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# **SUMMARY**

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1. The present study on “Grazing impact on plant diversity and productivity along a tourist trekking corridor in the Khangchendzonga Biosphere Reserve of Sikkim” was undertaken in the Sikkim Himalaya with the following main objectives: (i) to understand the general vegetation composition, animal rearing pattern along the trekking corridor and its economic utility; (ii) to analyze the impact of grazing on plant structure, species richness and diversity at selected locations at four different vegetation zones; (iii) to estimate the impact of grazing on biomass and productivity of different plant communities; (iv) to analyze nutrient dynamics under grazing and protected conditions and (v) to evaluate grazing carrying capacity of pastures at different vegetation zones.
2. The area of the study was Khangchendzonga Biosphere Reserve ( $27^{\circ}25'$  to  $27^{\circ}55'$  N latitude and  $88^{\circ}3'$  to  $88^{\circ}38'$  E longitude, area  $2620\text{ km}^2$ ), particularly the Yuksam-Dzongri trekking corridor (elevation range from 1600 to 4200 m) which is one of the most important trekking corridor for domestic and international tourists. The Yuksam village, which is inhabited by 274 households of Bhutia and Nepali communities, is the entry point for the biosphere reserve as well as trekking trail. The trail passes through the pristine forest types ranging from warm temperate to subalpine, and finally opens in alpine meadows with cushion and small vegetation type. Thus, the trail provides an indepth view of natural vegetation,

water bodies and mountain system, and particularly the Mt. Khangchendzonga (8598 m). Tshoka (elevation 3000 m) is the last settlement within the biosphere reserve and is inhabited by 11 families of Tibetan refugee.

3. The daily minimum temperature goes down to  $-8^{\circ}\text{C}$  during January in alpine areas and rose to  $24^{\circ}\text{C}$  during August in warm temperate lower elevation site. The annual rainfall was recorded ranged from 2319 to 3760 mm across the study sites.
4. The soil is silty loam in texture with moisture content ranging from 18.9 to 29.0 % and pH from 4.53 to 5.41 across the study sites. Total nitrogen of the soil ranged from 0.31 to 0.55%, total phosphorus from 0.016 to 0.030% and organic carbon from 3.24 to 5.86% at different depths.
5. The buffer zone of the biosphere reserve is extensively used for collection of basic amenities, i.e. fuelwood, fodder, timber, non-timber forest products by the inhabitants of Yuksam Block. The people of Yuksam and other nearby villages use the biosphere reserve, particularly alpine meadows as summer grazing grounds during May to September. During other periods animals graze at low altitude forest areas, except for yaks which graze rhododendrons and other bushes near the timberline even during winter. The important grazing livestock are cows, dzos, yaks, horses, goats and sheep. Lactating cows and goats (in small numbers) free graze and were also stall-fed. These animals receive supplement fodder collected from forest areas as well as

agricultural byproducts. During winter, agroforestry species meet a part of the fodder requirement.

6. Yuksam village has 454 cows, 22 horses, 461 sheep, 122 dzos and 311 goats, and the Tshoka village maintains 45 cows, 7 horses and 23 dzos, which graze in the biosphere reserve. Besides, some animals of Rhimbi village were also sent to alpine pasture for free grazing during summer months. Total number of 40 cows, 160 yaks, 120 dzos, 13 horses and 508 sheep extensively graze in alpine pastures.
7. The livestock are important source of income generation for local people in the subsistence agriculture system. It was estimated that livestock generated an income of Rs 11,37,600/- and Rs 10,29,300/- in 1997 and 1998 respectively, along the trail that was generated from animal products and pack animals. In 1997, out of the total income, Rs 5,87,600/- was generated from pack animals, Rs 3,56,400/- from milk and milk products, Rs 81,4000/- from wool products and remaining from skin products. During 1998, Rs 5,87,600/- was generated from pack animals, Rs 3,56,400/- was from milk and milk products, Rs 81,400/- from wool products and remaining from skin products. A decrease of 9.52% was recorded in income from 1997 to 1998, which was due to severe landslide at the later year that disrupted the tourists' flow.
8. For stall-fed animals, 80% of total fodder demand came from forests, which was mostly met from 43 species. The remaining 20% was supplemented by the agroforestry species (10 species, mainly *Ficus* group) that are maintained by the villagers as "forage bank"

in their farms for scarcity period (December to February). An average household in Yuksam produced about 793 kg fodder annually.

9. Crude fibre content of fodder species ranged from 8.55 to 30.43%; cellulose 4.59 to 37.32%; hemicellulose 6.00 to 35.85%; lignin 6.56 to 35.89%; nitrogen 1.04 to 4.97%; phosphorus 0.038 to 0.377% and crude protein between 6.25 to 31.06%.
10. Foraging characteristics study of livestock showed that bite rate ranged from 41.2 to 59.5 ( $\text{bite min}^{-1}$ ), apparent bite size 52.0 to 105.6 ( $\text{mg bite}^{-1}$ ), foraging hours 7.8 to 11.9 ( $\text{hours day}^{-1}$ ), and forage intake rate ranged from 1.17 to 4.03  $\text{kg day}^{-1}$ .
11. Barbed wire fence-exclosures were established at 4 elevation zones (Yuksam-warm temperate, Sachen-cool temperate, Deorali-subalpine/timberline and Dzongri-alpine) along the Yuksam-Dzongri trail to observe the impact of livestock grazing on plant structure and productivity, soil properties and nutrient dynamics. Exclosure has increased the density of palatable species while decreased unpalatable/least palatable species. Density ranged from 96 to 2290 plants  $\text{m}^{-2}$  in grazed plots while 105 to 3747 plants  $\text{m}^{-2}$  in exclosure plots. Grazing increased basal coverage of plants significantly in higher altitude but reduced in temperate pastures ( $P<0.0001$ ) and the value ranged from 16 to 439  $\text{cm}^2 \text{m}^{-2}$ .
12. Livestock grazing exclosure showed no drastic changes in species richness in all the study sites. The value (Margalef's index) ranged from 0.71 to 3.75 in grazed plots while 0.93 to 3.36 in exclosure plots. Plant diversity was more in grazed plots that ranged from

1.48 to 2.70 while it ranged from 1.14 to 2.66 in exclosure plots. Plant dominance was more in exclosure plots and Simpson's index ranged from 0.098 to 0.322 in grazed plots while 0.101 to 0.472 in exclosure plots.

13. Exclosure of forest ground from livestock grazing increased the density of seedling of tree species by 29% in cool temperate and 46% in warm temperate sites. Regenerating plant density ranged from 7000-10750 seedlings  $\text{ha}^{-1}$  in cool temperate and 3750-8750 seedlings  $\text{ha}^{-1}$  in warm temperate forest sites at Yuksam.
14. Exclosure in grazed pasture increased aboveground biomass by 50% at all the elevations ( $P<0.0001$ ) and 78.06 to 92.66% of biomass was contributed by palatable species. Exclosure increased biomass contribution of palatable species by 25% at Yuksam, 12% at Sachen, 11% at Deorali and 75% at Dzongri. Dicot plants were more in grazed plots while monocot plants more in exclosure plots at all the study sites. Aboveground biomass contribution by different growth forms was dominated by shrub/undershrub (33.2%) at Yuksam, tall forbs (41.2%) at Sachen, and graminoid at both Deorali (41.2%) and Dzongri (37.5%). Aboveground biomass showed strong positive relationship with rainfall in all the study sites ( $P<0.01-0.001$ ).
15. Protection from livestock grazing for two years has increased accumulation of litter mass significantly ( $P<0.0001$ ) at all the study sites. Litter accumulation decreased with increase in elevation.
16. No significant change was recorded in belowground root biomass after 2 years of fencing at all the study sites. Root:shoot ratio

increased with increasing elevation and the values ranged from 0.84 to 1.84 at Yuksam, 0.96 to 1.85 at Sachen, 1.35 to 4.14 at Deorali and 1.57 to 5.04 at Dzongri.

17. Protection from livestock grazing has enhanced the productivity of pastures by 63.5% at Yuksam, 75.6% at Deorali and 113.7% at Dzongri. Species contribution to the net aboveground biomass productivity was highest by *Pilea scripta* (19.29% in grazed) and *Brachiaria* sp. (23.09% in exclosure) at Yuksam; *Urtica dioica* (15.98% in grazed) and *Diplazium umbrosum* (29.73% in exclosure) at Sachen; *Potentilla peduncularis* (23.01% in grazed) and *Poa* sp. I (24.19% in exclosure) at Deorali, and *Potentilla peduncularis* (39.68% in grazed) and *Poa* sp. I (20.78% in exclosure) at Dzongri. Turnover rate of aboveground biomass was more at exclosure plots in all the study sites except in Sachen and the value ranged from 0.329 to 0.584 in grazed plots while 0.475 to 0.620 in exclosure plots. Turnover rate of belowground biomass decreased with exclosure at Yuksam and Sachen while increased at Deorali and Dzongri. The value ranged from 0.06 to 0.479 in grazed plots while 0.072 to 0.307 in exclosure plots.
18. Nitrogen concentration of aboveground biomass of different species increased at the exclosure plots ( $P<0.01$ ). It ranged from 0.92 to 2.14% in species of grazed plots, while 0.91 to 2.71% in exclosure plot species.
19. Phosphorus concentration of aboveground shoot ranged from 0.113 and 0.231% in the species of grazed plots, and 0.141 to 0.247% in exclosure plots. Nitrogen concentration has decreased in

belowground biomass in exclosure ( $P<0.001$ ), and the values ranged from 0.64 to 1.50% in grazed plots and 0.63 to 1.13% in exclosure plots. In belowground parts the phosphorus concentration ranged from 0.111 to 0.238% in grazed plots and 0.103 to 0.231% in exclosure plots.

20. Nitrogen concentration of soil increased in grazed plots ( $P<0.0001$ ) and the values ranged from 0.413 to 0.488% (grazed) and 0.33 to 0.461% (exclosure) at Yuksam; 0.443 to 0.547% (grazed) and 0.407 to 0.464% (exclosure) at Sachen; 0.491 to 0.551% (grazed) and 0.490 to 0.539% (exclosure) at Deorali, and from 0.310 to 0.477% (grazed) and 0.361 to 0.403% (exclosure) at Dzongri. Nitrogen content of soil upto 30 cm depth ranged from 380 to 423 g m<sup>-2</sup> (grazed) and 292 to 400 g m<sup>-2</sup> (exclosure) at Yuksam; 465 to 586 g m<sup>-2</sup> (grazed) and 428 to 497 g m<sup>-2</sup> (exclosure) at Sachen; 520 to 561 g m<sup>-2</sup> (grazed) and 519 to 548 g m<sup>-2</sup> (exclosure) at Deorali and 463 to 575 g m<sup>-2</sup> (grazed) and 479 to 601 g m<sup>-2</sup> (exclosure) at Dzongri.
21. There was no significant change in phosphorus concentration of soils as an impact of grazing in all the study sites. It's concentration in soil ranged from 0.016 to 0.036% in grazed plots and 0.007 to 0.030% in exclosure plots. Phosphorus content of soil upto 30 cm depth ranged from 16.81 to 36.60 g m<sup>-2</sup> in grazed plots and 10.47 to 26.54 g m<sup>-2</sup> in exclosure plots across the study sites.
22. Grazing exclosure has resulted into significant decrease in organic carbon content of soil ( $P<0.0001$ ) and the values ranged from 4.13 to

5.86% (grazed) and 3.46 to 5.89% (exclosure) across the study sites. Organic carbon content of soil upto 30 cm depth ranged from 4427 to 4866 g m<sup>-2</sup> (grazed) and 3058 to 4354 g m<sup>-2</sup> (exclosure) at Yuksam; 4226 to 5342 g m<sup>-2</sup> (grazed) and 3921 to 5599 g m<sup>-2</sup> (exclosure) at Sachen; 4494 to 5960 g m<sup>-2</sup> (grazed) and 3921 to 5990 g m<sup>-2</sup> (exclosure) at Deorali and 5375 to 6961 g m<sup>-2</sup> (grazed) and 4965 to 5689 g m<sup>-2</sup> (exclosure) at Dzongri.

23. Total net uptake of nitrogen was 5.37 g m<sup>-2</sup> year<sup>-1</sup> in grazed and 14.36 g m<sup>-2</sup> year<sup>-1</sup> in exclosure plots at Yuksam; 11.00 g m<sup>-2</sup> year<sup>-1</sup> (grazed) and 18.21 g m<sup>-2</sup> year<sup>-1</sup> (exclosure) at Sachen; 14.04 (grazed) and 16.96 g m<sup>-2</sup> year<sup>-1</sup> (exclosure) at Deorali and 20.69 g m<sup>-2</sup> year<sup>-1</sup> (grazed) and 21.66 g m<sup>-2</sup> year<sup>-1</sup> (exclosure) at Dzongri. Total net uptake of phosphorus was 1.47 g m<sup>-2</sup> year<sup>-1</sup> in grazed and 2.6 g m<sup>-2</sup> year<sup>-1</sup> in exclosure plots at Yuksam; 2.09 g m<sup>-2</sup> year<sup>-1</sup> (grazed) and 2.87 g m<sup>-2</sup> year<sup>-1</sup> (exclosure) at Sachen; 2.09 g m<sup>-2</sup> year<sup>-1</sup> (grazed) and 2.51 g m<sup>-2</sup> year<sup>-1</sup> (exclosure) at Deorali and 2.64 g m<sup>-2</sup> year<sup>-1</sup> (grazed) and 3.05 g m<sup>-2</sup> year<sup>-1</sup> (exclosure) at Dzongri.
24. In terms of forage consumption rate, different animals were converted into cow equivalent unit (CEU). In temperate pastures, 1 dzo, 1 horse, 1 sheep and 1 goat is equivalent to 1.14 cow, 1.03 cow, 0.37 cow and 0.38 cow, respectively. In alpine and subalpine pastures 1 dzo, 1 yak, 1 horse, 1 sheep is equivalent to 1.14 cow, 0.92 cow, 1.01 cow and 0.33 cow, respectively.

25. The annual stocking rate was recorded as 1.29 cow ha<sup>-1</sup> at Yuksam, 0.49 cow ha<sup>-1</sup> at Sachen, 1.02 cow ha<sup>-1</sup> at Deorali and 0.56 cow ha<sup>-1</sup> at Dzongri.
26. The carrying capacity of pastures at different elevation zones was estimated. The carrying capacity of 1.34 cow ha<sup>-1</sup> year<sup>-1</sup> was recorded at Yuksam pasture, 1.18 cow ha<sup>-1</sup> year<sup>-1</sup> at Sachen pasture, 0.96 cow ha<sup>-1</sup> year<sup>-1</sup> at Deorali pasture and 0.86 cow ha<sup>-1</sup> year<sup>-1</sup> at Dzongri pasture. The potential carrying capacity of pastures were calculated as 1.61 cow ha<sup>-1</sup> year<sup>-1</sup> for Yuksam pasture, 1.42 cow ha<sup>-1</sup> year<sup>-1</sup> for Sachen pasture, 1.15 cow ha<sup>-1</sup> year<sup>-1</sup> for Deorali pasture and 1.03 cow ha<sup>-1</sup> year<sup>-1</sup> for Dzongri pasture.
27. Livestock number shoud not be increased anymore in Yuksam and Deorali pastures that already has reached the carrying capacity level. Strong scientific management is urgently required. The Maintenance of current stocking rate at Dzongri and Sachen pasture is expected to keep these two pastures healthy and productive ■