LIVESTOCK ECONOMY AND HERBIVORE EFFECTS ON PLANT COMMUNITY IN THE KHANGCHENDZONGA BIOSPHERE RESERVE OF SIKKIM HIMALAYA, INDIA

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ABSTRACT

Livestock economy and grazing effect on plant structure, species richness, diversity, biomass and productivity along an altitudinal gradient, covering temperate to alpine zones from 1600 m to 4000 m in a 26-km tourist trekking trail in the Khangchendzonga Biosphere Reserve of the Indian Sikkim Himalaya was studied. Common livestock grazing animals were cattle, goat, sheep, horse, dzo and yak. Livestock numbering 1300 and 1500 were recorded grazed in the trail areas during 2007 and 2008, respectively, which show an increment of 15%. An annual amount of more than one million rupee was generated from livestock mainly from pack animals, milk and milk products and wool and wool products. Grazing has changed the number of plant species significantly (P<0.0001). Grazing reduced plant density in all the altitudinal sites (P<0.0001). Plant density ranged from 96 to 550 plants m^{-2} in temperate, 906-3249 plants m^{-2} in subalpine and 920-3747 plants m^{-2} in alpine. Grazing decreased plants species richness but tends to increase plant diversity. Grazing increased basal coverage of plants in subalpine (13 to 28%) and alpine (0.7 to 83%) but decreased in temperate (16 to 52%). Aboveground plant biomass was reduced significantly by to livestock grazing (P<0.0001) but no significant change in belowground biomass. Just two years of grazing protection of grazed pastures have increased the above ground biomass by 90 % in warm temperate, 42% in cool temperate, 67% in subalpine and 74% in alpine areas. Protection from livestock grazing for a short span of 2 years has increased the net primary productivity of plant communities in all the altitudinal sites except in subalpine. Net primary productivity ranged from 175-567 g m^{-2} year^{-1} in grazed sites and from 374-583 g m^{-2} year^{-1} in enclosure sites.

Keywords: Grazing livestock, Pack animals, Plant communities, Biomass, Palatability.

INTRODUCTION

Herbivores affect directly or indirectly on plant communities (McNaughton 1985, Milchunas *et al.*, 1993, Augustine *et al.*, 1998) affecting plant species composition, above and belowground plant productivity, and nutrient cycling (Naiman *et al.*, 1986; Deangelis 1992; Ritchie *et al.*, 1998). Plant communities and species react differently to varying degrees of grazing pressures (Milchunas *et al.*, 1993). Herbivores may indirectly control the form and function of ecosystems (Naiman *et al.*, 1986, Pastor *et al.*, 1992, Jones *et al.*, 1994). Plant responses to grazing are conditioned by past history, current environmental conditions, and interaction among the biotic components (Mack *et al.*, 1982, Milchunas *et al.*,1988, Trilica *et al.*, 1993). although most effect of grazing on annual net primary productivity (ANPP) were negative, some were not and the statistical models predicted increases in ANPP with grazing under conditions of long evolutionary history, low consumption, few years of treatment and low ANPP (Milchunas *et al.*, 1993).

Animals form an integral part of local economy all over the Himalayas, and domestic animals are frequently grazed in forest areas and also in high alpine areas by nomads (Sundryal 1995, Tambe and Rawat 2009). Rearing animals through seasonal migration between alpine meadows and lower elevation in selected forested areas is a common strategy of securing sufficient forage for animals in the Himalayan region (Ram *et al.*, 1989). The number of animals increases with increasing elevation and at higher elevation economy is totally dependent on animals and its products.

Khangchendzonga Biosphere Reserve of Indian Sikkim Himalaya falls within the "Indo-Burma" center of biodiversity hotspot of global significance (Tambe and Rawat 2009, 2010). Yuksam-Dzongri trekking trail within the biosphere reserve is one of the most important tourist trails in Sikkim, which have been trekked by around 2000 tourist of both national and international every year. Besides, many training programs of the Himalayan Mountaineering Institute have also been conducted every year in this trail. Tourists and mountaineers engage a large number of Dzongri and horses as pack animals during March to May and September to November. These pack animals are grazed on the surrounding trail and alpine pastures. Besides, cows, yaks and sheep are also widely grazed in the alpine pastures during summer months and in lower altitude forest areas round the year. Although a source of revenue for locals, these livestock have significant impact on vegetation and soil due to continuous grazing and trampling. Although livestock grazing is officially banned inside the biosphere reserve but a large number of animals are seen grazed freely. The present investigation was undertaken to find out plant-herbivore interaction and its causatives on vegetation which includes; (i) species structure, richness, diversity and distribution pattern and (ii) biomass components utilization, its modification and productivity with a view to help in the development of grazing management strategies of Sikkimese important trekking trails. As the number of animals grazing in the area is increasing over the years, the study has larger implications for conservation of this biosphere reserve and need to be addressed immediately.

STUDY AREA AND METHODOLOGY

Yuksam-Dzongri tourist trekking trail falls at the south-western part of the Khangchendzonga Biosphere Reserve (2725$^{/}$ to 2755$^{/}$ N and 883$^{/}$ to 8835$^{/}$ E) of the Sikkim Himalaya and covers four ecological zones viz. warm temperate (1600-2700 m), cool temperate (2700-3200 m), subalpine (3200-3800 m) and alpine zone (> 3800 m). The trail is 26 km long and trekking experience for the nature lovers with an exhilarating climb through dense mixed forests and alpine meadows are some of the most biologically diverse in India. Yuksam village (1600m) is the trail- head and settled by 274 households (1780 population). About 16 km away from Yuksam along the trail is Tshoka settlement (3400 m), which is the last settlement with 9 households (52 persons). Majority of the populations are Bhutias, Lepchas, Gurung, Rai, Subba and Tibetan refugees. Many mountaineering training programs are also conducted in this trail and a large number of pack animals are used for the purpose. The alpine region remained snow-cover from November to March. The main vegetation of the alpine area is with bushes of Rhododendrons, *Poa*, *Potentilla*, *Primula*, *Pedicularis*, *Bistorta*, etc. The timberline and subalpine is markedly distinguished by big trees of *Abies densa* and various species of rhododendron. Temperate zone can be distinguished as cool and warm based on temperature and vegetation elements. Cool temperate zone is mostly dominated by big trees of Magnolias and *Rhododendron arboreum* and ground vegetation by species of *Selaginella*, *Pilea* and *Urtica*. In warm temperate zone, *Cedrela toona*, *Macaranga pustulata* and *Cinnamomum* spp. are the common top-level species while species of *Artemisia* and *Viola* are dominant ground level vegetation.

In alpine, the average maximum and minimum temperature was recorded as 13C (August) and –C (January), respectively. Subalpine is warmer with maximum temperature of 17.5C (July) and minimum of 3C (January). A maximum temperature of 23.8C (July) was recorded in temperate zone while minimum was 2.5C (January). The area receives heavy annual monsoon rainfall. In the alpine regions there was no rainfall during the months from December to April while maximum rainfall is generally in between July and August and recorded annual rainfall of 3648 mm and further higher in temperate zones (3760 mm). The maximum rainfall occurred in the month of August in all the study sites, which contributes more than 30% of the whole annual rainfall.

In the present study, five sites were identified along the trail based on physiognomic characteristics representing diverse ecological conditions. Twenty barbed-wire fence exclosures 1010 m size were established along the trail at different altitudes (four in alpine gentle slope site; four in alpine stiff slope site; four at near timberline; four at cool temperate and four at warm temperate forested pasture). Vegetative analysis at the beginning of growing season in April and subsequently in June, August and October were done using randomly placed 11 m quadrats (n=20) in the exclosure plots at different sites. Identical samplings were also made in the respective nearby-demarcated identical and designated open-grazed pastures. Plant density, species richness (Margalef 1957), species diversity (Shannon 1948), evenness or equitability (Buzas *et al.,* 1996) and concentration of dominance (Simpson 1949) were calculated. The standing biomass was harvested in August (biomass peak season) by clipping at the ground level and packed in polythene bags that were later separated into species. Litter mass was collected separately and packed into polythene bags. Belowground biomass was collected by digging out monoliths of 5050 cm size upto 30 cm depth and washed by a fine jet of water (n=3 each). The samples were dried in hot-air oven at 80 C till constant weight for dry weight conversion. Net primary productivity was measured through difference method, by subtracting the previous sampling months biomass with current sampling month biomass, and thus accumulating all positive increments (Singh *et al.,* 1974). Data were analyzed through Systat 1996 (version 6.0).

RESULTS

Livestock rearing pattern and its economy

A total number of 1324, 1365 and 1523 grazing livestock were recorded along the Yuksam-Dzongri area (both Yuksam and Tshoka villages). The animals are cattle, goat, sheep, horse, dzo and yak. In Yuksam village maximum of the animals were cattle, goat and sheep where as in Tshoka the animals are dominant (Table 1).

Table 1. Grazing livestock in Yukasm-Dzongri areas in the Khangchendzonga Biosphere Reserve of Sikkim Himalaya as recorded through field survey

Village/livestock type	Livestock number			% change
	1998	1999	2000	
Yuksam village				
Cattle	361	399	454	25.76 (+)
Goat	245	267	311	26.94 (+)
Sheep	441	435	461	4.54 (+)
Horse	31	31	22	29.03 (-)
Dzo	96	101	122	27.08 (+)
Yak	83	70	78	6.02 (-)
Total	1257	1303	1448	15.19 (+)
Tshoka village				
Cattle	35	30	45	28.57 (+)
Dzo	24	24	23	4.17 (-)
Horse	8	8	7	12.5 (-)
Total	67	62	75	11.94 (+)
Grand total	1324	1365	1523	15.03 (+)

An increment of about 15% in livestock was observed within a short span of two years. Livestock rearing pattern varied among the different altitudinal zones (Table 2).

Table 2. Livestock rearing pattern in the Khangchendzonga Biosphere Reserve

Environmental zones	Livestock rearing practice
Temperate (1600-3200 m)	Most of the livestock are stall-fed while some of them are freegrazing in forest and surrounding wastelands. Milking cows and calves are stall-fed and supplements with agricultural byproducts and fodder from the agroforestry species maintained in the agricultural fields mostly during winter lean period. A large share of fodder is also collected from the surrounding forest.
Subalpine (3200-3800 m)	Most of the livestock are free grazing while milking cows and calves are stall-fed. The fodders are collected from the surrounding forest. Litters are collected as ground mat for milking cows.
Alpine (> 3800 m)	All the livestock are free grazing in alpine pastures. Most of the cattle sheds are temporary and mobile type according to the availability of fodder. Certain period of a year (May to November) livestock are free grazing whereas rest of the period the livestock are moved to lower altitude valley. But yak remained near the timberline forest.

Free grazing was less in temperate zone but all the animals in alpine zone were found grazed freely. In temperate zone especially in warm temperate a good number of agroforestry fodder species are maintained in the agricultural fields to supplement fodder during lean period whereas in alpine zone all the animals are free-grazing (Table 2). An amount of more than one million rupees was earned from grazing livestock in Yuksam and Tshoka village together. Out of the total amount 57.1% was from pack animals; 34.6% from milk and milk products; 7.9% from wool and wool products and rest from skin and skin products (Table 3).

Table 3. Income generated from grazing livestock along the Yuksam-Dzongri trail in the Khangchendzonga Biosphere Reserve

Income source	Animal types	Price rate (Rs)	Quantity	Revenue (Rs)
Pack animals	Dzo	120 per day per animal	4834	580080
	Horse	110 per day per animal	69	7590
	Subtotal	-	-	587670
Milk & milk products	Cattle	10 per litre	9500	95000
	Yak	10 per liter of milk 120 per kg of chhurpi	7000 litres of milk 1000 kg of chhurpi	190000
	Sheep	10 per liter of milk 160 per kg of butter	1094 litres of milk 344 kg of butter	71450
	Subtotal	-	-	356450
Wool & wool products	Yak	80 per kg of raw wool 35 per single rope 120 per sofa cover	125 kg 70 ropes 50 sofa covers	18450
	Sheep	120 per kg of raw wool 650 per blanket	444 kg 23 blankets	62950
	Subtotal	-	-	81400
Skin	Yak	45 per pair of shoes 250 per sofa cover	30 pairs of shoes 10 sofa covers	3850
Total	-	-	-	**10,29,370**

Impact of grazing on vegetation structure, species richness and diversity

Livestock grazing reduces significantly the total number of species throughout the months and in all the altitudinal sites (P<0.0001). The species encountered during the study period ranged from 19 to 30 in temperate forested pastures, 11-17 in subalpine and from 6 to 18 in alpine. Plant density also reduced significantly (P<0.0001) at all altitudinal sites and months by grazing and their interactions were also significant (P<0.0001). Plant density ranged from 105 to 550 plants/m^2 (exclosure) and 96-502 plants/m^2 (grazed) in temperate forested pastures; 1158-3249 plants/m^2 (exclosure) and 906-1645 plants/m^2 (grazed) in subalpine and 1090 to 3747 plants/m^2 (exclosure) and 920-2290 plants/m^2 (grazed) in alpine. Grazing increased basal coverage of plants significantly in subalpine (13-28%) and alpine (0.7-83%) (P<0.0001) but reduced in temperate forested pastures (16-52%) and their interactions were also significant (P<0.0001). Basal coverage was ranged from 16 to 124 cm^2/m^2 in temperate forested pastures; 128-238 cm^2/m^2 in subalpine and from 141 to 439 cm^2/m^2 in alpine zone.

Grazing reduces species richness in all the altitudinal sites during the peak growth season. Species richness increased with increasing altitude and the value was 2.93 (grazed) and 3.01 (exclosure) in warm temperate; 2.34 (grazed) and 2.36 (exclosure) in cool temperate; 1.22 (grazed) and 1.65 (exclosure) in subalpine and 1.30 (grazed) and 1.32 (exclosure) in alpine zone. Contrary to it, plant diversity increased with grazing in all the study sites except in subalpine. Plant diversity index during peak growing season was recorded as 2.69 (grazed) and 2.66 (exclosure) in warm temperate; 2.49 (grazed) and 2.29 (exclosure) in cool temperate; 1.89 (grazed) and 1.93 (exclosure) in subalpine and 1.99 (grazed) and 1.77 (exclosure) in alpine zone. Grazing does not have much change on species distribution pattern in warm temperate. In alpine and cool temperate some species became dominated in grazing protected plots ion but contrary to it some species were dominated in grazed plots in subalpine sites. Grazing resulted species distribution more homogeneously in all the altitudinal sites.

Biomass and productivity

Grazing reduces aboveground biomass significantly by 10-47% in warm temperate, 19-30% in cool temperate, 15-40% in subalpine and 11-52% in alpine (P<0.0001). The aboveground biomass ranged from 118 to 641 g/m^2 (exclosure) and 104-337 g/m^2 (grazed) in warm temperate; 125-693 g/m^2 (exclosure) and 94-490 g/m^2 (grazed) in cool temperate; 149-587 g/m^2 (exclosure) and 126-352 g/m^2 (grazed) in subalpine and from 145-539 g/m^2 (exclosure) and 129-310 g/m^2 (grazed) in alpine pastures (Table 4).

Table 4. Contribution to aboveground biomass (g m^{-2}) by selected important species after 2 years of grazing protection (during the month of August)

Study sites	Species	Open-grazed	Exclosure
Yuksam (Warm temperate)	***Eupatorium cannabinum***	39	24
	Plantago erosa	43	-
	Hydrocotyle javanica	34	78
	Fern	38	163
	Pilea scripta	65	81
	Brachiaria sp.	22	148
	Other species	97	146
	Total	337	641
Sachen (Cool temperate)	***Diplazium umbrosum***	75	206
	Pilea scripta	52	81
	Elatostema sessile	71	121
	Urtica dioica	78	79
	Rumex nepalensis	75	18
	Brachiaria sp.	27	87
	Other species	110	101
	Total	488	693
Deorali (Subalpine)	***Potentilla peduncularis***	81	51
	Anemone tetrasepala	42	55
	Poa spp. I	85	252
	Aletris pauciflora	28	76
	Potentilla coriandrifolia	22	56
	Other species	94	97
	Total	352	587
Dzongri (Alpine)	***Potentilla peduncularis***	123	101
	Bistorta affinis	61	78
	Poa spp.	60	181
	Aletris pauciflora	11	51
	Potentilla coriandrifolia	21	58
	Other species	34	70
	Total	**310**	**539**

Highest aboveground biomass was contributed by *Pilea scripta* (19%) in grazed and ferns (25%) in exclosure plots in warm temperate zone; *Urtica dioeca* (16%) in grazed and *Diplazium umbrosum* (30%) in exclosure plots in cool temperate; *Poa* sp. (24% in grazed and 43% in both grazed and exclosure plots) in subalpine and *Potentilla peduncularis* (40%) in grazed and *Poa* sp. (34%) in exclosure plots in alpine zone (Table 5).

In terms of growth forms of plants, the highest biomass was contributed by both undershrubs (31.2% in grazed and 33.2% in exclosure plots) in warm temperate; short forbs (26.2%) in grazed and tall forbs (41.2%) in exclosure plots in cool temperate; cushion and spreading forbs (32.8%) in grazed and graminoides (41.2%) in exclosure plots in subalpine and by cushions and spreading forbs (49.3%) in grazed and graminoides (37.5%) in exclosure plots in alpine zone (Table 6).

Grazing significantly reduced litter accumulation throughout the year at all the altitudinal sites (P<0.0001) but their interaction was not significant. Litter accumulation ranged from 7 to 148 g/m^2 in grazed and between 10 to 212 g/m^2 in exclosure plots in the study area (Table 7).

Grazing did not show significant change in belowground biomass but varied significantly among the different altitudinal sites (P<0.0001). Belowground biomass ranged from 307 to 1143 g/m^2 in grazed plots whereas 402 –1013 g/m^2 in exclosure plots (Table 8). Grazing increased root: shoot ratio of herbaceous plants in all the study sites. Root: shoot ratio increased with increasing altitude. The ratio ranged from 1.20 to 6.54 in grazed and from 0.84 to 5.04 in exclosure plots (Table 8).

Table 5. Contribution to aboveground biomass (%) by different growth forms of herbaceous plants after 2 years of grazing protection (during the month of August)

Study sites	Growth forms	Open-grazed	Exclosure
Yuksam (Warm temperate)	Graminoid	7.3	19.5
	Tall forb	21.5	28.5
	Short forb	15.2	13.5
	Undershrub	31.2	33.2
	Cushion/Spreading forbs	24.8	5.3
Sachen (Cool temperate)	Graminoid	11.2	17.5
	Tall forb	21.6	41.2
	Short forb	26.2	8.6
	Undershrub	21.3	28.5
	Cushion/Spreading forbs	19.7	4.2
Deorali (Subalpine)	Graminoid	19.6	41.2
	Tall forb	12.0	28.1
	Short forb	18.3	13.5
	Undershrub	17.3	10.1
	Cushion/Spreading forbs	32.8	7.1
Dzongri (Alpine)	Graminoid	13.0	37.5
	Tall forb	9.9	27.3
	Short forb	16.3	11.2
	Undershrub	11.5	11.2
	Cushion/Spreading forbs	49.3	12.8

Table 6. Monthly variation in aboveground shoot biomass (g m^{-2}) of herbaceous plants in open-grazed and exclosure plots at different study sites

Study sites	Months	In Year 1		In Year II	
		Open-grazed	Exclosure	Open-grazed	Exclosure
Yuksam	January	104	118	113	156
	April	209	236	226	252
	June	296	423	282	462
	August	310	567	337	641
	October	204	319	216	338
Sachen	January	94	125	101	132
	April	188	251	203	264
	June	306	440	328	443
	August	490	616	488	693
	October	242	297	209	286
Deorali	April	134	157	126	149
	June	297	387	278	389
	August	350	535	352	587
	October	197	253	184	281
Dzongri	April	129	145	134	157
	June	206	381	265	420
	August	243	510	310	539
	October	147	197	161	225

***ANOVA*:** Year $F_{1,704}$=1.75, NS; Site $F_{3,704}$=9.4, P<0.0001; Month $F_{3,704}$=102, P<0.0001; Treatment $F_{1,704}$=103, P<0.0001; Year Month $F_{3,704}$=0.60, NS; Year Site $F_{3,704}$=0.19, NS; Year Treatment $F_{1,704}$=0.44, NS; Month Site $F_{9,704}$=1.47, NS; Month Treatment $F_{3,704}$=12, P<0.0001; Site Treatment $F_{3,704}$=0.65, NS; Year Month Site $F_{9,704}$=0.15, NS; Year Month Treatment $F_{3,704}$=0.11, NS; Year Site Treatment $F_{3,704}$=0.152, NS; Month Site Treatment $F_{9,704}$=0.44, NS; Year Month Site Treatment $F_{9,704}$=1.00, NS; LSD$_{(0.05)}$=40.86.

Table 7. Monthly variation in litter mass accumulation (g m^{-2}) at different elevation study sites

Study sites	Months	In Year 1		In Year II	
		Open-grazed	**Exclosure**	**Open-grazed**	**Exclosure**
Yuksam	January	100	201	103	212
	April	50	77	53	91
	June	47	69	41	88
	August	39	38	37	82
	October	61	82	46	106
Sachen	January	148	172	108	154
	April	93	116	104	135
	June	88	91	78	102
	August	40	46	42	71
	October	63	103	88	111
Deorali	April	48	89	32	77
	June	23	37	20	56
	August	7	10	7	16
	October	13	66	10	73
Dzongri	April	40	80	28	86
	June	23	41	17	61
	August	9	10	7	20
	October	17	70	13	81

***ANOVA*:** Year $F_{1,704}$=13.69, P<0.0001; Site $F_{3,704}$=198, P<0.0001; Month $F_{3,704}$=130, P<0.0001; Treatment $F_{1,704}$=344, P<0.0001; Year Month $F_{3,704}$=1.20, NS; Year Site $F_{3,704}$=3.12, P<0.025; Year Treatment $F_{1,704}$=28, P<0.0001; Month Site $F_{9,704}$=6.01, P<0.0001; Month Treatment $F_{3,704}$=18, P<0.0001; Site Treatment $F_{3,704}$=3.03, P<0.05; Year Month Site $F_{9,704}$=1.27, NS; Year Month Treatment $F_{3,704}$=0.88, NS; Year Site Treatment $F_{3,704}$=2.02, NS; Month Site Treatment $F_{9,704}$=1.87, NS; Year Month Site Treatment $F_{9,704}$=1.20, NS; $LSD_{(0.05)}$=7.95. Data were not included for January month because no sampling was done in January at alpine and subalpine sites (due to snow-cover).

Table 8. Monthly variation of belowground biomass (g m^{-2}) of herbaceous plants

Study sites	Months	In Year 1		In Year II	
		Open-grazed	**Exclosure**	**Open-grazed**	**Exclosure**
Yuksam	April	393	402	315	463
	June	416	463	337	483
	August	489	502	481	536
	October	423	461	402	492
Sachen	April	318	429	307	463
	June	470	489	423	507
	August	593	621	589	668
	October	461	507	423	529
Deorali	April	1016	993	1143	923
	June	917	884	958	863
	August	869	816	848	794
	October	1008	958	1017	1013
Dzongri	April	1016	977	1104	993
	June	933	916	986	907
	August	923	902	927	845
	October	962	948	993	916

***ANOVA*:** Year $F_{1,704}$=0.07, NS; Site $F_{3,704}$=179, P<0.0001; Month $F_{3,704}$=0.53, NS; Treatment $F_{1,704}$=0.09, NS; Year Month $F_{3,704}$=0.075, NS; Year Site $F_{3,704}$=0.039, NS; Year Treatment $F_{1,704}$=0.015, NS; Month Site $F_{9,704}$=4.05, P<0.0001; Month Treatment $F_{3,704}$=0.046, NS; Site Treatment $F_{3,704}$=3.49, P<0.02; Year Month Site $F_{9,704}$=0.087, NS; Year Month Treatment $F_{3,704}$=0.052, NS; Year Site Treatment $F_{3,704}$=0.81, NS; Month Site Treatment $F_{9,704}$=0.174, NS; Year Month Site Treatment $F_{9,704}$=0.142, NS; $LSD_{(0.05)}$=100.

Table 9. Monthly variation in root:shoot ratio in open-grazed and exclosure plots at different study sites

Study sites	Months	In Year 1		In Year II	
		Open-grazed	Exclosure	Open-grazed	Exclosure
Yuksam	April	1.88	1.70	1.40	1.84
	June	1.41	1.09	1.20	1.05
	August	1.58	0.89	1.43	0.84
	October	2.07	1.45	1.86	1.46
Sachen	April	1.69	1.71	1.51	1.75
	June	1.54	1.11	1.29	1.14
	August	1.21	1.01	1.21	0.96
	October	1.90	1.71	2.02	1.85
Deorali	April	5.05	4.21	6.05	4.14
	June	3.09	2.28	3.45	2.22
	August	2.48	1.53	2.41	1.35
	October	5.12	3.79	5.53	3.60
Dzongri	April	5.26	4.48	6.34	5.04
	June	4.53	2.40	3.72	2.16
	August	3.80	1.77	2.99	1.57
	October	6.54	4.81	6.17	4.07

Table 10. Net primary productivity (g m^{-2} $year^{-1}$) of aboveground shoot biomass and belowground biomass in open-grazed and exclosure plots at different study sites after 2 years of grazing protection

Study sites	Plant components	Open-grazed	Exclosure
Yuksam	Aboveground shoot	224	485
	Belowground parts	166	73
	Total	390	558
Sachen	Aboveground shoot	285	329
	Belowground parts	282	205
	Total	567	534
Deorali	Aboveground shoot	163	364
	Belowground parts	169	219
	Total	332	583
Dzongri	Aboveground shoot	109	303
	Belowground parts	66	71
	Total	175	374

Net primary productivity of aboveground biomass of herbaceous plants decreased due to grazing in all the altitudinal sites. Net primary productivity was ranged from 109 to 285 g/m^2/year in grazed and 303 to 485 g/m^2/year in exclosure plots (Table 9).

Grazing increased net primary productivity of plants in both warm and cool temperate zones but reduced in subalpine and alpine zones (Table 10). Due to grazing, the total net primary productivity was reduced by 30% in warm temperate, 435 in subalpine, 53% in alpine but increased by 6% in cool temperate. Net primary productivity of 49 to 62% was contributed by aboveground biomass in grazed plots and from 62 to 87% in exclosure plots (Table 10).

DISCUSSION

Grazing exclosure of grazed pastures showed higher plant density in all seasons. *Poa* spp., which is highly palatable to livestock grazing, was most dominant species under exclosure plots, and its density reduced by 39-45% in grazed plots. It supports the observation of Noy-Meir *et al.* (1989) that the tall perennial and tall annual grasses dominated ungrazed sites, whereas small, prostrate annuals were abundant in the heavily grazed sites. On the other hand, the density of *Potentilla peduncularis* (least palatable to grazing) is much higher in grazed plots (> 50%) as compared to the ungrazed plots. It is widely documented that, as a result of grazing by herbivores, less palatable plants increased at the expense of more palatable ones (Ellison 1960; Thurow *et al.*, 1989; Curry *et al.*, 1990, Tambe and Rawat 2009, 2010). Basal area was generally more in the grazed plots, this might be due to grazing pressure on the top aerial parts resulted expansion at the ground and sub-ground level. A decrease in basal area or density of a species results in a reduction in resource acquisition within the community by that species. A change in species composition then alters the quantity and quality of production and, ultimately, the allocation and flow of energy in the ecosystem (Trlica *et al.*, 1993). Grazing reduced species richness but increased plant diversity. It was observed that the maximum grazing pressure was on the species, which are highly palatable and a detail study on these species will make right prediction of grazing pressure. It was observed that grazing results the species more evenly distributed, which gives an example of the niche space divided randomly, contiguous and non-overlapping segments. Singh *et al.* (1999) while studying the alpine meadow at the same site in the grazed and exclosure plots found 68% higher flowering species in the exclosure plots. Heavy grazing during flowering period might have cause severe effect in propagation especially for annual forbs. Density of monocot plants (highly palatable) decreased due to grazing and on the other hand increased forbs. This indicates that livestock preferred grass than forbs. Basal coverage and aboveground biomass of monocot plants were drastically reduced in grazed plots. This indicates that monocot plants are facing higher degree of grazing pressure. Although, generally monocot plants are propagated through vegetative and are expected to compensate the lost of herbage by grazing just by short duration rotational grazing and intensity.

In the present study the belowground biomass has been reported as 69% in the exclosure and 79% in the grazed plots. It showed that root biomass was decreased due to grazing exclosure. In alpine grasslands, higher amount of root material is considered beneficial for early spring growth (Sundriyal *et al.,* 1995). From 47 to 98% of the total phytomass was reported in belowground parts (Bliss 1966; Dennis *et al.*, 1970; Billings 1973, 1964). Sundriyal *et al.* (1990) reported 70-80% belowground biomass from the western Himalaya. The productivity decreased in grazed plots for all plant components. Lower amount of standing dead and litter material on grazed plots is indicative of cattle activities, which consume maximum green forage from the field and thus leave little chances to move the plant material into standing dead or litter stage.

Grazing increased root-shoot ratio is in contradiction with Sundriyal *et al.* (1990). It reveals that the removals of shoot due to grazing might have corresponds to a faster rate of root biomass reduction. Contrary to it the present study indicates that the shoot removal is slower than the root increment or root development is faster than the shoot biomass grazed. This observation is really an interesting to predict the grazing intensity and the favorable climatic factors supporting root and shoot growth. Singh (2000) indicated that livestock number in warm temperate and subalpine are already crossed the carrying capacity level. Strong scientific management option in these pastures is most urgently needed. Extraction of non-timber forest products especially fuelwood is one major factor responsible for degradation. Besides, concentrate livestock grazing was also observed in these two areas. Forage removal is also very high in warm temperate and alpine. Subalpine is transition zone and resting place therefore trampling causes loss.

CONCLUSION

Within a span of 2 years of grazing protection has resulted a significant change in species number, structure, richness, diversity, biomass (aboveground and litter), and root shoot ratio and annual net primary productivity especially in alpine, subalpine and warm temperate. Aboveground standing biomass regained by 90% in warm temperate, 67% in subalpine and 74% in alpine in very high and that shows the higher intensity of grazing. If the level of pressure has crossed the present limit, herbage compensation will be severely affected and non-palatable species might have proliferated to a higher intensity and larger area. This will definitely reduce the grazing carrying capacity and reduction of pasture quality. The importance of establishing an ecologically sound grazing regime with proper stocking rate in the Khangchendzonga Biosphere Reserve is obvious.

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