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Authors: Bhattarai, Khem Raj, and Upadhyay, Thakur Prasad

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Rangeland Management in Sagarmatha (Mount Everest) National Park and Buffer Zone, Nepal: An Ecological Perspective

***Khem Raj Bhattarai*[1,2]* *and Thakur Prasad Upadhyay*[2,3]**

** Corresponding author: bhattaraikhemraj@gmail.com*

[1] National Herbarium and Plant Laboratories, Department of Plant Resources, Godavari, Lalitpur, Nepal; GPO Box 7426, Sundhara, Kathmandu, Nepal

[2] Himalayan Resources and Development Centre (HIRDEC); GPO Box 7426, Sundhara, Kathmandu, Nepal

[3] Lakehead University, Faculty of Natural Resources Management, 955 Oliver Road, Thunder Bay, Ontario P7B5E1, Canada

Sustainable management of rangeland ecosystems has direct implications for conservation of biological diversity and for the livelihoods of local communities in the Himalayan region in general and the Sagarmatha National Park and Buffer Zone (SNPBZ) in particular. This study aims to analyze the status of rangeland management in the SNPBZ from an ecological perspective. We used multivariate and bivariate analysis and geographic information system techniques to analyze ecological data and land use trends. A significant annual change with a 3.38% decrease in glacier area was observed between 1978 and 1996. We observed 168 plant species in the SNPBZ with a range of 3–17 species per sample plot, where about 67% of plants were found to be palatable for livestock. Our study shows that total available fodder biomass on rangeland in the SNPBZ has not been fully utilized yet, because the total available supply exceeds the present demand under some assumptions: reduction of biomass through grazing causes higher productivity, resulting in a higher number of species, according to the intermediate disturbance hypothesis. The results of this study could help improve decision-making related to sustainable rangeland management.

Keywords: *Land use change; floristic composition; species richness; carrying capacity; rangeland ecosystem; Nepal.*

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Introduction

Currently, the dilemma of rangeland management is related to debates about the state of biodiversity and its relationship to productivity, biomass, and disturbance by grazing (Grime 2002). For instance, if some biomass is removed by grazing, the regeneration phase (secondary succession) will show higher productivity than the original mature vegetation. The disturbed vegetation with lower biomass but higher productivity may be characterized by an elevated number of species, according to the intermediate-disturbance hypothesis (Connell 1978; Grime 1979; Huston 1994). This hypothesis has generally been accepted (Katriona et al 2004) and has been verified in the Himalayas (Vetaas 2002; Bhattarai et al 2004). This may have greater implications for rangeland management, especially for traditionally managed conservation areas in Nepal.

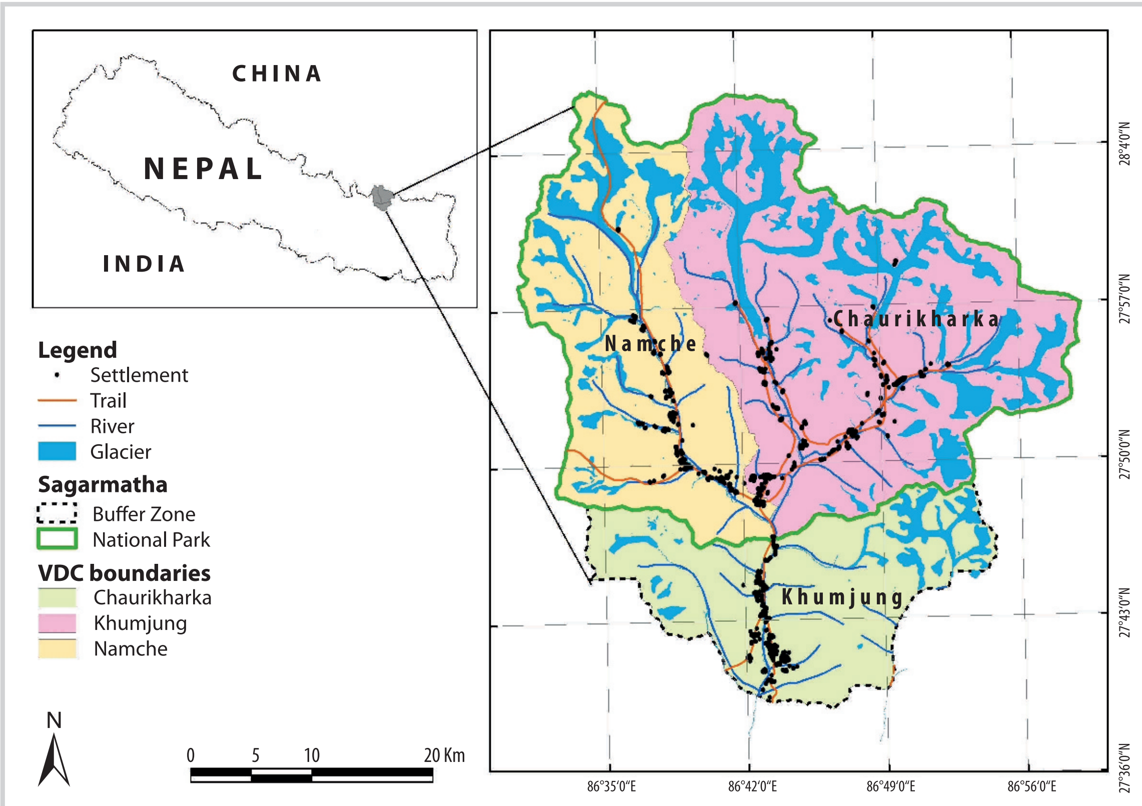
Rangeland in the Sagarmatha (Mount Everest) National Park and Buffer Zone (SNPBZ) is not just a resource for sustaining livestock but also one rich in biodiversity, including medicinal and aromatic plants. It is also a main source of other natural resources, as well as a tourist destination, a carbon sink, a valuable cultural landscape, a place for recreation and aesthetic value, and a landscape of spectacular scenery (Miehe 1989; Brower 1991). However, sustainable management of the rangelands in the Himalayan region has generally not followed an approach in line with sound ecological studies due to inadequate knowledge and lack of information that is available in integrated scientific studies (Weltz et al 2003).

In this context, the present study analyzes the status of rangeland management in the SNPBZ from an ecological perspective and identifies the future course of holistic, sustainable rangeland ecosystem management. The specific objectives of the study are to explore land use patterns, rangeland conditions in relation to vegetation distribution, species diversity, and productivity and to identify possible management recommendations for better long-term management of Himalayan rangelands.

Status of the debate: the ecological perspective on rangeland management

The effects of grazing by livestock on plant species diversity have not yet resulted in a consensus on the

FIGURE 1 Location map of study area. (Sources: Modified from Department of Survey 1996 toposheet; Field Survey 2007; map by the authors)



management of rangeland (eg Zervas 1998). Some authors suggest that moderate grazing increases plant species diversity (eg Grace 1999; Bhattarai et al 2004), while others report the opposite (eg Perelman et al 1997). The humped-back model suggests that herbaceous species diversity reaches a maximum at intermediate biomass that corresponds to moderate grazing (Grime 1973). Beyond the maximum, species diversity declines due to increased competition. According to this model, herbivores and livestock grazing may increase or decrease species diversity, depending on the grazing intensity and amount of available biomass. The decline of species diversity with high biomass in the absence of grazing is normally explained by competition, whereas less competitive species are replaced by one or a few dominant species (Grime 1973). The decrease in species diversity with low biomass is associated with high-intensity grazing. Thus, decrease in species diversity due to the absence of grazing and heavy grazing is the crucial factor in sustainable management of rangeland.

Early efforts imposed economic management models based on equilibrium carrying capacities (Gillson and Hoffman 2007). In the 1990s, however, the "new ecology" gained ascendancy and challenged the equilibrium models by exploring the variability and flux inherent in most ecological and social systems (Briske et al 2003). Recently, a synthesis viewpoint has emerged that suggests accommodating the concepts from both models to better manage the given rangeland. Various studies have shown that a mixture of palatable woody plants and perennial herbaceous species is replaced through heavy grazing by a system dominated by unpalatable woody species and annuals (eg Landsberg et al 2003; West 2003). Succession from herbaceous to woody vegetation depends on rainfall, grazing intensity, nutrient availability, and fire regime in the rangeland (Huston 1994). If the rangeland is maintained without grazing, the less competitive species will be excluded; ultimately, there will be a few dominant species (Gillson and Hoffman 2007). Thus, the main ecological issue on rangeland is how to maintain optimum conditions that help sustain the rangeland over the long term.

Methodology

Study area and climate

The SNPBZ is located in Solukhumbu District in the eastern part of Nepal. The Sagarmatha National Park (SNP) is located 27°41′59″–28°13′11″N, 86°30′55″–86°59′05″E in the Himalayan range, with an area of approximately 1130.97 km^2 (Figure 1). The buffer zone is located 27°38′38″–27°48′25″N, 86°33′30″–86°49′45″E,

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covering about 280.97 km^2. The SNPBZ has a rugged landscape of great mountains, interdigitating glaciers and ridges, glacial debris-burdened streams, hanging microvalleys, and constricted fluvial terraces (Hagen 1969; Brower 1991). The SNPBZ encompasses temperate to alpine vegetation zones.

The SNPBZ covers 3 village development committees (VDCs), namely, Chaurikharka as a buffer zone and Namche and Khumjung as core areas of the SNP in the northern part of Solukhumbu District (Figure 1). The national park shares its border with Makalu-Barun National Park to the east, Rolwaling (Dolakha) to the west, Chaurikharka VDC to the south, and Qumolongma National Reserve of Tibet to the north. The national park is a government organization that works with a set of government policies, rules, and regulations, whereas the buffer zone is managed by a buffer zone management committee within each village that takes care of location-specific issues by collaborating with the national park authority.

About 80% of precipitation falls from June to September and about 10% falls from May to October in the SNPBZ (Miehe 1989). The monsoon rains arise from the Bay of Bengal and fall most heavily on the south-facing slopes. Frequent thunderstorm activity also occurs during April and May. The month of July is the wettest month for Khumjung (Miehe 1989), with all rivers and lakes reported to be full, a pattern that is applicable to the Khumbu region (Brower 1991). Winter snowfalls arrive with frontal systems borne on the westerlies. The climatic station located in Namche Bazar at an elevation of 3450 m has recorded 1166.14 mm mean annual precipitation, a 12.15°C mean annual maximum temperature, a 1.08°C mean annual minimum temperature, and a 6.6°C mean annual daily temperature (DOHM 1999).

Field survey and data collection

Fieldwork for the study was carried out twice, in April and November 2007. According to the information obtained from participatory rural appraisal (PRA) and focus group discussion (FGD), we broadly divided the rangeland into 3 categories on the basis of grazing pressure and pattern of cattle movements: (1) winter grazing rangeland, ie grazing land near the village where livestock graze during winter; (2) transit rangeland, where livestock are kept 1–2 months in April and May on the way to summer pasture and in the autumn (1–2 months) on the way back to village settlement before winter; and (3) summer rangeland *(mainkharka),* ie the main rangeland located in alpine pasture areas. Preliminary physiographic information about the SNPBZ was gathered from study of toposheet and FGDs with SNPBZ staff and local people. The rangeland area is highly heterogeneous, encompassing the river basin, valley, mountain terrain, and cliffs. In this study, rangeland is classified as a combination of grasslands and bush or scrublands managed as natural ecosystems that are traditionally used for grazing (eg James et al 2003).

Due to the significant heterogeneity of the study area, a stratified random sampling method was used to cover the major representative sites. The principle of stratification is that the vegetation of the area under study is divided into different strata before samples are chosen on the basis of major and usually obvious variations within it (Gauch 1982). Among those strata, we selected most representative types. Sampling plots were then allocated randomly to those strata. We sampled 160 plots on three categories of rangeland. The plot size was fixed at 1×1 m, a standard size for study of grassland vegetation (Kent and Coker 1995; Bhattarai et al 2004). The distance between one plot and the next was randomly chosen as 1–50 m. If a plot touched a large stone or woody shrub, the location was moved 1 m farther. But small saplings of woody species and seedlings of tree species were considered other herbaceous flora (eg Bhattarai et al 2004). All vascular and nonvascular plants, including mosses rooted inside 1 m^2 plots, were recorded (Grime 1979). Plant identification was done on the field for some familiar plants; for the rest, identification was done at the National Herbarium and Plant Laboratories in Godawari, Nepal.

We clipped the standing biomass at approximately 0.5–1 cm above ground-level vegetation and harvested from the 10 most representative plots in each category of rangeland to estimate dry matter production from the rangeland. The harvested biomass was dried in the field. The dry weight was taken 5 days after harvesting and continued until a constant weight was obtained (Wheeler and Shaw 1991).

Data analysis

Both bivariate and multivariate statistical methods were used to explore the relationship between species composition and measured environmental variables. To elucidate the relationship between species richness (diversity) and elevation, a generalized linear model (GLM) was used (McCullagh and Nelder 1989; Dobson 1990). The species richness is defined as the number of species present per 1 m^2 plot, which is a surrogate measurement of biodiversity (Gaston and Spicer 1998). The number of species per plot, ie species richness, is a discrete data set that requires a logarithmic link function, so GLM was used rather than traditional regression methods.

The vegetation data were analyzed by ordination technique, which is the collective term for multivariate analysis. We used detrended correspondence analysis (DCA) to check the magnitude of change in species composition along the first ordination axis (Hill and Gauch 1980).

A geographic information system (GIS) was used to classify and obtain the areas under different land uses in the SNPBZ. During field observation, some errors regarding land use and land cover were identified on the topographic map (Department of Survey 1996 toposheet). One of the major errors on the topographic map concerned distribution of grazing land and barren land,

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TABLE 1 Land use change in the SNPBZ between 1978 and 1996.

Land use/cover	Within SNP core area 1996 (ha)	Chaurikharka/ buffer zone 1996 (ha)	Total land area 1996 (ha)	% of total land area 1996	Total land area 1978 (ha)	Annual % change
Barren land	65,133	11,818	76,951	54.50	66,708	0.80
Settlement and agriculture	632	497	1129	0.80	1212	−0.39
Forest	4521	4346	8867	6.28	8338	0.34
Glacier	20,371	1856	22,227	15.74	34,304	−2.38
Rangeland	20,976	9253	30,229	21.41	29,942	0.05
Sand	975	300	1275	0.90	520	5.11
Water body	489	27	516	0.37	170	6.36
Total area	11,3097	28,097	141,194	100.00	141,194	

including rocks. Even local people marked such errors on the topographic map during community mapping procedures. Other available land use maps of the region, prepared by different organizations and agencies, were also found to be misleading. So an attempt was made to prepare a land use map of the SNPBZ area based on a Land Satellite (Landsat) image from 1978 (30 m resolution), a topographic map for 1996, and information from community mapping procedures. No recent toposheet was found to compare the land use categories, so we compared the land use patterns between 1978 and 1996. Information from field observations, participatory mapping, and FGDs and interviews concerning land cover history were used to classify the images.

Satellite images were classified on the basis of a supervised maximum likelihood classification method (ERDAS 1997). During the assigning of signatures (training samples) for supervised classification and later finalizing of the layer, information from participatory mapping and field observations was heavily incorporated. First, 2 layers of land use maps (one from the Landsat Thematic Mapper image and another from the topographic map) were prepared. The derived land use layers were overlaid. Portions that did not match exactly were verified through field observations and information from community mapping. The final land use map of the SNPBZ was prepared by combining the layers: the previous layer of proportion matching and the verified and corrected layer of the portion not matching exactly.

Results

Land use patterns and grazing lands

In the SNPBZ we observed 7 types of land use patterns. The major land use patterns in the SNPBZ and their changes between 1978 and 1996 are presented in Table 1. Snow cover and glacier area declined, and the land was classified in the category of barren land, as shown by the positive growth of the barren land category and the negative growth of the glacier category. Positive growth in rangeland area was found, which appears to have resulted from decreased glacier and increased barren land.

There are 3 types of rangelands in the SNPBZ: winter grazing, transit grazing, and summer grazing rangeland. Livestock are kept in transit rangeland on the way back to a village settlement before winter commences. When snow has melted and grass has developed to the full green stage, the livestock extend to higher areas and are kept there during the whole summer and autumn from May to October; this is referred to as summer rangeland. Figure 2 shows a map of rangeland in the SNPBZ, prepared based on PRA information, which details the distribution patterns for summer, transit, and winter pasture.

Vegetation patterns

The major tree species observed between 2800 and 3000 m in the buffer zone area were *Quercus semecarpifolia, Tsuga dumosa, Michelia doltsopa, Pieris formusa, Lyonia ovalifolia, Pinus wallichiana, Rhododendron arboreum*, and *Ulnus nepalensis*. In general, the subalpine zone of SNPBZ forest is dominated by *Quercus, Tsuga, Pinus,* and *Rhododendron.* The major tree species observed in the 3000–4000 m range were *Q. semecarpifolia, T. dumosa, M. doltsopa, P. formusa, L. ovalifolia, P. wallichiana,* and *R. arboreum.* The major shrub species observed were *Berberis asiatica, Piptanthus nepalensis, Xanthoxylum nepalensis, Arundinaria* sp, *Daphne bholua, Rosa* sp, *Elaeagnus parvifolia, R. lepidotum,* and *Jasminum humile.* The major herbaceous flora in this range were *Artemisia* sp, *Gentiana strobilacea, Euphorbia wallichii, Stipa roylei,* and *Poa* sp.

Within the buffer zone, forest is dominated by *P. wallichiana,* which accounts for about 60% of the forest cover, *T. dumosa* accounts for about 10%, and

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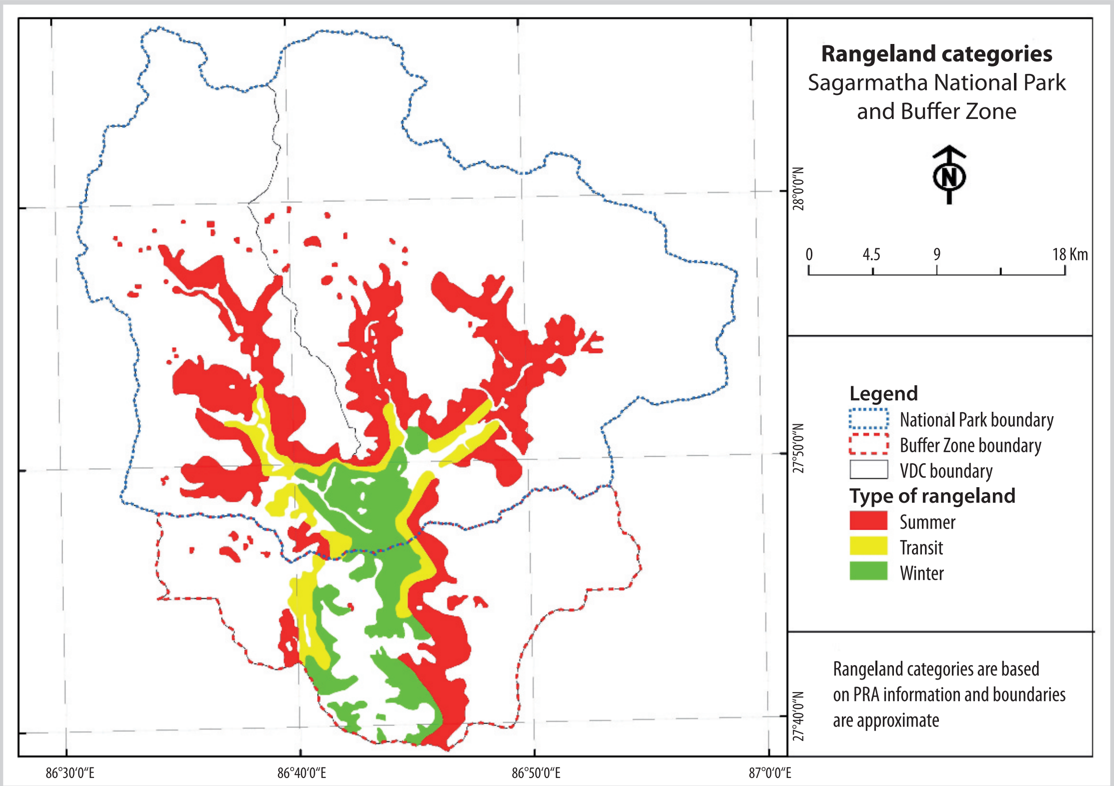
FIGURE 2 Distribution map of pastures in the SNPBZ. (Sources: Modified from Department of Survey 1996 toposheet; Field Survey 2007; map by the authors)



Rhododendron and *Q. semicarpifolia* account for about 20% of the total forest cover. The tree line forest is mainly dominated by *Juniperus* sp on the slope exposed to the east, but the moist slope exposed to the north is dominated by *Betula* sp. Above 4000 m, there is an alpine vegetation belt where the vegetation is dominated by shrubs (*R. anthopogon, R. lepidotum, J. recurva, J. indica, Berberis* sp, *Rosa* sp, and *Hippophae* sp) and alpine meadows. The upper elevation limits for *Abies spectabilis, P. wallichiana,* and *B. utilis* were found to be between 4000 and 4300 m. The upper alpine zone extends to 5200 m, which is the normal vegetation limit for the SNPBZ. In high alpine meadow, the major dominant genera of grasses and sedge were *Stipa, Juncus, Kobresia,* and *Carex.* Similarly, there were species of forbs, mainly *Saxifraga, Pedicularis, Cremanthodium, Gentiana,* and *Stellaria.*

Species richness along the elevation gradient

To check the plant diversity pattern in the SNPBZ, the total species found on the rangeland were regressed against elevation; statistically significant patterns between species richness and elevation were observed. When total species are divided into forbs and grasses and each class of species is regressed against the elevation, no statistically significant pattern between grass and elevation was observed. However, the relationship between forbs and elevation was found to be statistically significant (Table 2).

Floristic composition

The number of observed species on 160 sample plots was 168. The range of species richness per plot varied from 3 to 17. The life-form spectrum of rangeland species is presented in Figure 3. The forbs include all herbaceous species except sedge and grasses and are the most dominant group, accounting for 62% of the total number of species. The grasses included species belonging to Graminae, Juncaceae, and Cyperaceae families, accounting for 29%, and woody species, accounting for 9% of all flora (Figure 3). The most frequently available grass species were *S. roylei, Trisectum spicatum, Kobresia hookeri,* and *S. capensis,* which had frequencies of 71, 40, 39, and 36%, respectively. The least frequent grass species were *Agrostis* sp, *Digitaria* sp, *Juncus* sp, *P. falconeri,* and *Stipa* sp, which had only a 1.25% frequency. Five poisonous species were found in the SPBZ, namely, *Bupleurum tenue, L. ovalifolia, P. formusa, Euphorbia* sp, and *R. campanulatum.* The degree of toxicity varied from plant to plant and season to season. Animals generally avoid these plants but sometimes graze them accidentally and become sick, if small amounts are eaten, or perish, if significant amounts are eaten.

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TABLE 2 Summary of regression statistics.

Species	GLM order	df	Res. dev.	% dev.	*F* value	*P* value
Total species	1	158	153	10	9.0	$P < 0.010$
Forbs	1	158	147	11	21.5	$P < 0.001$
Grass	ns	158				ns

df, degree of freedom; Res. dev., residual deviance; % dev., % deviance explained; ns, not significant.

The summary of DCA is presented in Table 3. The lengths of the gradients for two axes were estimated at 5.76 and 3.94 SD. When sample plots from the buffer zone were separated from the total data set, the gradient length was found to be SD = 3.95, which is still close to 4 SD.

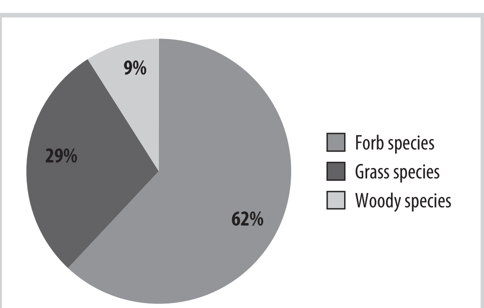
The eigenvalue for the first DCA axis was larger than 0.5, which indicates good dispersion of species along the axes. When plots in the buffer zone area were separated, the eigenvalue was still close to 0.5, indicating good dispersion of species (Table 3). The variance explained by both axes was found to be relatively low but was statistically significant.

The species composition pattern for the SNPBZ is presented in a DCA diagram (Figure 4A). Species were found to be homogeneously dispersed along two DCA axes. In the DCA diagram, some species are located near one another, some are located a little farther apart, and some overlap. The closely located species have more similar ecological characteristics and requirements than those found far apart.

In another DCA analysis, where total species were classified into 3 groups, (1) forbs, (2) woody, and (3) grasses, species were found to be homogenously dispersed along the first DCA axis to some extent, whereas along the second axis the forbs and woody species were found to have a longer range of dispersion compared to the grasses (Figure 4B). Relatively more grass species were found in the central part of the DCA diagram. Species found at the edge of the diagram are often rare species.

DCA analysis was performed with samples plots within the core park areas according to 3 rangeland types: winter grazing, transit or intermediate grazing, and summer grazing. Three categories of rangeland are well separated along DCA axis 1 in terms of species composition. The winter grazing plots are located at the bottom of DCA axis 1. The plots in the transit rangeland have an intermediate position in the DCA diagram. The plots of summer rangeland are located toward the end of DCA axis 1. The summer grazing plots are more dispersed along DCA axis 2 compared to their dispersal along axis 1 (Figure 4C).

FIGURE 3 Percentage of plant groups in the rangelands of the SNPBZ.



Biomass production and carrying capacity

Among 168 rangeland species, approximately 67% are palatable and only about 33% were found to be nonpalatable to livestock; the latter are neither grazed by livestock nor used by people for hay production. According to field observations and PRA and FGD information, all grass species including sedges were found to be palatable to livestock, whereas some forbs and woody species of rangeland are not palatable. We considered only palatable biomass, which was estimated from all categories of rangelands (winter grazing, transit grazing, and summer grazing) and buffer zone areas in the SNPBZ (Table 4; Figure 5). The biomass ranged from 30 to 250 g/m^2. The mean biomass production was found to be 119.41, 113.06, 76.34, and 64.60 g/m^2 in the buffer zone (Lukla area), winter grazing, transit grazing, and summer grazing rangelands, respectively. When the buffer zone was excluded from the calculation, the mean biomass was estimated to be 3.36 g/m^2, including all rangeland categories in the SNPBZ.

Livestock weight of 1000 pounds was considered 1 livestock unit (LSU; Manske 2004), and in our case an adult *zopkio* (a cross between yak and cow) was considered 1 LSU, because its weight approximates this value. The fodder consumption requirements in the field were recorded as per this reference. Besides *zopkio,* the body weight of other grazing livestock in the SNPBZ was relatively low; therefore, total number of *yak/nak,* horses, and mules was factored out, with 0.7 (and cows with 0.6), to convert their values into LSU (HMGN/ADB/FINNIDA 1988). Our estimates of livestock population in the field survey were assumed to cover approximately 70% of total number livestock; hence, to get the total number of livestock, we multiplied the given numbers by 1.3, thereby getting an estimate for total LSU in the SNPBZ of 3935. The consumption requirements per LSU while grazing on *kharkas* were averaged from the different estimates obtained through PRA and FGD, which was

TABLE 3 Summary of DCA results for plots in the SNPBZ.

Ordination axis	I	II	III	IV	Total inertia
Eigenvalues	0.76	0.44	0.30	0.26	11.73
Lengths of gradient	5.76	3.94	3.07	3.73	
Cumulative percentage variance	6.50	10.20	12.80	15.00	

estimated at 15.6 kg of dry matter per day. Thus, the total fodder requirement for the total LSUs in the SNPBZ per year was estimated at 22,405.89 tons; this constitutes the demand side of the carrying capacity calculation.

To calculate the total supply of palatable fodder from the given rangeland area, we computed the estimates as follows: the mean total biomass production per year was estimated at 2.96 tons per hectare in the SNPBZ, and according to field information, out of a total rangeland area of 30,229 ha, about 35% either was not grazed due to inaccessibility factors or was covered with scrub and thus did not yield the effective supply of fodder for the livestock in the SNPBZ. This means only 19,649 ha of rangeland provide the fodder supply, with a total of 58,161 tons per year. Of this estimate of total fodder supply, only 67% is palatable, so the actual palatable biomass available to the livestock per year was estimated

FIGURE 4 (A) DCA ordination diagram: species are distributed along the two axes, with scale marks −2 to 8 along axis 1 (horizontal) and −2 to 6 along axis 2 (vertical) in standard deviation units; (B) DCA ordination diagram showing distribution of grasses, forbs, and woody plant species on rangeland in the SNPBZ; the scale marks −2 to 8 along axis 1 (horizontal) and −2 to 6 along axis 2 (vertical) are in standard deviation units; (C) ordination diagram of DCA (horizontal axis 1 and vertical axis 2) of 140 sample plots of rangeland within the park. Plots are well dispersed along two DCA axes.

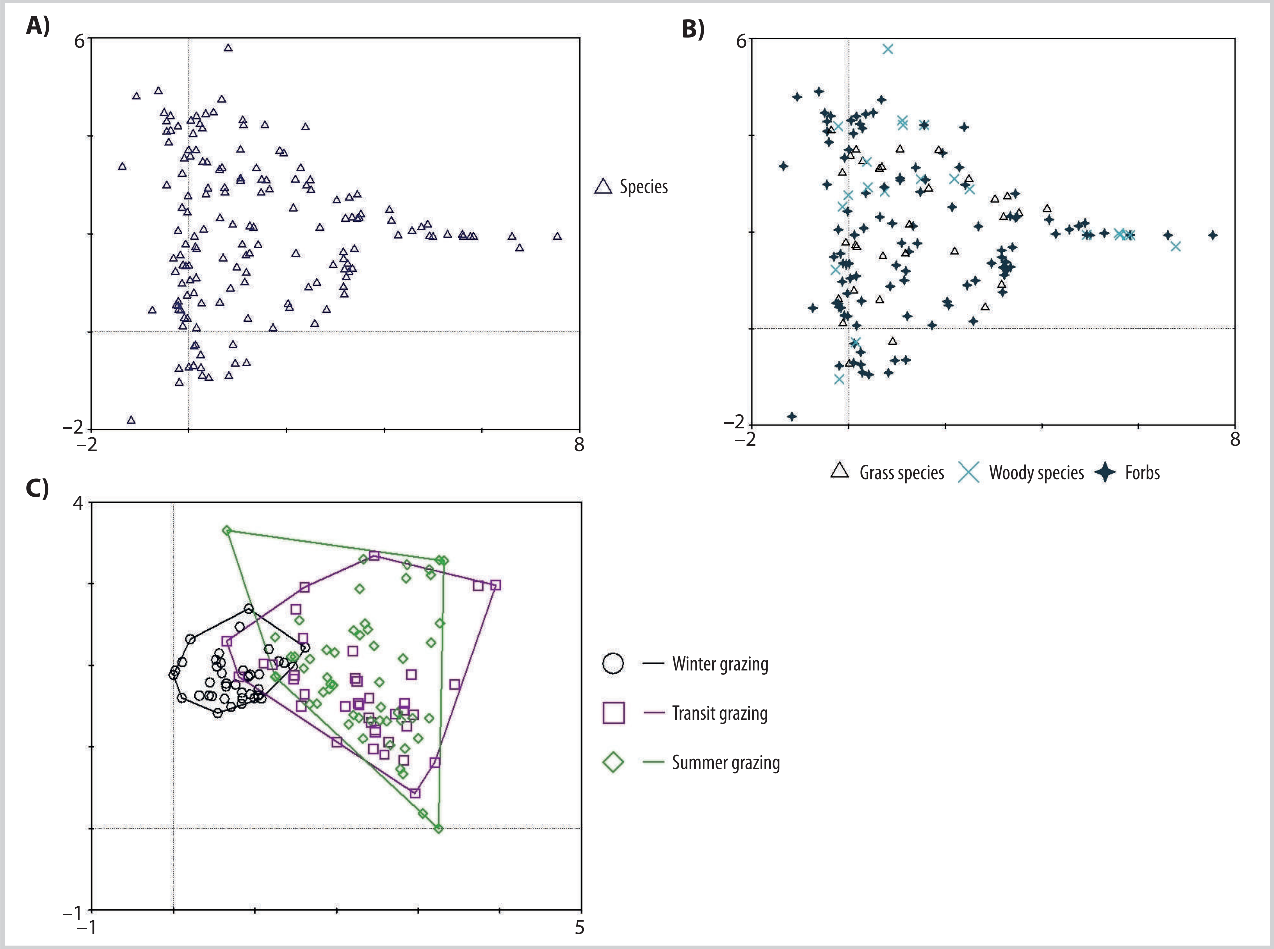


TABLE 4 Summary statistics on dry matter production (1×1 m) plots in the SNPBZ.

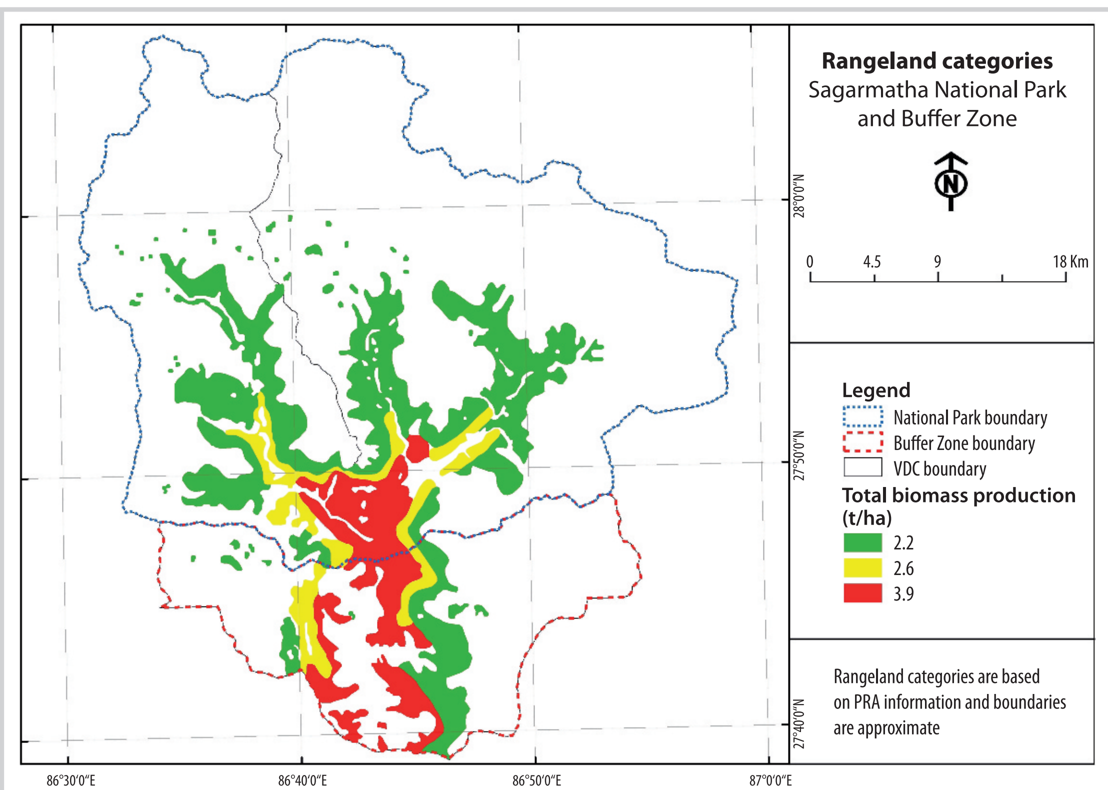
Variables	Winter grazing	Transit grazing	Summer grazing	Buffer zone, Lukla
Mean (g/m^2)	113.06	76.34	64.60	119.41
Standard error	5.75	5.08	4.77	11.29
Median	100.00	60.00	52.50	120.00
Standard deviation	40.27	32.52	33.70	46.57
Sample variance	1621.68	1057.53	1135.55	2168.38
Range	200.00	90.00	150.00	140.00
Minimum	50.00	30.00	30.00	40.00
Maximum	250.00	120.00	180.00	180.00

at 38,967.87 tons, giving a surplus biomass of 16,561.98 tons.

Discussion and conclusions

From 1978 to 1996, the snow cover and glacier area declined, with the land then classified in the barren land category, as shown by positive growth of the barren land category and negative growth of the glacier category. This increased barren land category was attributed to climate change and global warming. Positive growth in rangeland area might be due to decreased glacier and increased barren land. The portion of cultivated land was relatively small in the core area of the SNP and somewhat more abundant in the buffer zone, indicating less dependence on agriculture. The share of rangeland area was found to be 23.5%, indicating the importance of rangeland for livestock production, which is inextricably

FIGURE 5 Biomass production in pastures of the SNPBZ. (Sources: Modified from Department of Survey 1996 toposheet; Field Survey 2007; map by the authors)



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linked with agriculture and the local economy in the SNPBZ.

The SNPBZ is a species-rich area, as indicated by variations of 3 to 17 per 1 m^2 sample plot. Species richness decreased linearly with increase in elevation. Altitude, aspect, climate, and history control the plant distribution pattern in general (Woodward 1987). The complex interaction of these biophysical factors and to a lesser extent social factors influences the vegetation pattern of the SNPBZ, as well as others parts of the Himalayas. The SNPBZ encompasses part of the cool temperate zone (2800–3000 m) and the whole subalpine and alpine zones. Even below the tree line ecotone on some mountain flanks facing eastward and too windy for forest vegetation, a few hardy forbs, grass, lichens, and mosses were found, with low growth forms and high resistance to the constraints of winds, insulation, temperature, and a short growing season, as found on high alpine pasture.

The SNPBZ has a higher percentage of forbs and grasses, which may indicate the severity of climatic conditions. This finding is in line with the findings of previous studies by Woodward (1987) and Bhattarai and Vetaas (2003) in the Himalayan region. In terms of floristic composition, we found a heterogeneous distribution of plant species. This was confirmed by the length of the gradient in the total data set, which had a value of 5.76. A gradient length greater than 4 indicates that sites at opposite ends of the first axis had hardly any species in common (Lepš and Šmilauer 2003). Furthermore, the core area of rangeland inside the park did not show a homogeneous species composition. Each site ie rangeland in the SNP and buffer zone, if taken separately, represents lower beta-diversity than both combined. The eigenvalue for the first DCA axis is greater than 0.5, which indicates good dispersion of species along the axes. The separation of 3 rangeland types along the DCA axes indicates that there is a grazing pressure gradient from winter to summer and species respond correspondingly, which is reflected in their composition.

Of the total species observed, the majority were palatable. Previous studies have shown that the ratio between palatable and nonpalatable species occurs according to grazing pressure (Walker 2003). The high biomass production was found in the rangelands with lower elevation compared to rangelands with higher elevation. The cold and windy conditions, low temperature, shorter growing period, and stressful situation limit biomass production in high alpine pastures (Bhattarai et al 2004). However, present estimates of biomass are from earlier stages of herbaceous vegetation, which was just emerging from the ground. According to PRA and FGD information, when herbaceous vegetation attains its full stage of maturity, biomass becomes about 3 to 4 times greater than the present production, so we estimated the final biomass by multiplying the present biomass by 3.5.

Calculation of rangeland carrying capacity with respect to balance between fodder requirements for a given number of LSUs and fodder supply on a given rangeland area is important. We estimated the total annual edible biomass on the rangeland of the SNPBZ at 38,967.87 tons, with a surplus biomass value of 16,561.98 tons, while calculating the total present demand of livestock. These estimates imply that the total available fodder biomass on the rangeland of the SNPBZ has not been fully utilized yet, and there is scope for addition of livestock to balance the demand and supply of the biomass (an additional 2909 LSU could be added to the system). However, these estimates should be viewed with caution, because there are other factors involved in biomass production and consumption in the rangeland ecosystem. For example, there are other large herbivores (wild ungulates, eg deer, wild sheep, and wild goat), small herbivores (mice, rabbits, etc), and insects who also depend on rangeland biomass. Thus, available biomass not only is for livestock but is utilized by wild animals as well. This study focuses on issues related to wild herbivore grazing and biomass reduction in the rangeland; a separate study dealing with this pertinent issue of wild ungulates is warranted.

The dilemma of rangeland management in the SNPBZ is basically related to the debate about the state of biodiversity and its relationship to productivity as affected by various degrees of grazing and livestock density. Because the total biomass production exceeds the actual demand for livestock in the SNPBZ, moderate disturbance by grazing might favor greater species diversity, thereby enhancing rangeland productivity (Grime 1979). This requirement of a moderate level of grazing would not be met in the future due to gradual decline in livestock population in the SNPBZ, which would lead to future rangeland deterioration. Rangeland deterioration has already been noticed in other high mountain areas, with various factors understood as causing this change, depending on whose perspective is taken into account (Liechti 2012). This indicates that to manage the rangeland properly, the ecological and socioeconomic perspectives need to be integrated.

The following recommendations for the future management of rangeland in the SNPBZ are made based on the findings of this study. The number of livestock should be augmented in the SNPBZ to maintain moderate disturbance by grazing. A complete inventory of plant species and their communities should be undertaken, and thereafter palatability and nonpalatability of these plants need to be verified. Among the verified palatable plants, a detailed nutrition analysis should be conducted to determine the usable value of a given palatable plant. This study was able to list some plants in the SNPBZ and has covered about 70% of the total flora. A detailed study of population dynamics among the most palatable and dominant species should be undertaken to understand spatial, age, and size structures in terms of demographic parameters.

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