identified at National Herbarium and Plant Laboratory, Godawari, Lalitpur, Nepal. Soil samples were collected by making composite samples from the four corners and the center of the 20 m × 25 m quadrat. Single soil samples were collected from 0-15 cm depth (Timsina *et al.*, 2010) by using soil auger. The soil samples were air dried in shade and stored in airtight bags. For determining population density of livestock, fecal count method was used (Lioy *et al.*, 2015) in which, the fecal pellet count within the sampling plot was used. The dung of the cattle and pellets of goat were counted within the quadrat of 20 m × 25 m.

**Laboratory Analysis**

The physico-chemical parameters of soils were analyzed in the laboratory of Central Department of Environmental Science, Tribhuvan University. Soil parameters were determined from the air-dried soil samples following standard laboratory procedures. Soil pH and electrical conductivity (EC) were determined using calibrated pH meter and conductivity meter (1: 5 soil water ratio, Wagtech pH Meter and JENWAY Conductivity Meter respectively). Soil bulk density was measured by using the soil corer method (Blake & Hartage, 1986). Similarly, total nitrogen (nitrate and ammonia) was determined using the Kjeldahl method (Bremner & Mulvaney, 1982). Soil organic matter (SOM) was measured using Walkley-Black method (Walkley & Black, 1934). Available phosphorus and available potassium were measured using Modified Olsen's Bicarbonate Method (Olsen *et al.*, 1954) and Microcontroller Flame Photometer (LABTRONICS, Model: LT-671, India), respectively. For extracting potassium from the soils ammonium acetate solution was used.

**Data Analysis**

Shannon diversity and total richness for plants were determined for both high grazed and low grazed areas. The regeneration status (good, fair, poor, no regeneration and new regeneration) of the sampled species was assessed based on Shankar (2001). Grazing intensity was determined by calculating dung and pellet count of the animals and multiplying by the livestock unit equivalent given by Bedunah and Schmidt (2000). The unit equivalents for cattle, horse, sheep and goat are 6, 7, 1 and 0.9, respectively. Since different types of livestock consume different amounts of forage, and livestock at KTWR were cattle and goats, the total intensity of grazing was determined by a standardized livestock number using total grazing intensity = number of dung groups × 6 + number of pellet groups × 0.9. The grazing intensity was calculated in the unit, animal unit per hectare (AU $ha^{-1}$). Statistical analysis was carried in R, version 3.5.1 (R Core Team, 2018). The Shapiro-Wilk test was used to determine normality in the data. If the data were normal, Student's t test was used to determine the significant difference between two data sets i.e., if the parameters like plant richness, diversity and soil characteristics were different in high grazed and low grazed areas. Otherwise, Mann–Whitney U test was applied. Shannon diversity and observed richness were calculated using vegan package in R (Oksanen *et al.*, 2017). The differences in the vegetation composition between high grazed and low grazed area was determined by permutational multivariate analysis of variance (PERMANOVA) on Bray distance created using adonis function in the vegan package in R (Oksanen *et al.*, 2017). Figures were plotted using ggplot2 package (Wickham, 2016).

## RESULTS

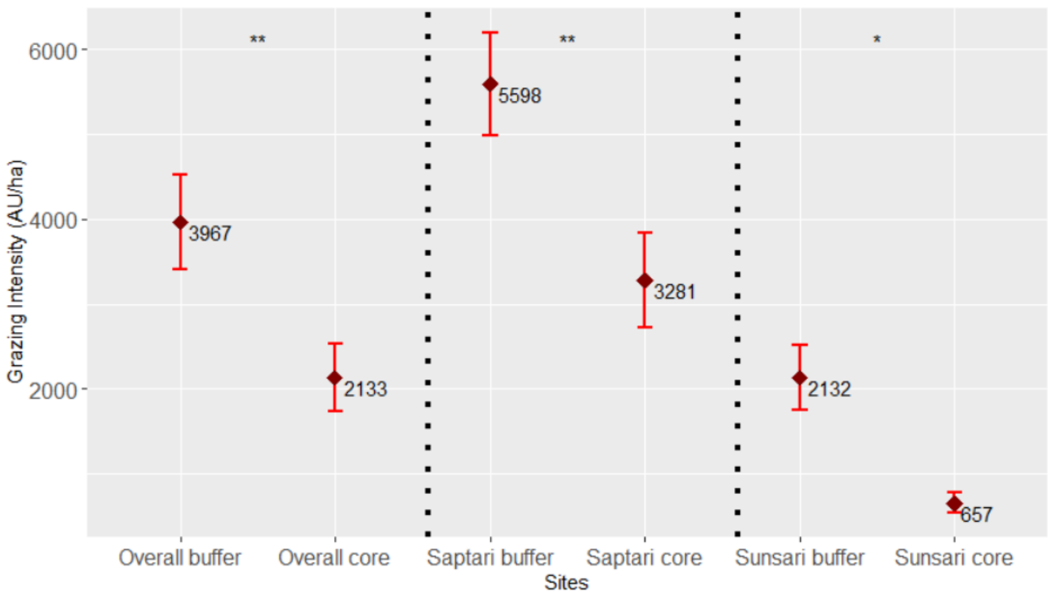
**Grazing Intensity at Core and Buffer Zone of KTWR**

Grazing intensity was significantly higher at buffer zone in both Sunsari transect ($p < 0.05$) and Saptari-Udaypur transect ($p < 0.01$), 2132 ± 385.72 AU $ha^{-1}$ and 5598 ± 605.13 AU $ha^{-1}$, respectively, in buffer zone compared to core zone (Fig. 2). The grazing intensity of core zone of Sunsari and Saptari-Udaypur transects were 657 ± 117.63 AU $ha^{-1}$ and 3281 ± 558.85 AU $ha^{-1}$, respectively (Fig. 2). In overall, low grazing intensity ($p < 0.01$) was observed at the core zone of KTWR i.e., 2133 ± 391.84 AU $ha^{-1}$ than in buffer zone which was 3967 ± 560.88 AU $ha^{-1}$ (Fig. 2). Since the core zone at KTWR was found to have lower grazing intensity than the buffer zone, the core zone was categorized as low grazed area and the buffer zone was categorized as high grazed area. Following this observation, other parameters were analyzed comparing core and buffer zone of KTWR as low grazed and high grazed areas, respectively.

In total, 80 herb species of 33 families, 14 shrub species of 9 families and 8 tree species of 5 families were found during the study. Among them, 11 plant species, viz. *Ageratum conyzoides* L., *Amaranthus spinosus* L., *Bidens pilosa* L., *Sena tora* (L.) Roxb, *Chromolaena odorata* L., *Mikania micrantha* Kunth., *Mimosa pudica* L., *Parthenium hysterophorus* L., *Argemone mexicana* L., *Ipomoea carnea* Jacq. and *Lantana camara* L. observed were invasive alien plant species to Nepal.

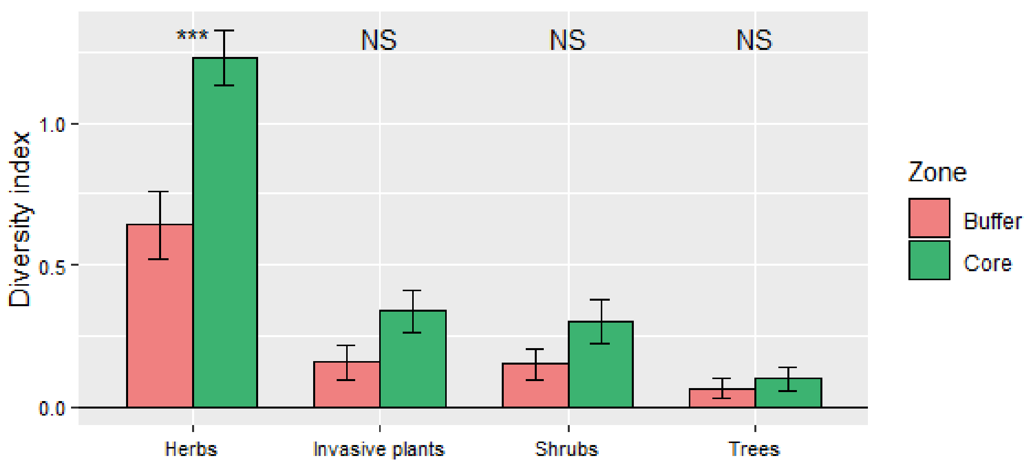
**Vegetation Composition and Diversity**

The results showed significant difference in the species composition of herb ($p < 0.05$) and tree ($p < 0.01$) communities between core and buffer zones of KTWR, but shrub species composition and invasive plant species composition were however not significantly different (Table 1). Herb species diversity at core zone of KTWR (low grazed area) (1.23 ± 0.10) was found to be higher ($p < 0.001$) than at buffer zone (high grazed area) (0.64 ± 0.12) (Fig. 3). However, significant difference was not observed in the diversity of shrubs, trees and invasive plant species between core zone and buffer zone of KTWR (Fig. 3).




*Note: significance: *p < 0.05, **p < 0.01, ***p < 0.001; NS = not significant*

**Figure 2. Grazing intensity at core zone and buffer zone of KTWR**



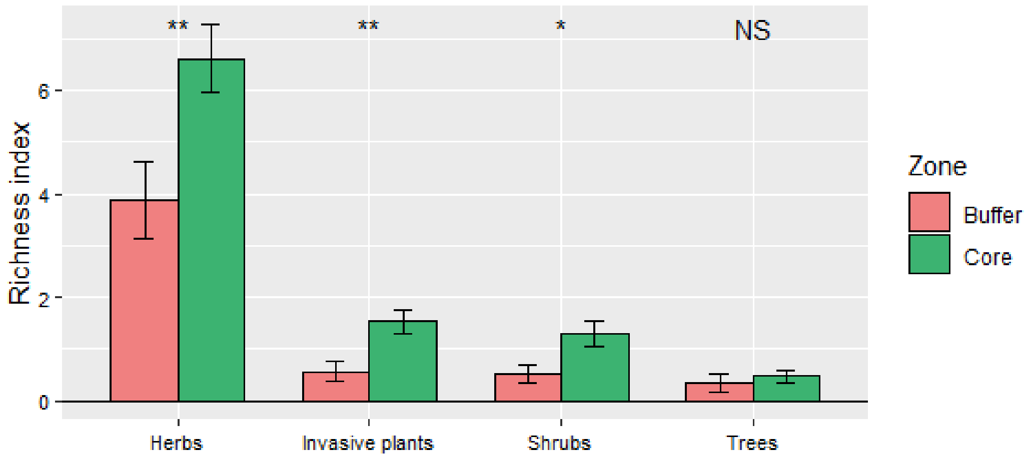

*Note: significance: *p < 0.05, **p < 0.01, ***p < 0.001; NS = not significant*

**Figure 3. Species diversity at core zone and buffer zone of KTWR**

Herb species richness at core zone of KTWR (6.61 ± 0.65) was found higher (Fig. 4) (p = 0.01) than at buffer zone (3.89 ± 0.75). Similarly, shrub species richness at core zone of KTWR (1.31 ± 0.25) was also found to be higher (p < 0.01) than at buffer zone (0.53 ± 0.18) (Fig. 4). However, significant difference was not observed in the richness of trees between core zone and buffer zone (Fig. 4). In contrast, high richness (p < 0.01) of invasive species was observed in core zone (1.53 ± 0.27) compared to buffer zone (0.56 ± 0.19).

**Regeneration Status of Tree Species**

Saplings were not observed in any plots during the study. However, 5 seedling species were observed. Four seedling species (*Dalbergia sissoo, Trewia nudiflora, Syzygium cumini, Litsea monopetala*) were observed in core zone whereas 3 seedling species (*Dalbergia sissoo*, *Leucaena leucocephala, Litsea monopetala*) were observed in buffer zone area (Table 2). In core zone, tree species like *Bombax ceiba* and *Senegalia catechu* had no regeneration and were found only in their adult stage. Fair regeneration status of *Dalbergia sissoo* and *Trewia nudiflora was* observed as their seedling density was higher than adult density. However, new regeneration was observed of *Syzygium cumini* and *Litsea monopetala* as they were only present in seedling form. In buffer zone, *Bombax ceiba*, *Phanera purpurea* and *Syzygium cumini* did not have regeneration as they were only present in their adult stage. Species like *Dalbergia sissoo* and *Leucaena leucocephala* had fair regeneration as their seedling density was higher than adult density whereas *Litsea monopetala* had new regeneration as its seedlings were present despite the absence in adult stage.




*Note: significance: *p < 0.05, **p < 0.01, ***p < 0.001; NS = not significant*

**Figure 4. Species richness at core zone and buffer zone of KTWR**

**Table 1. Permutational MANOVA (Bray method) for herbs, shrubs, trees and invasive species composition in the core zone and buffer zone of KTWR**

| Source | | DF | SS | MS | F | p-value |
|---|---|---|---|---|---|---|
| Herbs | | | | | | |
| | Treatment | 1 | 0.86 | 0.86 | 2.71 | 0.029 |
| | Residuals | 47 | 14.96 | 0.32 | | |
| | Total | 48 | 15.82 | | | |
| Shrubs | | | | | | |
| | Treatment | 1 | 0.21 | 0.21 | 0.82 | 0.584 |
| | Residuals | 26 | 6.68 | 0.26 | | |
| | Total | 27 | 6.89 | | | |
| Trees | | | | | | |
| | Treatment | 1 | 1.09 | 1.09 | 3.87 | 0.009 |
| | Residuals | 14 | 3.93 | 0.28 | | |
| | Total | 15 | 5.01 | | | |
| Invasive Species | | | | | | |
| | Treatment | 1 | 0.58 | 0.05 | 1.49 | 0.129 |
| | Residuals | 28 | 10.82 | 0.39 | | |
| | Total | 29 | 11.39 | | | |

*Note: Treatment refers to core or buffer zones. DF: degrees of freedom, SS: sums of squares, MS: mean squares, F: value for F statistics, p = probability value.*

**Table 2. Regeneration status of tree species in core zone and buffer zone of KTWR**

| S.N. | Tree species | Local Name | Adult tree density (ind ha$^{-1}$) | Sapling density (ind ha$^{-1}$) | Seedling density (ind ha$^{-1}$) | Result |
|---|---|---|---|---|---|---|
| | **Core zone** | | | | | |
| 1. | *Bombax ceiba* L. | Simal | 3.3 | 0.0 | 0.0 | No regeneration |
| 2. | *Dalbergia sissoo* Roxb. ex DC. | Sisau | 8.9 | 0.0 | 2777.8 | Fair regeneration |
| 3. | *Trewia nudiflora* Linn. | Bhellar | 38.9 | 0.0 | 138.9 | Fair regeneration |
| 4. | *Senegalia catechu* (L. f.) P. J. H. Hurter & Mabb. | Khayar | 5.0 | 0.0 | 0.0 | No regeneration |
| 5. | *Syzygium cumini* (L.) Skeels | Jamun | 0.0 | 0.0 | 416.7 | New regeneration |
| 6. | *Litsea monopetala* (Roxb.) Pers. | Kutmiro | 0.0 | 0.0 | 555.6 | New regeneration |

| | | | | | | |
|---|---|---|---|---|---|---|
| | **Buffer zone** | | | | | |
| 1. | *Bombax ceiba* L. | Simal | 0.8 | 0.0 | 0.0 | No regeneration |
| 2. | *Dalbergia sissoo* Roxb. ex DC. | Sisau | 2.3 | 0.0 | 277.8 | Fair regeneration |
| 3. | *Leucaena leucocephala* (Lam.) De Wit | Ipil-Ipil | 0.1 | 0.0 | 277.8 | Fair regeneration |
| 4. | *Phanera purpurea* (L.) Benth. | Tanki | 0.4 | 0.0 | 0.0 | No regeneration |
| 5. | *Syzygium cumini* (L.) Skeels | Jamun | 0.1 | 0.0 | 0.0 | No regeneration |
| 6. | *Litsea monopetala* (Roxb.) Pers. | Kutmiro | 0.0 | 0.0 | 416.7 | New regeneration |

**Table 3. Soil physico-chemical parameters in core zone and buffer zone of KTWR**

| S.N. | Soil parameters | Core zone | Buffer zone | p |
|---|---|---|---|---|
| 1. | pH | 8.02 ± 0.04 | 7.99 ± 0.07 | NS |
| 2. | EC (μS cm$^{-1}$) | 89.45 ± 9.11 | 269.59 ± 65.53 | *** |
| 3. | Bulk density (g cm$^{-3}$) | 0.12 ± 0.02 | 0.23 ± 0.04 | * |
| 4. | SOM (%) | 6.96 ± 0.26 | 7.58 ± 0.42 | NS |
| 5. | Total nitrogen (%) | 0.49 ± 0.11 | 0.65 ± 0.15 | ** |
| 6. | Available phosphorus (kg ha$^{-1}$) | 234.15 ± 35.74 | 208.92 ± 41.72 | NS |
| 7. | Available potassium (kg ha$^{-1}$) | 92.82 ± 3.07 | 101.16 ± 7.14 | NS |

*Note: significance: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$; NS = not significant*

**Soil Characteristics**

A significant difference between soil parameters like soil EC, bulk density, and total nitrogen (N) were found in between core zone and buffer zone at KTWR (Table 3). On the other hand, no significant difference was seen in the parameters like pH, SOM, available phosphorus (P) and available potassium (K).

## DISCUSSION

### Grazing Intensity, Vegetation Composition and Diversity

The core zone and buffer zone of KTWR were observed with difference in plant species composition. The multivariate results showed significant difference in the herb species community and tree species community between core and buffer zones. However, in the case of shrub species, a significant difference was not observed between the communities of core and buffer zones. This showed that the livestock grazing has not affected the shrub species community in the study area. Grazing influences the extent of an ecosystem through limiting and facilitating their spread to open ground, their structure and openness and composition of the plant species (Ramirez *et al.*, 2018) mainly by modifying the competitive interactions through selective feeding by livestock between plants (Olofsson *et al.*, 2001; Li *et al.*, 2011). The heterogeneous spatial distribution of local disturbances induced by grazing, such as trampling, gap creation, or nutrient deposition, can create spatial variability in plant species composition (Adler *et al.*, 2001). This variability in plant composition induced by grazing can play a major role in community functioning and dynamics (Murrel *et al.*, 2001; Shameem *et al.*, 2010).

The results showed that herb species richness was significantly higher at the low grazed area compared to high grazed area. The result was consistent with the other studies (Osem *et al.*, 2002; Alados *et al.*, 2004; Akhzari *et al.*, 2015; Papanikolaou *et al.*, 2011), which reported that the plant species richness alters negatively under livestock grazing conditions. Similarly, high species diversity was observed at core zone than in buffer zone as consistent with the results observed by Alados *et al.* (2004), Zhao *et al.* (2006), Bergmeier and Dimopoulos (2004) and Akhzari *et al.* (2015). This shows that the species diversity and richness decrease with increase in the grazing intensity. In contrast to herb species, despite significantly higher richness at core zone than in buffer zone, shrub species did not show any difference in species diversity in between highly grazed and low grazed areas. This might be due to the presence of unpalatable shrub species and presence of larger variety of herb species which are preferred by livestock (Chetri, 2002; Calleja *et al.*, 2019). Grazing alters plant communities by selective grazing, reducing plant cover and biomass, and shifting the balance between grasses and woody vegetation (Blaum *et al.*, 2009). Calleja *et al.*, (2019) reported that livestock grazing had very low impact on shrub encroachment as it was observed that the cattle prefer herbaceous plants to woody species. Similarly, consistent with the results of Sapkota and Stahl (2018), invasive species richness was found higher at low grazed area despite having no significant difference in species diversity with high grazed area (Fig. 4 and Fig. 3, respectively).

### Regeneration Status of Tree Species

The population structure, proportion of seedlings, saplings and mature trees, of a particular species determines the regeneration behavior. Moreover, regeneration of species also depends on the internal community processes and natural and anthropogenic disturbances (Barker & Kirkpatrik, 1994). No saplings were observed during the study in both core area and buffer area; however, seedlings were present. This might be due to grazing as it may reduce the development of seedling into sapling, checking the growth and development of shoot part of the plant species. This might also be due to the more presence of herbaceous species in both core and buffer area as more herbaceous species are observed to have influence on seed, germination and seedling establishment affecting the regeneration of tree species (van Kuijk *et al.*, 2014). The results showed that the regeneration status of trees in KTWR, both in buffer zone and core zone, is not sustainable, reflecting the negative effects of grazing in the regeneration.

**Soil Characteristics**

The effect of grazing on soil pH is caused by inputs of livestock excreta and urine along with the effects of foraging and trampling, which has the capacity to influence the soil nutrient cycling (Zhang *et al.*, 2018). Soil pH usually increases with increasing grazing intensity (Qu *et al.*, 2016). However, some studies observed no relation between grazing and pH (Milchunas & Lauenroth, 1993; Akhzari *et al.*, 2015; Bakhshi *et al.*, 2019), similar to the result of this study which did not show significant change in pH between high grazed and low grazed areas at KTWR. EC was higher at the buffer zone i.e., highly grazed area. The soil EC tends to increase with increasing grazing intensity (Shahriary *et al.*, 2012; Chaneton & Lavado, 1996; Qu *et al.* 2016). Grazing increases bare soil and promotes soil salinity due to the increase in evaporation and the consequent rise of salts to the surface (Yu & Chmura, 2010). Moreover, some salts are also present in cattle excreta contributing to the increase in soil salinity (El-Dewiny *et al.*, 2006). The bulk density generally increases with the increase in grazing intensity (Hamza & Anderson, 2005). Higher bulk densities and a lower water content, proportion of stable aggregates, and infiltration rate, as a result of increased animal trampling, have been observed for different grazing animals in different grassland ecosystems (Ilan *et al.*, 2008). The bulk density of the soil at KTWR was also found significantly higher at buffer zone i.e., highly grazed area than at core zone i.e., low grazed area. A study by Galleguillos *et al.* (2018), Yates *et al.* (2000) also observed the similar result.

SOM increases, decreases, or remains unchanged under contrasting grazing conditions across temperature and precipitation gradients, which suggests that grazing influences the SOM in a complex way (Pineiro *et al.*, 2010). Some studies stated no significant difference in SOM between the grazed and grazing excluded areas due to the return of organic matter as manure in the grazed areas and better mixing of plant remains due to livestock movement to the soils (Bakhshi *et al.*, 2019). Similar results were observed in this study. Nitrogen in the soil was observed to be significantly higher in high grazed areas than in low grazed areas. Livestock grazing may influence the balance of nitrogen storage by altering the nitrogen input to output from the soil. Higher grazing intensity can also lead to the increase of soil nitrogen storage through changes in the species composition and increase in root allocation (Stewart & Frank, 2008). Moreover, the urine and dung of livestock may accelerate nitrogen cycling in grassland ecosystems (McNaughton *et al.*, 1997). No significant difference was observed in phosphorus content between the high grazed area and low grazed area in KTWR. Similar results were observed at a study done at Pampa Grassland of Argentina (Chaneton & Laavado, 1996; Bakhshi *et al.*, 2019). However, other studies have shown grazed sites with higher phosphorus content than non-grazed sites (Ruess & McNaughton, 1987; Zarekia *et al.*, 2012). With contrasting results observed in other studies (Hosseinzadeh *et al.*, 2010; Zarekia *et al.*, 2012), significant differences in mean values of potassium were not observed in this study. Moreover, this study has focused on livestock impacts on vegetation assuming that grazing by other wildlife is low in the sampling areas, however, future studies can address the impacts and interaction among livestock and wildlife in the grassland of the reserve.

## CONCLUSIONS

Livestock grazing was observed to have negative effects on plant diversity and richness causing the difference in plant community assemblages between high grazed and low grazed areas. Invasive alien plant species richness was, however, high in low grazed areas. An elevated level of soil nitrogen was found in the high grazed areas. Controlled grazing is recommended at grasslands of buffer zone of KTWR to enhance vegetation diversity and nutrient availability. The core areas need interventions for controlling the abundance and distribution of invasive alien plant species.

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## AUTHORS CONTRIBUTION STATEMENT

Ritu Tuladhar: Conceptualization, field work, laboratory work, original draft; Ramesh Prasad Sapkota: Conceptualization, data analysis, revision, review; Ashok Parajuli: Conceptualization, project administration; Birendra Gautam: Conceptualization, field support.

## CONFLICT OF INTEREST

The authors do not have any conflict of interest pertinent to this work.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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