CHAPTER II

THE STUDY AREA, OBJECTIVES, SOIL AND CLIMATE

2.1 THE SIKKIM HIMALAYA

Sikkim, a tiny Himalayan state in the northeastern India with 7096 km^2 area falls in the Eastern Himalayan range and lies between 27°4′46″ to 28°7′48″ N latitude and 88°55′25″ to 88°58′ E longitude, extending approximately 114 km from north to south and 64 km from east to west, with parallel ranges of mountains like a staircase from north to south. The state is bounded in the north by the Tibetan Autonomous Region of the People's Republic of China, in the east by Bhutan and the Chumbi Valley of Tibetan Autonomous Region of the People's Republic of China, in the west by Nepal and in the south lies the Darjeeling Gorkha Hill Council of West Bengal (Fig. 2.1). The elevation range of the state varies from as low as 300 m in the valleys to as high as 8598 m being the height of massive Khangchendzonga. Owing to such high variations in elevation, the climatic conditions vary from subtropical to temperate to alpine to snowline. The subtropical zone has better growing conditions throughout the year, whereas the temperate zone showed greater seasonality, which further sharpens in the alpine areas where snow perpetuates virtually for five months during winter.

Sikkim has a wide spectrum of cultural diversity culminating from major ethnic groups such as Lepchas, Bhutias, Limboos and Nepalese. The Lepchas are the aboriginal of Sikkim and are predominantly Buddhists. The Bhutias are the people of Tibetan origin. The people of Nepalese origin have migrated to Sikkim in large number from the middle of the nineteenth century. At present, Nepalese are the dominant community constituting nearly 80% of the total population of the state (Verma 1995). Nepalese are primarily agriculturists and they introduced the terrace system of cultivation.

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and virtually brought large tracts of hilly terrain into food grain cultivation including large varieties of other crops in the region.

The state is divided into four administrative districts viz. North (district headquarter at Mangan), South (at Namchi), East (at Gangtok which is also the capital of the state) and West district (at Gayzing). The rich natural and cultural heritage of Sikkim makes this small Himalayan state an attractive destination for international and domestic tourists (Rai & Sundriyal 1997). The state has high potential for religious, nature, recreational, adventure and aesthetic tourism. The tourism is rapidly becoming an important sector of economic activity for Sikkimese people as nearly 1,50,000 tourists from the country as well as abroad visits the state each year. State Tourism Department has provided facilities for tourists by constructing trekker huts in trekking corridors and maintenance of trekking trail. The state government is taking up steps to increase quality and responsible tourism (ecotourism), and has developed a Master Plan for tourism development. The most popular tourist destinations are Yuksam-Dzongri-Goecha La trail, Khecheopalri lake (regarded as one of the most sacred lake in Sikkim), Tshangu lake, Nathu La, Pelling, Pemayangsey Monastery, Tashiding Monastery, Rumtek Monastery, etc. The Khangchendzonga Biosphere Reserve in the state has many trekking trails, the most popular one is Yuksam-Dzongri-Goecha La tourist trekking corridor, which extends to a length of 45 km length within the biosphere reserve, covering three main ecological zones viz. temperate (<3000 m), sub-alpine (3000-3800 m) and alpine (>3800 m). This trekking corridor is a representative of all the available climatic, geographical and biological features of the Khangchendzonga Biosphere Reserve. The present study deals with Yuksam-Dzongri trekking corridor.

2.2 THE KHANGCHENDZONGA BIOSPHERE RESERVE

The Khangchendzonga Biosphere Reserve falls between 27°25′ to 27°55′ N latitude and 88°3′ to 88°38′ E longitude in the West and North Districts of Sikkim. It was given the status of National Park on the 27th August 1977 with a total area of 846 km^2. Due to it's biological, ecological and landscape significance the area of this park was further extended to 1784 km^2 in 1996. Considering the biological diversity, habitat types and uniqueness of the area, the former Khangchendzonga National Park along with further some more surrounding areas (total area of 2619.9 km^2) has been recently (7th February 2000) notified (No. J-22016/76/91-BR) as Khangchendzonga Biosphere Reserve. The location map of the Khangchendzonga Biosphere Reserve and other protected areas of Sikkim are presented (Fig. 2.1).

As such the biosphere reserve has many glaciers, most prominent and largest amongst them is Zemu glacier. The lofty Mt. Khangchendzonga (Kanchanjunga) forms the highest peak with 8598 m elevation and is the third highest mountain peak in the world. The Mt. Khangchendzonga literally means 'Abode of the Gods' and consists of five 'treasure houses' indicating the other five adjacent peaks, which are the guardian deity of Sikkim. These adjoining peaks are Mt. Narsing (5825 m), Mt. Pandim (6691 m), Mt. Simvo (6811 m), Mt. Kabur (7338 m) and Mt. Siniolchu (6888 m). The scenic, aesthetic, religious and natural beauty which is provided by the unique topography and landscapes along with the forest and pasture wilderness almost in pristine set up and wild flowers of varied forms and colours in the reserve forms the main attraction, which draws nature lovers and trekkers from all over the world.

The alpine zone consists of three main grazing pastures, namely Dzongri, Thangsing-Samiti and Chawrigang-Basecamp, covering an area of 1360 ha. There are areas, which are not conducive for grazing due to steep and unpalatable bushy vegetation. The sub-alpine zone pasture, which is closer to timberline, has an approximate area of about 200 ha which separates from alpine area through a distinct timberline. This zone extends from Tshoka, which is the last human settlement area, upto Deorali (Fig. 2.2). The area between Tshoka and Yuksam falls in temperate zone (cool and warm) dominated by thick forest cover. The cool temperate has an area of about 200 ha pasture and while the warm temperate has 800 ha. Total pasture area is 2560 ha which forms the present study sites. About 62.5% of the pasture area are conducive for active grazing. The details of the pasture names, location, altitude, size of the pastures are given in Table 2.1. The present research work was undertaken in "Sikkim Biodiversity and Ecotourism" (SBE) Project.

2.2.1 The Sikkim Biodiversity and Ecotourism Project

The Sikkim Biodiversity and Ecotourism (SBE) project was a collaborative initiative designed to conserve the biological diversity of key destinations in Sikkim. The present project aimed to support the development of viable enterprises which would provide sustained incentives and support for local communities and the Sikkimese tourism industry to effectively protect the unique biodiversity at major nature tour sites (Anonymous 1995). The project was highly participatory which links enterprise operation with conservation action, while merging traditional cultural practices. The broad areas of activities of SBE project were: (i) biodiversity conservation and destination enhancement (which included

enterprise stakeholder biodiversity conservation, and enterprise destination site enhancement), (ii) ecotourism marketing (mainly consisted of tourist market analysis, and market promotion), (iii) entrepreneurial skill & product development- it composed of community ecotourism entrepreneurial skills, and production and marketing of indigenous products, tour operations, management and products, and (iv) planning, monitoring and applied research (which mainly consisted planning and policy development, enterprise monitoring, socio-economic monitoring, biodiversity monitoring, and community resource management research). The present piece of work was undertaken as a part of monitoring and applied research with a goal to increase knowledge of key relationship between habitat structure, species composition and human activities related to tourism, especially livestock grazing in order to protect biodiversity and grassland pastures and forest related to fodder tree species in a sustainable way. The Sikkim Biodiversity and Ecotourism project focused on Khangchendzonga Biosphere Reserve the then Khangchendzonga National Park and surrounding areas in West Sikkim for applied research on livestock grazing. The main sites for the work undertaken in SBE project were on Yuksam-Dzongri trekking corridor.

2.2.2 Yuksam-Dzongri Trekking Corridor

In the Khangchendzonga Biosphere Reserve exists Sikkim's major trekking route, the Yuksam-Dzongri-Goechha La trail, which is exhilarating climb through dense forests and past impressive mountain views. The forests and alpine meadows are some of the most biologically diverse in India and composed of some of 36 species of Rhododendrons, 400 species of orchids and many other flowering plants. The reserve and surrounding

areas also contain a large proportion of 144 mammals, 550 birds, and 600 butterfly species that are recorded from Sikkim state (Lepcha 1997). This trekking corridor receives about 2000 national and international tourists every year. At the trailhead is Sikkim's first capital, Yuksam, from where tourists can visit several places of attractions such as archeological ruins of the old palace at Norbu Gang and "Dubde" which is Sikkim's oldest monastery. Yuksam and Tshoka settlement comprises of ethnics such as Lepchas, Bhutias, Nepalese, Limboos and Tibetan refugees. Subsistence agriculture is the main livelihood. However in recent years, the increased tourism activities have drawn the attention of local people and they have diversified their activities to tourism during trekking season. Some of the important sectors of communities involvement in tourism are services provided as porters, trek cooks, guides, pack animals owners, lodge operators and vegetable growers. Besides, the area also provides important pasturage for local and transhumance herders who graze their yaks, dzos, cows, horses and sheep on many pastures along with entrepreneurs owning pack animals for trekking groups and mountaineers. A large number of dzos and horses are engaged as pack animals during tourist season (March to May and September to November). A large number of sheep, cows, and yaks use alpine pasture during April to October for forage. The reserve is frequently visited by local communities for fuel, food and fodder collection, and the demand has increased tremendously during recent times (Rai & Sundriyal 1997). Use of firewood while on trekking is another issue being handled separately by the project. The continuous grazing, collections of fodder, fuel wood and trampling by animals have left visible signs of deterioration. This has seriously affected the vegetation, soil and habitat of certain areas. There are certain questions that need to be answered for

devising the management strategies in KBR. These questions are (i) Is grazing adversely affecting the vegetation? (ii) How the plant communities respond to livestock grazing with particular reference to their structure, biomass productivity and nutrient cycling? (iii) What is the approximate stocking and carrying capacity level for this area? and (iv) What are the management options available for overgrazing areas? There is a need to draw an immediate attention for seeking the answers to above questions which can be utilized for the management of pastures in the Khangchendzonga Biosphere Reserve for biodiversity conservation and economic benefits needs for the local communities.

2.3 HYPOTHESES

The preliminary field surveys in the Khangchendzonga Biosphere Reserve in early 1996 helped in drawing two hypotheses regarding livestock and grazing in Yuksam-Dzongri areas.

Hypothesis 1: Increased number of tourists will require more pack animals and milk products; local villagers will respond to this demand by increasing the number of;

(i) Dzo and horse for carrying loads

(ii) Cattle, yak and sheep for milk and dairy products like cheese

Hypothesis 2: This will result in increased grazing pressure on alpine and forest pastures resulting the following changes;

(i) Decrease in abundance of grazing palatable plant species and increase non-palatable plant species

(ii) Change in species composition

(iii) Decrease in standing biomass and productivity of pastures

(iv) Change in nutrient content of plant species

(v) Change in frequency of seedling and sapling of tree species in forested pastures

(vi) Change in soil properties and increase in nutrient loss from grazing-land system

2.4 OBJECTIVES

In order to test the above hypotheses the study was devised with the following objectives:

1. To understand the general vegetation composition, animal rearing pattern along the trekking corridor and its economic utility.
2. To analyze the impact of grazing on plant structure, species richness and diversity at selected locations at four different vegetation zones.
3. To estimate impact of grazing on biomass and productivity of different plant communities.
4. To analyze nutrient status and cycling under grazing and protected conditions.
5. To evaluate current stocking rate and grazing carrying capacity at different vegetation zones.

The study presents a compilation on grazing livestock, agriculture linkages and also impact of livestock grazing on vegetation, nutrient and soil properties. Economic return from livestock was evaluated and linkages of grazing on rangeland and biodiversity of forested pasture have been developed that would help drawing management and conservation plans.

2.5 EXPERIMENTAL EXCLOSURE PLOTS

The present study focused to see the impact of livestock grazing on vegetation and soil along the Yuksam-Dzongri trail in Khangchendzonga

Biosphere Reserve. The exclosure plots establishment for protection of vegetation from grazing was decided after discussion with experts and reserve managers. Representative vegetation locations were selected along the trail and fenced with barbed wire of 10×10 m size (n = 4 at each site) to protect the vegetation from livestock grazing and trampling. The locations of the four ecological zones for establishments of the exclosures were made at the warm temperate forested site at 1700 m; cool temperate forested site at 2100 m; sub-alpine/near timberline at 3800 m and alpine pasture at 3900 m asl. The ground vegetation plant communities of the four study sites were designated as *Pilea-Eupatorium-Silaginella* community (warm-temperate); *Elatostema-Pilea-Rumex* community (cool-temperate); *Poa-Potentilla-Geranium* community (subalpine) and *Bistorta-Poa-Potentilla* community (alpine). Open-grazed corresponding sites having similar vegetation structure, composition, slope aspect, etc. were also designated for comparative impact assessment of livestock grazing. The location map showing the experimental exclosure plots have been provided (Fig. 2.2).

2.6 SOIL PROPERTIES

Soil moisture, bulk density, porosity, texture, pH, total nitrogen, total phosphorus and organic carbon were estimated at two soil depths (0-15 cm and 15-30 cm) at the different ecological zones following standard methods (Piper 1949; Jackson 1967; Birkeland 1984; Anderson & Ingram 1993).

2.6.1 Physical

Soil moisture content was higher in upper (0-15 cm) depth at all the study sites. The value ranged from 23.8 to 29.0% in (0-15 cm) soil depth and 18.9 to 24.9% in (15-30 cm) soil depth at four sites (Table 2.3). The bulk density increased with the soil depth that ranged from 1.08 to 1.18 g

cm^{-3} in (0-15 cm) and 1.18 to 1.23 g cm^{-3} in (15-30 cm) soil depth. Soil porosity increased with altitude ranging from 39.2 to 54.3% in upper (0-15 cm) and 43.8 to 60.0% in lower (15-30 cm) soil depths. Generally, the soil of alpine site had higher clay and sand proportion than the soil of other sites. Subalpine site at Deorali had maximum silt percentage. Gravel per cent was higher in lower temperate site at Yuksam (Table 2.3). Clay proportion was more in higher elevation which ranged from 4.2 to 10.9% in (0-15 cm) and 5.7 to 14.0% in (15-30 cm) soil depth. Silt content also showed the similar trend like clay whose range varied from 6.1 to 11.5% in (0-15 cm) and 4.5 to 11.3% in (15-30 cm) soil depth. There was no marked difference in sand content of upper and lower soil layers. Sand ranged from 37.6 to 52.0% in (0-15 cm) and 36.1 to 62.0% in (15-30 cm) soil depth. Gravel content decreased with increasing altitude having a range of 25.6 to 51.0% in (0-15 cm) and 15.6 to 52.0% in (15-30 cm) soil depth (Table 2.3).

2.6.2 Chemical

At Yuksam, soil pH was 5.17 in (0-15 cm) soil depth and 5.06 in lower (15-30 cm) depth; at Sachen 5.29 (0-15 cm) and 5.26 (15-30 cm) depth; at Deorali 4.53 (0-15 cm) and 4.94 (15-30 cm) depth and 5.41 (0-15 cm) and 4.93 (15-30 cm) depth.

At Yuksam, total nitrogen concentration of soil was 0.481% (0-15 cm) and 0.413 (15-30 cm) depth; at Sachen 0.530% (0-15 cm) and 0.443% (15-30 cm) depth; at Deorali 0.551% (0-15 cm) and 0.511% (15-30 cm) depth; at Dzongri 0.406% (0-15 cm) and 0.31% (15-30 cm) depth. The lowest value of nitrogen was recorded in alpine pasture at Dzongri. Its concentration was always higher in upper compared to lower soil depth.

At Yuksam, soil total phosphorus content was 0.029% (0-15 cm) and 0.019% (at 15-30 cm) depth; at Sachen 0.018% (0-15 cm) and 0.016% (15-30 cm) depth; at Deorali 0.03% (0-15 cm) and 0.028% (15-30 cm) depth and at Dzongri 0.019% (0-15 cm) and 0.024% (15-30 cm) depth. Except for Dzongri alpine pasture other sites showed that total phosphorus was higher in upper soil depth compared to lower depth.

At Yuksam soil organic carbon was 5.56% (0-15 cm) and 3.24% (15-30 cm) depth; at Sachen 4.83% (0-15 cm) and 4.53% (15-30 cm) depth; at Deorali 5.86% (0-15 cm) and 4.81% (15-30 cm) depth and at Dzongri 4.46% (0-15 cm) and 4.66 (15-30 cm) depth. All the three sites except the four alpine pasture site at Dzongri showed that the organic carbon was higher in upper soil depth (Table 2.4).

2.7 CLIMATE

Temperature (minimum and maximum) and rainfall data were recorded for three climatic zones in the Khangchendzonga Biosphere Reserve during the study period. The three weather stations were located at Yuksam (1700 m), Tshoka (3000 m) and Dzongri (3900 m) along the Yuksam-Dzongri trail. These locations were selected keeping in view of the three ecological zones viz. temperate, subalpine and alpine. Daily records were made on minimum and maximum temperatures and rainfall at each station by employing locals who were trained before giving the responsibility. In order to provide the information on overall weather conditions, data of a temperate site (1900 m amsl at Pangthang) using dataloger based Campbell Scientific Inc, (USA) automatic weather station established by GBPIHED was used.

2.7.1 *Temperature*

A maximum temperature of 24°C was recorded in the month of August at temperate site while minimum was 3.8°C in January. Sub-alpine was a bit cooler with maximum temperature of 16.1°C (September) and minimum of -3°C (January). Alpine zones was under snow cover for at least five (November-March) months during winter, ice melted in April and again are mostly covered by snow in November. Here, the maximum and minimum temperatures were recorded as 13°C (August-September) and -8°C (January), respectively. After the snow melt in April, temperature rises promoting the growth of new shoots and most plants produced flowers during July and August. Temperature is one of the keys environmental for plant growth especially in alpine zone. Data on temperature for all the three locations are given in Fig. 2.2.

2.7.2 *Rainfall*

Annual rainfall of 3760 mm was recorded in temperate zone (maximum rainfall of 1279 mm in August). Comparatively, sub-alpine has slightly lesser average annual rainfall of 3648 mm (maximum rainfall of 985 mm in August). The maximum rainfall occurred in the month of August in all the study sites, which contributed more than 30% of the total annual rainfall. In alpine region maximum rainfall was recorded in August (720 mm) with a total annual rainfall of 2319 mm. The main precipitation during the months between December to March was in the form of snow at the alpine zone.

The snowmelt at alpine site starts in the beginning of April. This resulted in abundance of soil moisture even prior to the monsoon rain. Thus contrary to the situation of lower valley, where the period is very dry, in alpine areas soil moisture was high from start of the growing season. Prior

to the rainy season, cloud and fog formation was a constant phenomenon at high altitudes, which not much prevalent at the lower valleys. With the onset of rainfall the plants show good growth. Rainfall is equally important as temperature for luxurious vegetation growth. Rainfall and temperature in the eastern Himalaya are higher compared to central and western Himalaya, and thus vegetation growth is fast and species richness are very high in the eastern Himalaya.

2.7.3 *Climatic data of temperate zone*

The climatic data recorded by G.B. Pant Institute of Himalayan Environment and Development (GBPIHED) during 1994-96 through automatic weather station for temperate zone are pooled and the mean values are presented (Fig. 2.3). The minimum rainfall (23.8 mm) was recorded in December while the maximum (686.5 mm) in July (which contributes by 18.2%) with the total average annual rainfall of 3771.5 mm. A minimum air temperature of 2.56°C was recorded in January while the maximum was 23.66°C during July. Mean monthly relative humidity ranged between 73.18% to 97.19% which was least during April and highest in July. Rainy season had the highest relative humidity, followed by winter and short summer season. The soil temperature at 10 cm depth was recorded 15.11°C, highest being 20.34°C in July while lowest being 9.12°C in January. Mean soil temperature at 20 cm depth was recorded to be highest 20.36°C in July and lowest 8.85°C in February. Photosynthetic active radiation (PRA) was recorded to be highest (655 μ mol s^{-1} m^{-2}) in the month of April and lowest (357 μ mol s^{-1} m^{-2}) in September. Higher PRA was received during the rainy season (Fig. 2.3). ■

Table 2.1 Study area location at different ecological zones and their characteristics along the Yuksam-Dzongri trail of Khangchendzonga Biosphere Reserve

Ecological zones	Pasture name	Elevation range (m)	Slope range (terrain)	Length of the pasture (m)	Breadth of the pasture (m)	Area of the pasture (ha)	Area of the pasture conducive to active grazing (ha)
Temperate (warm)	Yuksam	1700-2000	Steep slope (40-60°)	4000	2000	800	700
Temperate (cool)	Sachen	2000-3000	Medium slope (20-50°)	2000	1000	200	160
Subalpine	Deorali	3000-3800	Gentle slope (10-30°C)	2000	1000	200	140
Alpine	Dzongri	3800-4000	Gentle slope (10-30°C)	3000	2000	600	250
	Thangsing-Samiti	3800-4200	Gentle slope (10-30°C)	8000	700	560	200
	Chawrigang-Basecamp	3900-4200	Gentle slope (10-30°C)	4000	500	200	150
Total						2560	1600

Table 2.2 Experimental plots locations (grazing exclosure) and their dominant vegetation along the Yuksam-Dzongri trail (exclosure established during 1997; size 10×10 m; $n = 4$ each at each location).

Exclosures /location	Altitude (m)	Geographical position	Plant community	Dominant ground vegetation
I (Yuksam)	1700	27°22′11″N & 88°13′22″E	*Eupatorium – Pilea-Silaginella*	*Pilea scripta, Pilea umbrosa, Silaginella* sp., *Eupatorium cannabinum, Hydrocotyle javanica, Astilbe revularis, Cyanotis vaga*, etc.
II (Sachen)	2100	27°24′51″N & 88°11′59″E	*Pilea-Rumex-Elatostema*	*Elatostema sessile, Rumex nepalensis, Silaginella* sp., *Brachiaria* sp., *Plantago erosa, Pilea umbrosa*, Ferns, etc.
III (Deorali)	3800	27°28′7″N & 88°10′2″E	*Poa-Potentilla-Geranium*	*Poa* spp., *Potentilla peduncularis, Anemone tetrasepala, Geranium nakaoanum, Aletris pauciflora,* etc.
IV (Dzongri)	3900	27°28′52″N & 88°9′38″E	*Poa-Bistorta-Potentilla*	*Poa* spp., *Bistorta affinis, Potentilla peduncularis, P. microphylla, Potentilla coriandrifolia, Gentiana* spp., etc.

Table 2.3 Physical properties of soils at four elevation sites along the Yuksam-Dzongri trail (during 1998).

Study site	Soil depth (cm)	Moisture content (%)	Bulk density (g cm^{-3})	Soil porosity (%)	Soil texture (%)			
					Clay	Silt	Sand	Gravel
Yuksam	0-15	23.9±1.2	1.18±0.11	39.2±3.1	5.3±0.3	6.1±0.1	37.6±1.3	51.0±0.8
	15-30	21.6±0.8	1.23±0.06	43.8±2.6	6.7±0.6	5.1±0.1	36.1±1.7	52.1±1.5
Sachen	0-15	23.8±0.9	1.17±0.16	46.8±2.4	4.9±0.2	7.1±0.2	49.0±0.4	39.0±0.7
	15-30	18.9±1.8	1.20±0.13	50.2±1.1	5.9±0.7	4.5±0.1	48.0±0.8	41.6±0.8
Deorali	0-15	26.2±1.6	1.13±0.09	54.3±1.6	4.2±0.1	10.9±0.3	39.0±0.6	40.0±1.7
	15-30	24.1±1.2	1.21±0.09	46.0±1.8	5.7±1.2	11.3±0.7	41.4±1.7	41.6±1.9
Dzongri	0-15	29.0±1.3	1.08±0.11	53.2±2.2	10.9±0.8	11.5±1.1	52.0±1.6	25.6±0.8
	15-30	24.9±0.9	1.18±0.11	60.0±3.4	14.0±1.3	8.4±0.8	62.0±2.2	15.6±0.3

Table 2.4 Chemical properties of soils at four elevation pastures along the Yuksam-Dzongri trail (during 1998).

Study site	Soil depth (cm)	Soil pH	Total nitrogen (%)	Total phosphorus (%)	Organic carbon (%)
Yuksam	0-15	5.17±0.06	0.481±0.003	0.029±0.001	5.56±0.13
	15-30	5.06±0.13	0.413±0.012	0.019±0.002	3.24±0.07
Sachen	0-15	5.29±0.08	0.530±0.031	0.018±0.001	4.82±0.07
	15-30	5.26±0.03	0.443±0.027	0.016±0.001	4.53±0.04
Deorali	0-15	4.53±0.14	0.551±0.009	0.030±0.003	5.86±0.11
	15-30	4.94±0.04	0.511±0.026	0.028±0.001	4.81±0.08
Dzongri	0-15	5.41±0.11	0.406±0.011	0.019±0.002	4.46±0.06
	15-30	4.93±0.11	0.310±0.008	0.024±0.001	4.66±0.07

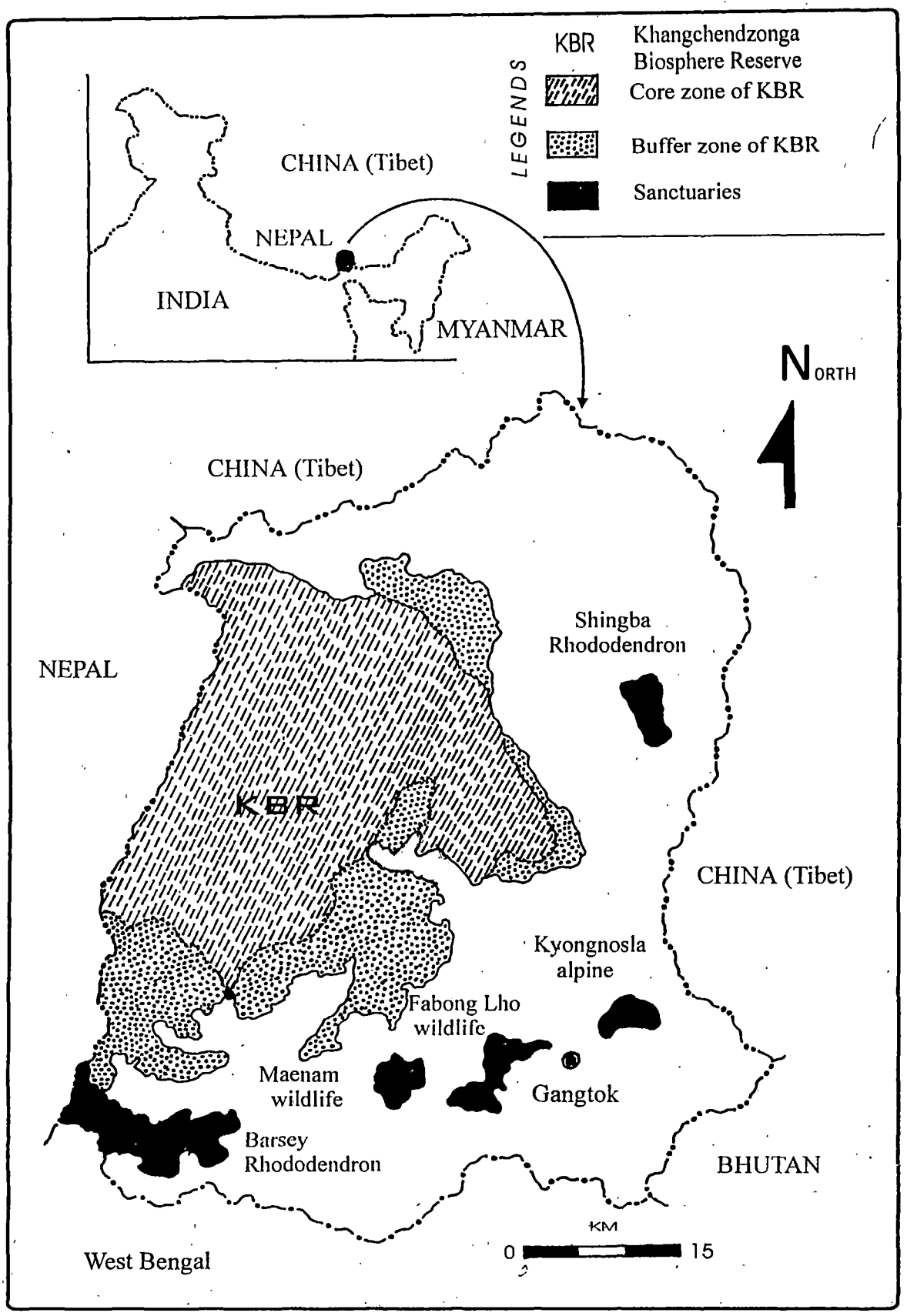

Fig. 2.1 Location map showing the protected areas in Sikkim

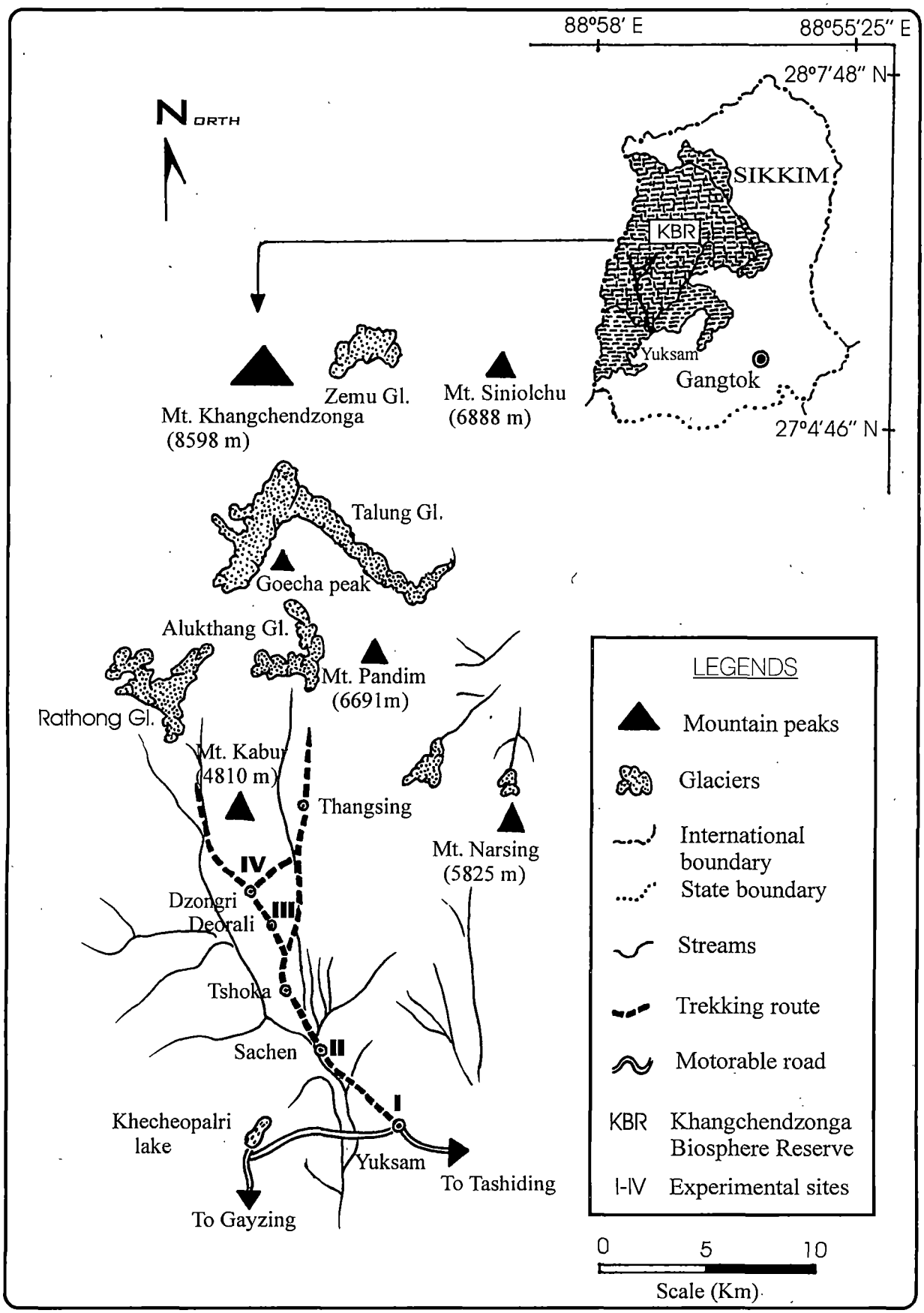

Fig. 2.2 Location map showing livestock grazing exclosure sites along the Yuksam-Dzongri trail in Khangchendzonga Biosphere Reserve

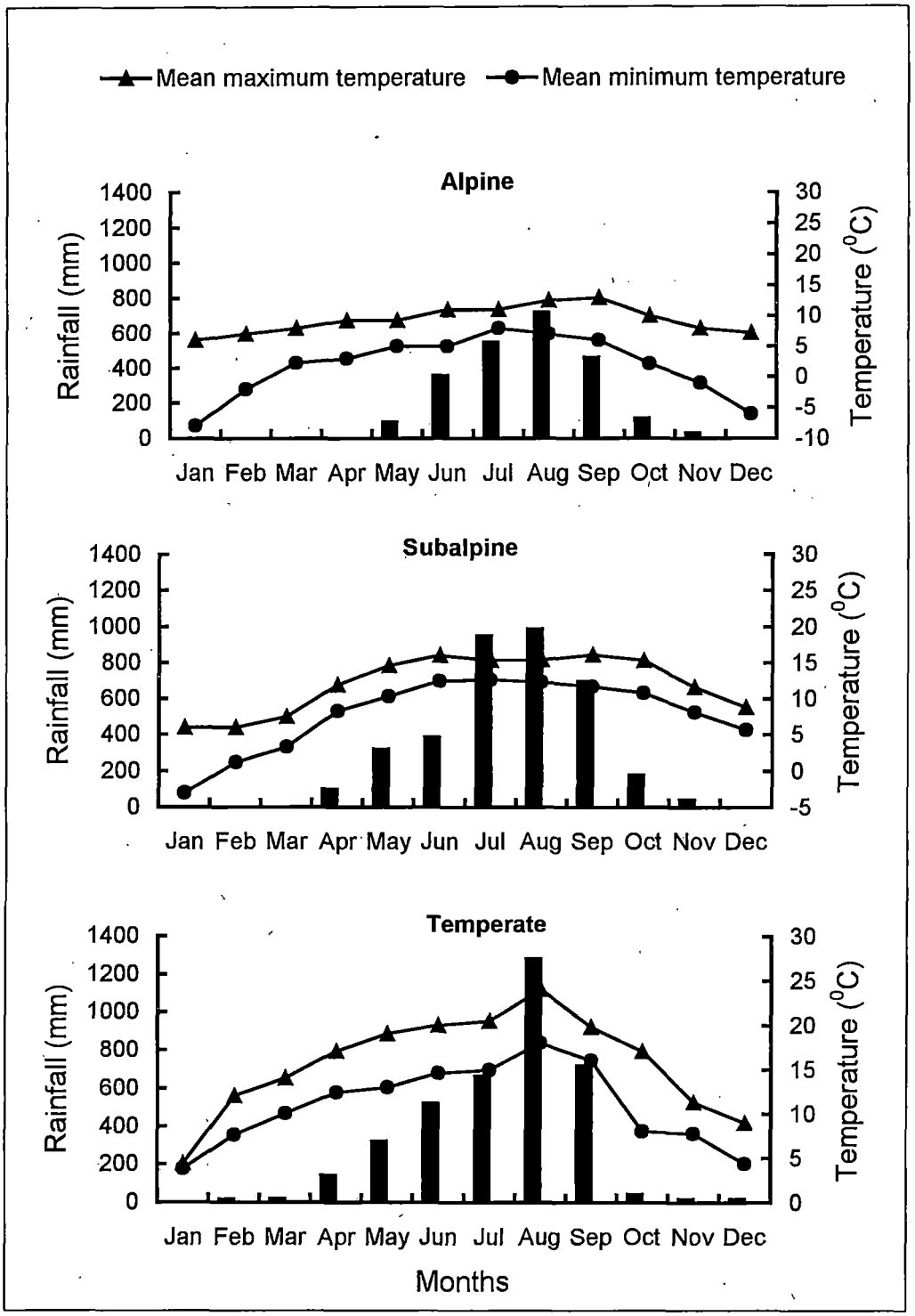

Fig. 2.3 Climatic data of the study area [alpine zone at Dzongri (3900 m), subalpine zone at Tshoka (3000 m) and temperate zone at Yuksam (1600 m) along the Yuksam-Dzongri trail in Khangchendzonga Biosphere Reserve (record for 1998)

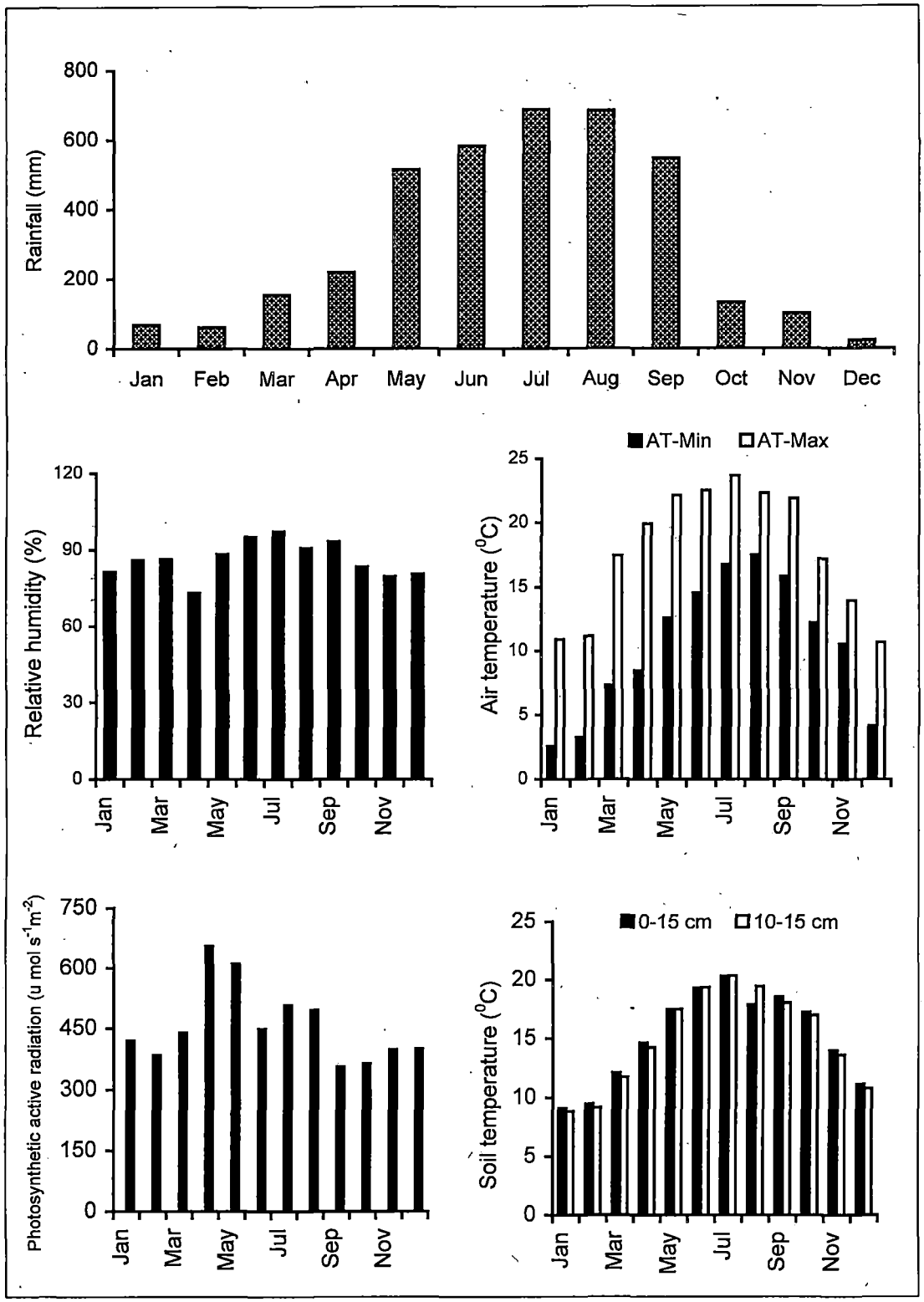

Fig. 2.4 Weather data for temperate zone at Pangthang (elevation 2000 m) for the Sikkim Himalaya (values pooled for 3 years: 1994-96)