GRAZING IMPACT ON PLANT DIVERSITY AND PRODUCTIVITY ALONG A TOURIST TREKKING CORRIDOR IN THE KHANGCHENDZONGA BIOSPHERE RESERVE OF SIKKIM

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for the degree of

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in

SCIENCE (BOTANY)

By

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I have a great pleasure in forwarding the thesis of Mr Huidrom Birkumar Singh, M.Sc. (Botany), entitled "Grazing Impact on Plant Diversity and Productivity along a Tourist Trekking Corridor in the Khangchendzonga Biosphere Reserve of Sikkim" for the degree of *DOCTOR OF PHILOSOPHY IN SCIENCE (BOTANY)*.

This is to certify that the research work presented in the thesis is original and taken up by him under our supervision at the Sikkim Unit of the Institute.

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I have a great pleasure in forwarding the thesis of Mr. Huidrom Birkumar Singh, M.Sc. (Botany), entitled "***Grazing Impact on Plant Diversity and Productivity along a Tourist Trekking Corridor in the Khangchendzonga Biosphere Reserve of Sikkim***" for the degree of DOCTOR OF PHILOSOPHY in Science (Botany).

This is to certify that the thesis is a piece of original research work carried out by him under our guidance at the Sikkim Unit of the Institute. He fulfills all the conditions prescribed by North Bengal University as well as by the Institute.

11 May 2000

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Contents

PREFACE

THE "Himalaya" is the name applied in ancient India to the great snowy mountain ranges where the snow remains throughout the year. It is regarded as the largest, youngest, loftiest and most fragile mountain systems in the world that stretches about 2500 km long and 240 to 340 km in breadth, and occupies an area of 2,36,000 km^2 in India. It was originated by the tectonic breakup of Gondwanaland and subsequent drift and collision of peninsular plate (Decan plateau) out of the bed of Tyeth Sea some 140 million years ago. It supports successively, subtropical, temperate, subalpine and alpine vegetation in response to increasing elevation.

Seasonal animal migration between alpine meadows and lower elevation forested areas is a common strategy for securing sufficient forage for grazing animals in the Himalayan region. The Indian Himalayan alpine pastures cover an area of about 1.7 million hectares. The Himalaya supports 20 million cattle, 10 million buffaloes, 3 million sheep and 6 million goats. Sikkim Himalaya constitute around 3% of the Indian Himalayan geographical area and support more than 2,00,000 cattle, 3000 buffaloes, 16,300 sheep, 1,15,000 goats, 5400 yaks & dzos and 1800 horses. There has been an observable sign of deterioration of Himalayan pastures due to overgrazing in the past few decades and management of these pastures has become a major issue. As far as livestock grazing is concerned, there has been no report available for the Sikkim Himalaya. Scientific baseline information data on livestock grazing and its causative effect on pasture health are prior need in formulation of grazing management regime. The present thesis deals with livestock-agroforestry-rangeland-tourism linkages in the Khangchendzonga Biosphere Reserve of Sikkim Himalaya.

The transformation of half-baked ideas into an acceptable form takes patience, time and more than a fair amount of good guidance. The culmination of my shaky ideas into a presentable forms owes much to the patience and guidance of my supervisors, Dr. Eklabya Sharma, FNASc, Scientist 'D' and Incharge, Sikkim-

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The Mountain Institute (TMI) has facilitated the work along with the other collaborators of the Sikkim Biodiversity and Ecotourism (SBE) Project such as Travel Agents Association of Sikkim and The Green Circle.

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In the course of the work, I have had the opportunity to profitably interact with different experts and the discussions with them have helped me not only for the purpose of this thesis, but also in getting a better understanding of the subject. I gained much by having discussions with Dr. Sonam Paljor, Principal Director, Animal Husbandry and Veterinary Dept., Government of Sikkim; Prof. J.S. Singh, Banaras Hindu University, Varanasi; Prof. A.N. Purohit, Director High Altitude Plant Physiology Research Centre (HAPPRC), Garhwal; Prof. S.P. Singh, Head, Dept. of Botany, Kumaun University, Nainital; Prof. R.D. Gaur, Head, Department of Botany, H.N.B. Garhwal University, Garhwal; Drs. Rhodney Jackson and Alton Byer, Consultants, TMI; Drs. R.K. Maikhuri, G.C.S. Negi, Hem Rikhari, Dhrupat Chaudhury, Uma Sankar and T.C. Upretti of GBPIHED, Dr. M.C. Nautiyal, Senior Scientist, HAPPRC; Dr. Ajit Kumar, Salim Ali Centre, Coimbatore.

I am indebted to Mr. Renzino Lepcha, Project Officer of SBE for his ability to mobilize the local communities and graziers whose information was valuable in understanding livestock-rangeland-agriculture-tourism linkages. Mr. Nakul Chettri, Ms. Iyatta Maharana and Ms. Bidhya Pradhan of SBE Project are highly thankful for their cordial support and help. Mr. M.V.S. Manian's help in computer works made do away fear of handling computers. I would like to record my special thanks to Mr. Bhanu R. Sharma, who always assisted me during the field study trips, without his support it would have been difficult for me to conduct tough trekking at the high altitude sites.

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The librarians of the G.B. Pant Institute of Himalayan Environment and Development, Almorah, Ratan Tata Library, New Delhi, Banaras Hindu University, Varanasi and Kumaun University, Nainital allowed and extended help during library consultation.

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(Huidrom Birkumar Singh)
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List of Tables and Appendices

List of Figures and Photoplates

CHAPTER I

INTRODUCTION AND REVIEW OF LITERATURE

The Himalaya is among the youngest and structurally most complicated mountains, and its higher altitudes are well known for ecological uniqueness. Extending from the Indus in the west to the Brahmaputra in the east for about 2500 km length and 240-340 km width (Khosoo 1992), the Himalaya represents a great deal of variation in altitude, latitude, topography and exposition giving rise to considerable differences in eco-climate that resulted into high biological diversity. The intrinsic fragility of Himalayan ecosystem has brought this mountain as being the most critical in the world (Valdiya 1980). Himalaya is one of the twenty-six "Hot Spots" of biodiversity in India and is a reservoir of over 5000 glaciers with permanent ice and snow cover (Khoshoo 1992). It is the source of several large rivers together with their tributaries, which flown southward in the Indo-Gangetic plains and finally discharge into the sea. On this water potential depends the well being of the millions of people in the entire belt in Indo-Gangetic plains and northeast (Khoshoo 1992). Northeastern region of India which is the easternmost part of the Himalayan ranges is very rich in biodiversity and harbours the largest number of endemic and Schedule I species in the country (MacKinnon & MacKinnon 1986). The region is a meeting ground of Indo-Malayan and Indo-Chinese bio-geographical realms as well as Himalayan and Peninsular Indian elements (Khoshoo 1992). The region is also called as "Cradle of Flowering Plants" (Takhtajan 1969). Therefore, the effort during recent years has been to bring more and more land under conservation network in the Himalaya.

Agriculture and animal husbandry are main occupation of the majority of populace in the Himalayan regions. Nomadic graziers move along with their livestock to high altitude areas during summer months. Livestock rearing is an integral part of farming system throughout the Himalayan region. Dependence on livestock increases with increase in elevation, and economy at the high altitude areas is primarily dependent on animal and their byproducts (Purohit & Samant 1995). The health of an average animal is poor due to various reasons, and availability of fodder is considered one major constraint (Jackson 1981, 1983; Balaraman & Golay 1991). There has been an increasing awareness about grasslands as the source of fodder specially when more and more land is being utilized for production of food and other requirements for mankind. In hills the problem is more critical where tree fodder is depleting exponentially against rising bovine population and narrowing of pasture lands (Sundriyal 1995). Subsistence economy of hilly region has strong linkage between agriculture, livestock and rangelands (Sundriyal 1995).

For centuries the alpine meadows in the Himalayan region have been used for grazing by the migratory livestock of transhumance as well as livestock from adjacent lower valleys during summer months (Farooquee 1996). During the winter months the livestock come down to subtropical and temperate forested grounds (Miller 1996). Some of the families adopt stall feeding and collect fodder from the nearby forests with a little supplement from agroforestry species and residue of other agricultural byproducts. The alpine meadows have high species diversity and constitute nutritious pasture for livestock during the summer months. In Himalaya, the herbage productivity is mainly influenced by great seasonality of climate i.e. summer, rainy and winter, and biotic pressure on it (Sundriyal 1995a).

The Sikkim State is the house of 4500 flowering plants, which consist of varieties of orchids, rhododendrons and medicinal plants (Singh & Chauhan 1998). The state also harbours 150 species of mammals, more than 550 species of birds, 26 species of reptiles, at least 11 species of amphibians, 48 species of fishes and over 600 species of butterflies (Lachungpa U 1998). In recent years the exploitation of the natural resources has increased tremendously that threatens the natural habitats, plants and animals and especially the endemic species. The Government of Sikkim has shown increased concern over such exploitations and thus is bringing new and pristine areas under conservation network (Lepcha 1997; Lachungpa C 1998).

In Sikkim, the farming is an integrated system of agriculture, animal husbandry and horticulture (Sundriyal *et al.* 1994). Most farming systems are mixed cropping with the exception of large cardamom growing (Sharma *et al.* 1992; Sharma & Sharma 1997). Agriculture is mainly to secure home consumption, although a small surplus is sold in the local market (Sundriyal *et al.* 1994). The cash income thus comes from either through sales of surplus food crops or through animal husbandry products. Substantial income is generated through large cardamom agroforestry system (Sharma & Sharma 1997; Sharma *et al.* 2000). The scope of dairy development in the state is very high and can generate more economic benefits compared to other developments. During recent years, there has been an increasing trend to look for off-farm income, particularly for Government services. Tourism services have also become very remunerative in recent years. This sector is receiving due attention from the

Government side (Sharma 1997). Tourism offers scope for involving people at different levels i.e. as porters, naturalist guides, pack animal owners, lodge operators, trek cooks, etc. Recently Sikkim Biodiversity and Ecotourism Project focused on human resource development initiatives through training, and also enhancement of infrastructure and tourism services, conservation of natural resources and channelizing the revenue generation (Anonymous 1997). Grazing impact by livestock and pack animals have been also realized whose carrying capacity have not been worked out. Unregulated and unscientific grazing could be detrimental to the rangeland health.

The Khangchendzonga Biosphere Reserve provides a picturesque view of snowclad mountains, lakes, alpine vegetation, thick forest of temperate to subalpine zones, rich wildlife and thus holds to be the most popular tourist destination in Sikkim. Many village settlements with varied ethnic groups such as Lepchas, Bhutias, Limboos and Nepalese are in the buffer zone of the reserve and that surrounds the core zone (former Khangchendzonga National Park) while only a small settlement of 10 families of Tibetan origin settles inside the core zone at a place called as Tshoka. A 45- km Yuksam-Dzongri-Goecha La trekking corridor inside the Khangchendzonga Biosphere Reserve is one of the most important tourist destinations in Sikkim, which has identified as the priority area for tourism development by the State Government. The reserve receives supports a large number of animals from surrounding settlements as well as animals of nomadic graziers. Animals graze throughout the year at lower elevation pastures whereas during rainy and summer months at higher elevation pastures. The trail sites, camping grounds and surrounding of permanent sheds at high altitudes show signs of overgrazing and deterioration of landscapes.

1.1 CONSERVATION AREAS OF INDIA VIS-A-VIS HIMALAYA

A "protected area" is a broad term given primarily to national parks and sanctuaries meant for affording protection to wildlife and their habitats. They also include game and biosphere reserves. The country's first wildlife sanctuary was set up towards the close of the last century as the Vedanthangal Bird Sanctuary in Tamil Nadu, however, the first National Park came into being only in 1936 in the Himalayan region with the setting up of the Hailey National Park in Uttar Pradesh, renamed as Ramganga National Park and finally as Corbett National Park. Many protected areas have been created after the enactment of Wildlife Protection Act of 1972. The state governments are empowered to constitute national parks and sanctuaries (Maikhuri *et al.* 1998). National parks and sanctuaries not only protect the wildlife but also help in educating the people about wild animals and plants and thus have importance in the present day context.

Biosphere reserves are protected areas of respective terrestrial, coastal and marine environments that have been internationally recognized for their value in conservation and in providing the scientific knowledge, skill, and human values to support sustainable development (Maikhuri *et al.* 1998). At the international level the biosphere reserve programs was launched under the auspices of the Man and Biosphere Programme in 1971 (Maikhuri *et al.* 1998). The first biosphere reserve came into being in 1976. Since then a wide network has steadily built up with about 300 biosphere reserves in more than 75 countries all over the world (Maikhuri *et al.* 1998). In India, the Indian National Man and Biosphere Committee, set up by the Central Government, created a core group of experts in 1979 for submitting recommendations for potential areas to be constituted into biosphere reserves. The principles for declaring the area under network are; *in-situ* conservation of biodiversity (genetic resources, species, ecosystem) of natural and semi-natural ecosystems and landscapes; contribution to foster sustainable economic development of the human population living within and around the biosphere reserves and provide facilities for long-term ecological studies; environmental education and training; and research and monitoring related to local, national and global issues of conservation and sustainable development (Maikhuri *et al.* 1998). The present status of biosphere reserves in India is given in Table 1.1. Only 27% of the total area of India's biosphere reserves are in Himalayan region. In Sikkim, the area under conservation as national park/biosphere reserve and wildlife sanctuaries covers 40.66% of the total geographical land area of the state and many more areas are proposed for sanctuary status. The recently declared Khangchendzonga Biosphere Reserve and sanctuaries of Sikkim are presented in Table 1.2. Details of vegetation, wildlife and the linkages between flora, fauna and human interaction are not available in these conservation areas.

1.2 REVIEW OF LITERATURE

International scenario

Focus of this thesis is on the impact of livestock grazing on vegetation and soil properties, the review of literature has concentrated on these aspects only. The effect of grazing and environmental factors like rainfall on annual net primary productivity, species dissimilarity, quantitative and qualitative changes on herbage utilization are well documented worldwide (Gardner & Hubbell 1943; McGinnies 1943; Canfield 1948; Gardner 1950; Biddiscombe 1953; Ketling 1954; Launchbaugh 1955; Johnson 1956; Kucera 1956; Tomanek & Albertson 1957; Carr & Turner 1959; Klipple & Costello 1960; Dix 1959; Orr 1980; Hurd 1961; Penfound 1964; Duvall & Linnartz 1967; Pieper 1968; Brown & Schuster 1969; Williams 1968, 1969; Kennan 1969; Risser & Kennedy 1972, 1975; Pearson & Whittaker 1974; Smith & Schmutz 1975; Breman & Cisse 1977; Sims *et al.* 1978; Rawes 1981; Floret 1981; Laycock & Conrad 1981; Waser & Price 1981; Chew 1982; Ayyad & El-Kadi 1982; Holechek & Stephanson 1983; Edroma 1984; Bock *et al.* 1984; Wood & Blackburn 1984; Belsky 1986; Collins 1987; Gibson 1988; Roundy & Jordan 1988; Lewis *et al.* 1988; Novellie 1988; Abulfaith *et al.* 1989; Thurow & Hussein 1989; Brady *et al.* 1989; Milchunas *et al.* 1989; Hofmann & Ries 1989; Dormarr *et al.* 1989).

Effect of livestock grazing on soil chemical properties has been studied by many workers (Ruess & McNaughton 1987; Dormaar & Willms 1990; Dormaar *et al.* 1990; Manley *et al.* 1995) and had reported the increase of soil organic carbon and nitrogen due to livestock grazing while other studies have found no response in soil organic carbon and nitrogen to grazing (Milchunas & Lauenroth 1993; Kieft 1994; Mathew *et al.* 1994). On the other hand it has been reported that grazing reduced soil organic carbon and increased soil organic nitrogen (Bauer *et al.* 1987). In contrary there is a report that says grazing losses soil carbon and organic carbon (Holland *et al.* 1992). Precipitation and temperature limit aboveground biomass production and soil organic matter (Parton *et al.* 1987), and influence the rate of litter decomposition and nutrient cycling (Charley 1977).

Alpine areas have been the centre of curiosity and investigation since long past. The early alpine studies centered upon descriptions of plant communities and floristic (Cooper 1908; Holm 1927; Cox 1933). During recent years studies were centered on integrating meso- and micro-environmental data to explain plant community patterns and production potentials (Bliss 1956, 1963, 1966, 1969, 1979; Johnson & Billings 1962; Douglas & Bliss 1977; Scott & Billings 1964; Kuramoto & Bliss 1970; Webber & May 1977). Some workers also synthesized the studies of International Biological Program for characterizing and understanding of structural and functional relationships in alpine ecosystems (Bliss 1977; Tieszen 1978; Brown *et at.* 1980; Tieszen *et al.* 1981; Bliss 1962; Scott & Billings 1964; Bliss 1966; Whittaker 1966). Estimation of primary productivity and yield in alpine and arctic vegetation has been assembled by Bliss (1962a). More detailed analysis of field standing crops and productivity in two widely separated alpine regions have been provided by Scott & Billings (1964) and Bliss (1966). Bliss (1962a) says that annual shoot productivity of tundra ecosystem are within the range of 40-128 g m^{-2} $year^{-1}$ but may be as low as 3 g m^{-2} $year^{-1}$ in high arctic. On the world-wide basis, grasslands (including savanna and shrub steppe) represent the potential natural vegetation on 25% of the land surface (Shantz 1954), and account for about 16% (1.89×10^{10} tons $year^{-1}$) of terrestrial-plant communities (Whittaker & Likens 1975).

Indian scenario

Grasslands of tropical India have been studied vastly by various workers like Pandeya (1961, 1964), Singh (1967, 1968), Singh & Yadav (1974), Billore & Mall (1976), Bisht (1980), etc.

At higher altitudes of the western Himalaya, Mani (1978), Pandey (1981), Gupta (1984, 1985, 1986), Sundriyal (1986), Ram *et al.* (1988, 1989), Sundriyal & Joshi (1990), have done extensive work on grassland ecology. In 1906 Duthie presented the revised catalogue of plants of Kumaon and adjacent areas of Garhwal, originally based on the collections of plants made by Strachey and Winterbottom during 1846-1849, including the works of Wallich, Royle, Falconer and Thomson. Rau (1964) has made comprehensive collections from different altitudes of North Garhwal. Rau (1975) has also published an extensive compilation of high altitude flowering plants of the western Himalaya. Royle, Coventry and Blatter studied the beautiful plants of the western Himalaya (Rau 1975) laying more emphasis on Kashmir valley in the extreme west of the Himalaya. Dhar & Kachroo (1993) did a good account on floral composition of Kashmir Himalaya. Agarwal (1959) and Gupta (1974) have reported different types of grasses in the western Himalaya. Numata (1983) and Tsuchida (1983) have done similar work in the Nepal Himalaya.

Biomass distribution of the Himalayan pastures are reported (Kaul & Sapru 1973; Yadav & Kakati 1974; Singh LN *et al.* 1975, Saxena & Singh 1980; Numata 1983; Melkania & Tandon 1983a, 1983b; Bisht & Gupta 1985; Gupta SK 1986; Tiwari 1986; Agarwal & Goyal 1987; Srivastava 1987; Joshi *et al.* 1988; Ram *et al.* 1989; Ramakrishnan & Ram 1988; Rodgers 1990; Sundriyal & Joshi 1990; Rikhari *et al.* 1992; Gupta RK 1993; Sundriyal 1995). There is a varying trend in aboveground phytomass at different areas showing 1000 kg ha^{-1} in low production grasslands to about 10,000 kg ha^{-1} at lower and mid-altitudes, and between 400-5000 kg ha^{-1} for high altitude grasslands in the Himalaya. Kira & Shidei (1967), Yoda (1968), Maruyama (1971) and Nautiyal (1982) have reported that the productivity in terms of dry weight biomass of plant decreases with the increasing altitude. In the Himalaya, productivity increases slightly from the western to central and maximizes in the eastern Himalaya, probably due to better growing conditions (Sundriyal 1995a). Joshi & Srivastava (1991) and Sundriyal *et al.* (1993) has documented effects of intermittent grazing. Saxena & Singh (1980) in the western Himalaya carried out relationship between forage yield and climatic condition. Grazing performance and quality and quantity of herbage production for dietary requirement have been made by Jackson (1981, 1983) and Balaraman & Golay (1991). Clipping, intermittent or rotational grazing are reported beneficial to the plant productivity (Srivastava 1987; Sundriyal *et al.* 1993; Rikhari & Negi 1993). A number of agroforestry species, which are good fodder, are being maintained by villagers throughout the Himalaya for meeting the fodder requirement of livestock (Pal *et al.* 1979; Balaraman 1981; Bhatt 1991; Sundriyal *et al.* 1994). Animals have the natural instinct of choosing habitats, vegetation types and plant species or parts of vegetation as per quality and availability of forage (Srivastava 1987; Agarwal & Dhasmana 1989; Singh 1991; Sundriyal 1994)

Economy and conservation of biodiversity can be regarded as interlocking to each other. Environmental degradation in grazed system is frequently exacerbated by socio-economic constrains in both developed (Conner 1991) and developing countries (Standford 1983). Noy-Meir (1993) emphasized the effect of grazing regime on forage quality and utilization, species composition and seasonality of supply are often just as important for animal production and economic success. In this wide sense, grazing optimization is a central concept of rational range management for production and on this aspect a lot of workers has done exclusive works

(Bartoloma 1993; Briske 1993; McNaughton 1993; Noy-Meir 1993; Painter & Belsky 1993; Mazacourt *et at.* 1998). Multiple factors (altitude, slope, aspect, basal coverage, soil types, biotic pressure and succession status) influence to grassland composition and are reported (Patil & Pathak 1980; Saxena & Singh 1980; Singh & Saxena 1978; Melkania & Tandon 1983a, 1983b; Gupta 1986). Singh & Naik (1987) reported overgrazing of about 9000 km^2 in UP hills. In the Central Himalaya 5.084 cattle units are grazing on per hectare land, which is about 2-3 times higher than the actual carrying capacity of the land (Pandey *et al.* 1982). A similar situation has also been reported in Nepal (Giri 1989).

The status and ongoing research activities concerning flora and fauna and their conservation strategies of biosphere reserves of India are available; Nilgiri in Tamil Nadu (Neelakantan 1998), Karnataka region (Yekanthappa 1998), Kerala region (Sinha 1998), Nanda Devi (Kumar 1998), Nokrek (Ashutosh 1998), Great Nicobar (Anonymous 1998a), The Gulf of Mannar (Anonymous 1998b), Manas (Agarwalla 1998), Sunderban (Singh 1998), Similipal (Srivastava & Singh 1998), Dibru-Saikhowa (Anonymous 1998c) and Dihang-Debang (Anonymous 1998d). All these researches are mainly based on compositional survey and pattern characterization. No detail report is available on livestock grazing, their causative effect on plants and soil, and on the relationship with rural economy. The present study is an attempt to find out the relationship between plant, animal, soil and economy related to livestock and their products and tourism related livestock entrepreneurial in a protected area.

Sikkim Himalaya

Hooker (1875) gave a comprehensive account on the floristic wealth of Sikkim Himalaya. Smith (1911) recorded the vegetational components of alpine and subalpine areas of South-East Sikkim. Smith & Cave (1911) studied the floristic composition of alpine and subalpine of Lhonakh Valley in Sikkim. A comprehensive work on medicinal plants from Sikkim Himalaya was also reported (Biswas 1956). A good account of the flowers of Himalaya was given by Polunin & Stainton (1984) but a very little was mentioned about Sikkim Himalaya. Pradhan & Lachungpa (1990) reported 38 species of *Rhododendron* from the Sikkim. Kumar and Singh (1993) reported about 250 species of grasses from Sikkim Himalaya. Balaraman & Golay (1991) carried out livestock and management studies of Sikkim emphasizing more on livestock health and maintenance. Village ecosystem study covering livestock rearing in the Mamlay watershed of South Sikkim was made by Sharma *et al.* (1992). Paljor (1997) has reported livestock economy and its impact on the environment in North Sikkim. Indo-Swiss Project has reported compiled comparative livestock health and development in six villages of Sikkim namely Luing, Central Pandim, Namthang, Poklok-Nandugaon, Dodak and Dentam (Kurup 1997).

No work has been done on monitoring and applied research on plant, animal and soil interaction especially of livestock grazing and its causative effect on the environment in the Sikkim Himalaya especially in the Khangchendzonga Biosphere Reserve. The present thesis deals with the findings of studies on livestock grazing, agriculture and tourism linkages. This work emphasizes on the impact of grazing on vegetation, nutrient and soil properties and its dynamics and linkages on rangeland and biodiversity for development of management and conservation strategies.

Table 1.1 Present status of conservation (biosphere reserves) areas in India.

Status	Name of the biosphere reserves	State (s)/UT	Date of notification	Area (km^2)
Declared	Niligiri	Karnataka, Kerala and Tamil Nadu	01/08/1986	5520.0
	Nanda Devi	Uttar Pradesh	18/01/1988	2236.7
	Nokrek	Meghalaya	01/09/1988	820.0
	Great Nicobar	Andaman & Nicobar	06/01/1989	885.0
	Gulf of Mannar	Tamil Nadu	18/02/1989	10500.0
	Manas	Assam	14/03/1989	2837.0
	Sunderbans	West Bengal	29/03/1989	9630.0
	Similipal	Orissa	21/06/1994	4374.0
	Dibru-Saikhowa	Assam	28/07/1997	765.0
	Dehang-Debang	Arunachal Pradesh	02/09/1998	5111.5
	Khangchendżonga	Sikkim	07/02/2000	2619.9
Identified	Namdapha	Arunachal Pradesh	-	-
	Valley of flowers	Uttar Pradesh	-	-
	Thar desert	Rajasthan	-	-
	Little Rann of Kutch	Gujrat	-	-
	Kaziranga	Assam	-	-
	Andaman	Nicobar	-	-
			-	-
Proposed	Abujmarh	Madhya Pradesh	-	-
	Pachmarhi	Madhya Pradesh	-	-
	Amarkantak	Madhya Pradesh	-	-
	Cold Desert	Jamu & Kashmir and Himachal Pradesh	-	-
	Seshachalam	Andhra Pradesh	-	-
	Chintapalli	Andhra Pradesh	-	-
	Lakshdweep Islands	Lakshdweep	-	-

Source: Maikhuri *et al.* 1998.

Table 1.2 Protected areas in Sikkim

Biosphere reserve/Sanctuary	Name of the Biosphere reserve/sanctuary	District (s)	Elevation (m)	Area (km^2)
Biosphere reserves	Khangchendzonga	North & West	1600-8598	2619.92
Sanctuaries	Shingba Rhododendron	North	3300	43.00
	Kyongnosla Alpine	East	3292-4110	31.00
	Fambong Lho Wildlife	East	1524-2750	51.76
	Barsey Rhododendron	West	1700-4500	104.00
	Maenam Wildlife	South	-	35.34
Total	-	-	-	2885.02

Source: Maikhuri *et al.* 1998.

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.

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

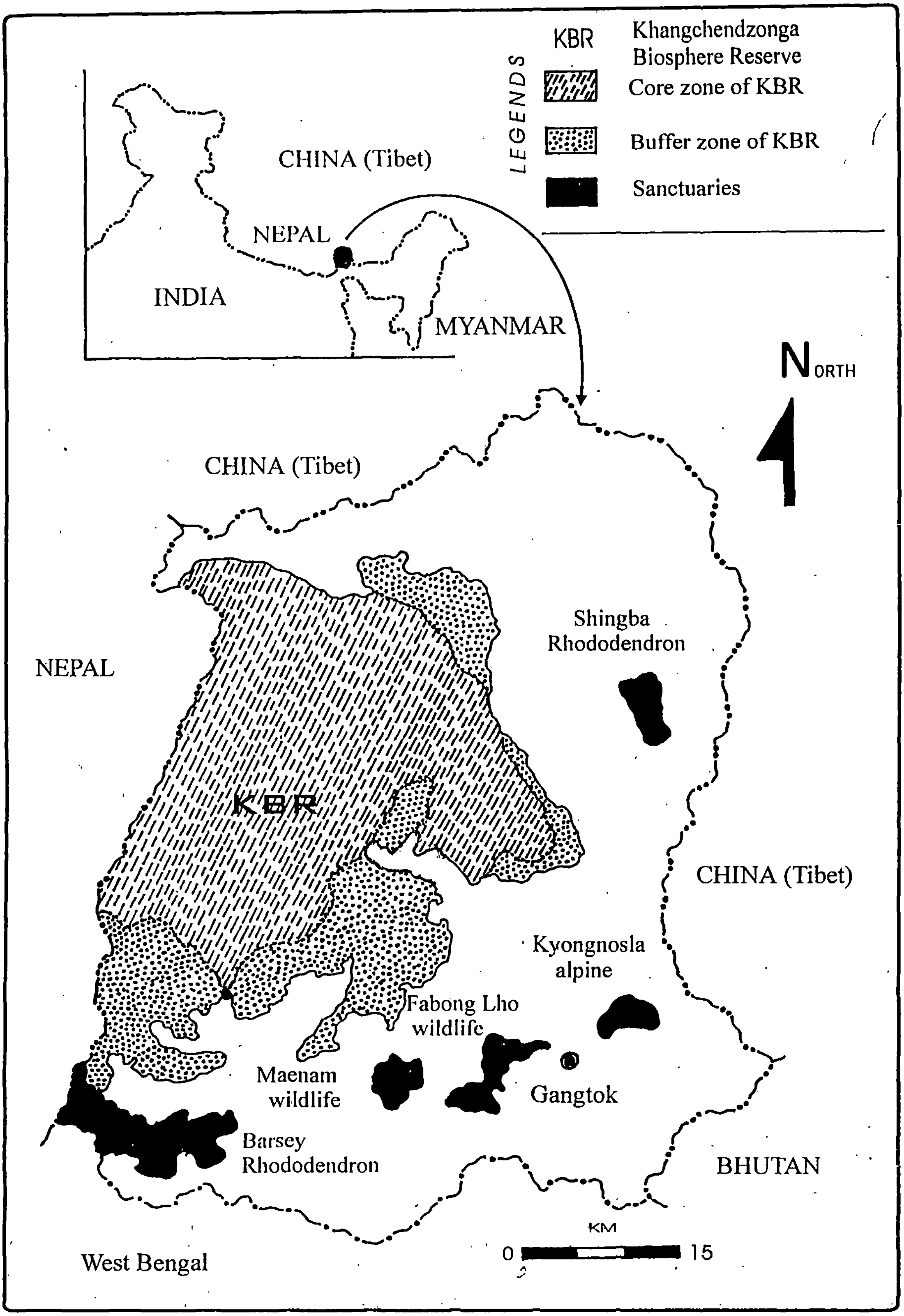

Fig. 2.1 Location map showing the protected areas in Sikkim

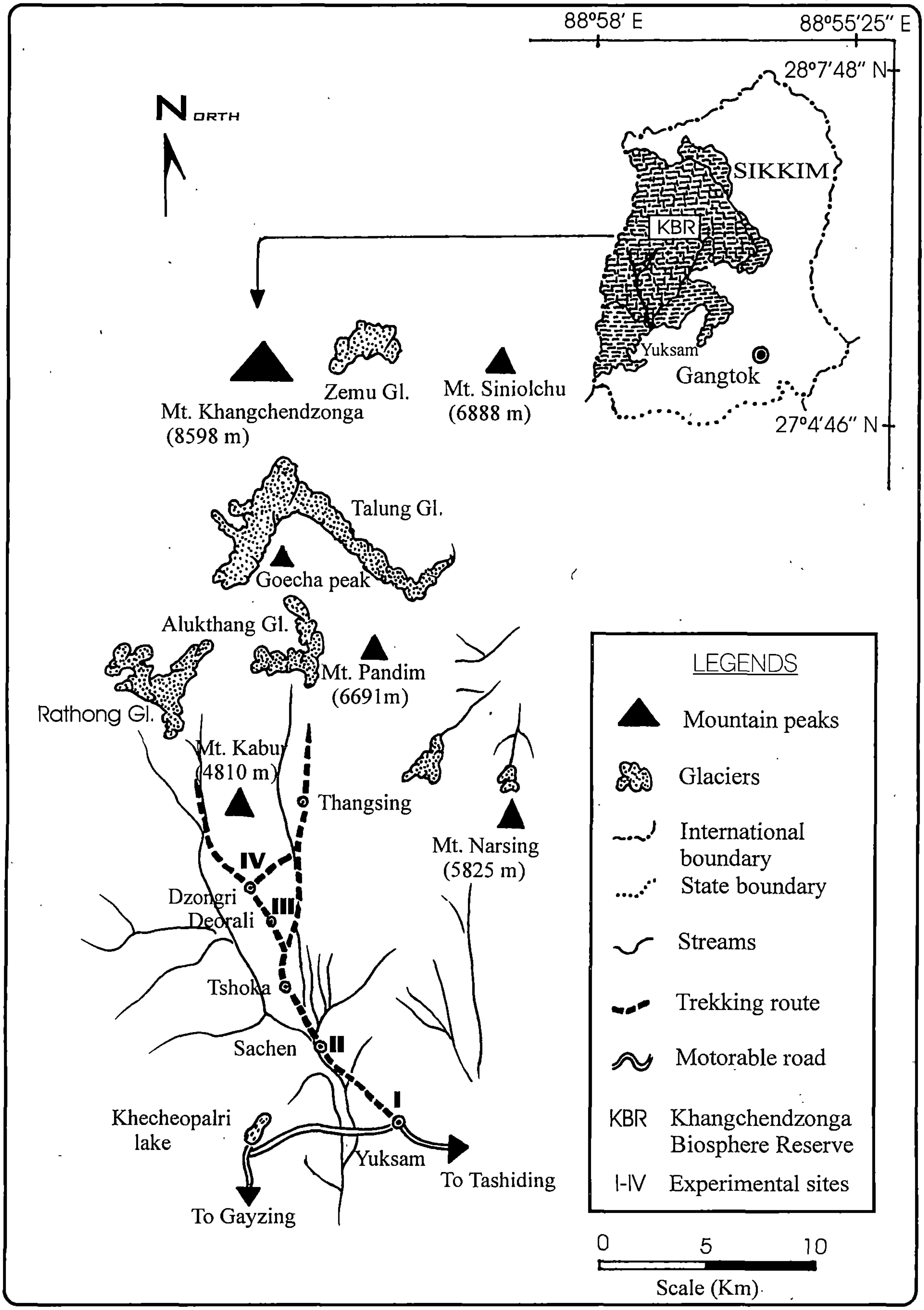

Fig. 2.2 Location map showing livestock grazing exclosure sites along the Yuksam-Dzongri trail in Khangchendzonga Biosphere Reserve

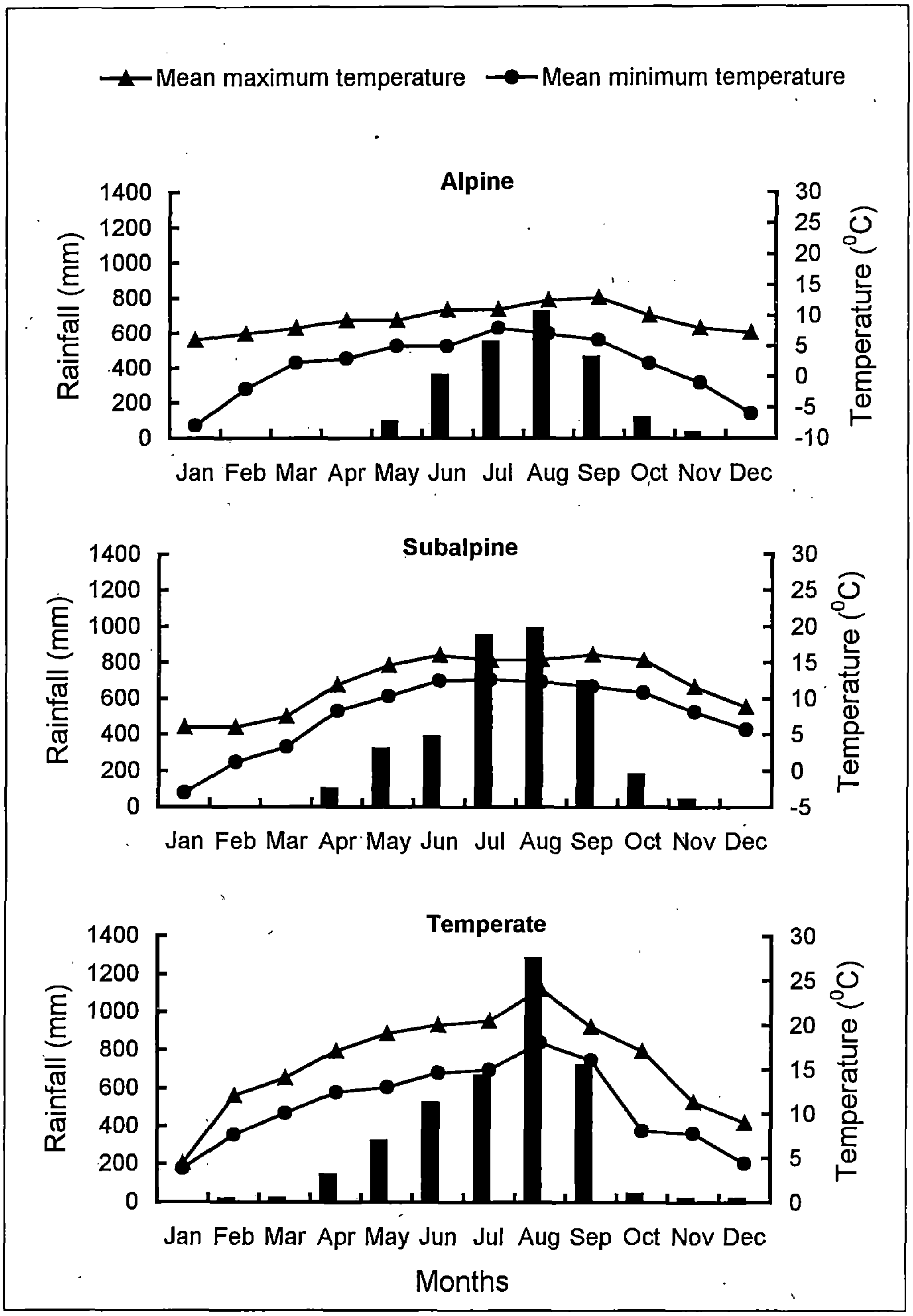

Fig. 2.3 Climatic data of the study area [alpine zone at Dzongri (3900 m), subalpine zone at Tshoka (3000 m) and temperate zone at Yuksam (1600 m) along the Yuksam-Dzongri trail in Khangchendzonga Biosphere Reserve (record for 1998)

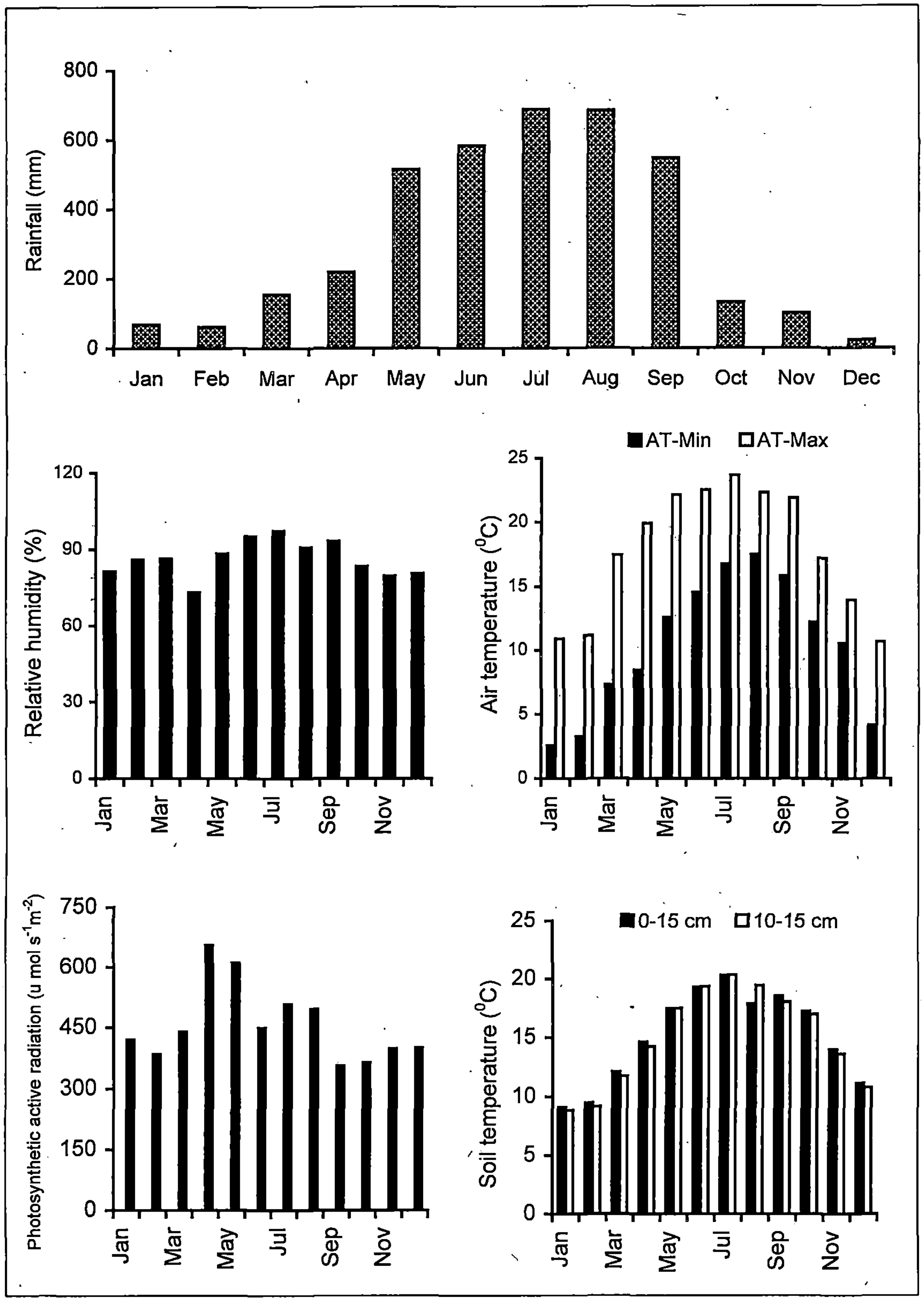

Fig. 2.4 Weather data for temperate zone at Pangthang (elevation 2000 m) for the Sikkim Himalaya (values pooled for 3 years: 1994-96)

CHAPTER III

ANIMAL-RANGELAND LINKAGES AND VEGETATION CHARACTERISTICS

3.1 INTRODUCTION

High altitude areas in the Khangchendzonga Biosphere Reserve are considered among the most important protected areas with high biological and landscape diversity in the region. The biosphere covers three main ecological zones; temperate, subalpine and alpine including permanent snow cover with elevation ranging from 1600 to 8598 m asl. (Lepcha 1997). It is estimated that Sikkim harbours nearly 4500 species of flowering plants with many endemic species, which represent a high diversity for this tiny state (Singh & Chauhan 1998). The vegetation of the region is used for diverse purposes, i.e. fuelwood, timber, fodder and non-timber forest products (Balaraman 1981; Sundriyal *et al.* 1994; Sundriyal & Sharma 1996)

Agriculture and animal husbandry are the primary occupation of the different ethnic communities of the Sikkim Himalaya and each household keeps on an average of about 4 animals i.e. 1 cow for milk, ox for ploughing, goat for cash need and pig for meat (Sundriyal 1994). Cattle rearing have been an integral part of farming system in the Sikkim State. The state housed about four hundred thousand livestock during 1992, which showed an increment of over 66% from 1987. Over the years these animals were reared as stall-fed (Balaraman 1981). A large number of plant species are used in feeding the domestic animals. Fodder from forest had the largest share in livestock feeding (Balaraman & Golay 1991; Sundriyal & Sharma 1996). Agricultural residues and agroforestry species maintained at the farms also contribute as fodder resources (Sundriyal 1995). Various fodder species maintained at the farms are highly nutritious and used during lean period. During recent years grazing has been replacing stall-feeding as a popular means because of easy access to forest areas. Family fragmentation is another cause for increase in livestock number.

In Sikkim, local communities have been practising the agro-pastoral system of livelihood in which livestock are the backbones of the system. With increasing elevation the dependence on animals becomes more substantial. The Yuksam-Dzongri trail supports a large number of grazing livestock that move to alpine areas in summer months for free grazing and come down to temperate zone during winter months. The vegetation of different elevations forms the main source of fodder to these animals. The livestock are the source of economy for some people which mainly comes from animal products and pack animals engaged in tourism or mountaineering. These pack animals either free graze along the trek or at the campsites, or sometimes fed from lopped fodder. Since large number of animals are dependent along this trekking corridor within the biosphere reserve, animal and rangeland linkages and vegetation composition have to be properly understood. The vegetation utilization pattern is equally important. This information would help in drawing guidelines for management of the rangeland. The present chapter describes the information on vegetation pattern, phenology, growth and life forms of plants, assessment of economic plant wealth and documentation of their uses, parts and mode of uses, livestock rearing pattern and revenue generation from livestock grazing animals.

3.2 LIVESTOCK GRAZING AND LINKAGE

3.2.1 Livestock Number and Rearing Pattern

During 1992, livestock number of 200035 cattle, 114707 goats, 16268 sheep, 44477 pigs, 5349 yaks/dzos, 2932 buffaloes and 1789 horses totalling to 385557 were recorded in Sikkim state (Paljor 1998) (Table 3.1). The average number of 54 animals per km^2 has been recorded for the state. Livestock population in Sikkim has increased by about 66% from 1987 to 1992 (Table 3.1). The livestock types and population of Yuksam-Dzongri trekking corridor is presented in Table 3.2. At Yuksam 274 families reared a total number of 1448 livestock which is 5.28 animals household^{-1} while in Tshoka village 75 livestock was recorded showing 7.5 animals household^{-1}. The total livestock of Yuksam block was 1324 in 1996, 1365 in 1997 and 1523 in 1998 showing a growth of 15% from 1996 to 1998 (Table 3.2).

Sikkim has four major grazing routes out of which two falls in the Khangchendzonga Biosphere Reserve (Fig. 3.2). All the routs lead to alpine pastures during summer months. The animals graze on lush-green vegetation in these areas. The major portions of the grazing land is under alpine pasture followed by 'khasmal' land and 'gaucharan'. The graziers take their animals to alpine and sub-alpine pastures during the warm period generally from April to October and bring them back to the lower valley during winter months. In the lower altitudes free grazing inside the forest is not a common practice and stall-feeding has been practised. Although, some households are continuing free grazing. Generally, villagers practised free grazing and stall-fed for cow and goat, free grazing for dzo, horse, yak and sheep (Table 3.3). Only a few milking animals and calves are kept at home and stall fed. At Tshoka village all the animals were free grazed. Around 40 cows, 160 yaks, 120 dzos, 13 horses and 508 sheep (total livestock 841) extensively graze in Dzongri and its surrounding alpine pastures during summer months. Yaks graze throughout the year at high altitudes because of their inability to adapt at lower elevations.

3.2.2 Agricultural Practices and Animal Husbandry

Cultivation of cash crops like large cardamom, ginger, mandarin orange and potato along with animal husbandry have became the major economic activity in farms. Animal husbandry has good scope for further development because the region has a high potential for fodder production. The main vegetable crops are cabbage, beans, mustard, peas, potato, etc. All these vegetables are grown in their private lands and are mainly for their own consumption. Small quantities of surplus are sold to the market. The crop residues are fed to animals and supplement a good proportion of forage demand. The villagers maintain a good number of fodder trees in the agricultural lands that provides fodder during the lean period. Details on fodder trees are covered in Chapter IV. Oxen are generally used to plough the land. Livestock dung forms a major traditional manure and many villagers maintain animal numbers especially to get the manure for their agricultural land. Large cardamom based agroforestry is a traditional practice whose area of cultivation has increased by 2.3 times from 1980 to 1995 (Sharma *et al.* 1998). This agroforestry has strong component of dense shade trees. These trees provide fodder for livestock in cardamom growing areas.

3.2.3 Tourism and Livestock

The 26-km Yuksam-Dzongri corridor inside the Khangchendzonga Biosphere Reserve is one of the most important trekking routes in Sikkim. Every year about 2000 domestic and foreign tourists trek in this popular destination. A tourist group of more than 3 persons generally hired pack animals. If the group is small than 3 persons then the local porters manage. Local porters are available at trail head i.e. Yuksam village whose rate is Rs. 80/- per day. Trekking cooks are hired @ Rs 100/- per day. The cost of one pack animal range between Rs 110-120/- per day, and the animal can carry about 40 kg load. Himalayan Mountaineering Institute (HMI), Darjeeling, West Bengal, conducts training programs every year (5 basic and 3 advance courses) at the base camp. These groups have trek along the same route. Around 100-120 trainees in each basic course and around 80-100 trainees in each advance course participate in HMI training. In every course they used around 40 pack animals for fairly long time. The area also provides pasturage for local and transhumance herders along with entrepreneurs owning pack animals for trekking groups and mountaineers.

The Forest Department started collection of fees for pack animals entering the reserve since September 1998 (Notification No.124/KNP/WL/F/01). The entry fee has been fixed as Rs 5/- per animal per day. However, it was observed that generally more number of pack animals freely graze in the area than the number of animals for which fees has been collected for entry.

Revenue generated from the grazing livestock in the Yuksam-Dzongri trekking corridor in 1997 and 1998 is presented in Table 3.4. There are three main items of revenue source from livestock viz. pack animals, dairy products and wool products. Some livestock products are shown in Photoplate 3. During 1997 a total revenue of Rs 11,37,600/- was generated; out of which 64.9% was from pack animals, 28.7% from dairy products, 6.04% from wool products and remaining 0.46% from skin products. The revenue during 1998 was Rs 10,29,300/-, out of which 57.09% was contributed from pack animals, 34.63% from dairy products, 7.91% from wool products and remaining 0.37% from skin products. Besides this, the Forest Department also collected a sum of Rs 19,800/- as state revenue during 1998 as entry fees for pack animals operating in the Yuksam-Dzongri trail. About 68% of the fees came from Himalayan Mountaineering

Institute's training program and remaining 32% came from pack animals hired by trekkers. Unit rates for different sources of income from livestock were: (a) pack animal Rs 110-120/- per animal per day, (b) raw wool Rs 70-80/- per kg, (c) yak and sheep milk Rs 10/- and Rs 15/- per litre, respectively, (d) butter (cheese) Rs 160/- per kg, and (e) dried cheese (chhurpi) Rs 120/- per kg. Reduction of about 10% in income from livestock in 1998 compared to 1997 was mainly because of less tourist arrivals resulting from road disruption due to landslides.

Livestock accounts far as much as 10 per cent of our Gross National Product (GNP), the cash equivalent being approximately Rs 15,000 crores or more (Anonymous 1986). The energy components of the livestock in the form of dung as a source of fuel and draught power derived from cattle and buffaloes are a very significant contribution to various agricultural operations in the rural areas. It has been worked out that 193 million of cattle population in the country produces as much as 37,000 mega watts of power for agricultural products (Bhat 1987). The cattle were considered chief sign of wealth and a person with 20 herds of cattle was considered a rich man in Lepcha community (Gorger 1984). In north Sikkim around 72% households receive income from livestock rearing (Paljor 1997). They also provide a good percentage of organic manure to the soil. But animal grazing in high mountains is considered as one of the major factors responsible for environmental degradation.

3.3 VEGETATION CHARACTERISTICS

3.3.1 Vegetation Pattern

Three distinct vegetation zones have been identified, viz. temperate (warm and cool), subalpine and alpine based on the elevation along the Yuksam-Dzongri trail (Table 3.5). The warm temperate starts from Yuksam

(1600 m elevation) upwards to 2000 m and this zone supports to fulfil the local resident's demands for fuel, fodder and timber. The area also receives heavy grazing pressure. The forest cover is very sparse mainly due to timber and fuelwood extraction. The area received medium to high level of grazing pressure. The dominant trees are *Castanopsis* spp. *Cedrela toona*, *Evodia fraxinifolia*, *Macaranga pustulata*, while *Rubus ellipticus*, *Edgworthia gardneri*, *Melastoma normale* formed the middle layer. *Eupatorium cannabinum, Cyanotis vaga, Hydrocotyle javanica, Pilea umbrosa, Pilea scripta, Persicaria capitata, Brachiaria* sp. are prominent ground vegetation (Table 3.5).

At the cool temperate (2000-3000m) the tree layer is formed by *Magnolia campbellii, Rhododendron arboreum*, *Quercus lamellosa*, *Acer campbellii*, etc., while *Aconogonum molle*, *Arundinaria maling*, *Zanthoxylum acanthopodium* formed the secondary layer. The dominant ground vegetations are *Tupistra nutans*, *Viola* sp., *Silaginella* sp., *Elatostema sessile*, *Urtica dioica*, *Girardinia palmata* and *Laportea terminalis*.

The maximum canopy coverage in the sub-alpine zone has been formed by *Abies densa* and secondary middle layer by *Rhododendron barbatum, Rhododendron hodgsonii, Viburnum cordifolium*, *Arundinaria maling* and *Rosa serecia*. Primulas, *Selinum tenuifolium*, *Fragaria* sp., *Prunella vulgaris*, with high density of *Abies densa* seedlings and saplings formed the ground vegetation.

Alpine areas were devoid of trees, shrubs of rhododendrons, Junipers and *Rosa serecia* formed the major species. High density of *Juniperus recurva* in the form of depressed circular patches were common in gentle slope side whereas bushes of rhododendrons in steep side. The ground vegetation was dominated by *Poa* spp. *Potentilla peduncularis, Potentilla* *microphylla, Potentilla coriandrifolia, Aletris pauciflora, Bistorta affinis, Pedicularis* spp. and Primulas. As the elevation goes higher to 4000 m and above, botanically curious plants like woolly *Swertia multicaulis*, *Eroiphyton wallichii* and pyramid-shaped *Rheum nobile* are seen and these plants are adapted to harsh climate.

3.3.2 Floristic Composition

Lists of plants encountered along with their flowering period, life forms and growth forms have been prepared according to the Bentham and Hooker's sequence of classification for temperate (Appendix 1), subalpine (Appendix 2) and alpine (Appendix 3). In the temperate zone, a total of 182 species were recorded whose 148 were dicots (81.3%), 32 monocots (17.6%) and only 2 species of gymnosperms (1.1%). These species belonged to 66 families (57 dicots, 7 monocots and 2 gymnosperms) and under 133 genera (109 dicot, 22 monocot and 2 gymnosperm) (Table 3.6).

At subalpine zone, a total of 73 species were recorded whose 60 species belonged to dicots (82.2%), 11 species monocots (15.1%) and remaining 2 species were gymnosperms (2.7%). These species belonged to 32 families (27 dicots, 4 monocots and 1 gymnosperms) and under 48 genera (38 dicots, 8 monocots and 2 gymnosperms).

No tree stratum was found in alpine zone, only the species of *Rhododendron* shrubs formed the major cover. A total of 120 species were recorded in alpine zone, out of which 105 were dicots (87.5%), 13 monocots (10.8%) and only 2 species of gymnosperms (1.7%). These plants belonged to 34 families (26 dicots, 7 monocots and only one gymnosperm). The families like Ericaceae (12 spp.), Primulaceae (10 spp.), Polygonaceae (8 spp.), Ranunculaceae and Scrophulariaceae (7 spp. each) were represented most. Rawal and Pangtey (1987) have reported similar observation from the central Himalaya. Some alpine flowering plants are shown in Photoplate 1.

3.3.3 Phenology

Flowering periods of species were recorded for temperate (Appendix 1), subalpine (Appendix 2) and alpine zones (Appendix 3). Temporal flowering pattern of the three ecological zones have been drawn (Fig. 3.2). In temperate zone, flowering of species occurred throughout the calendar year from January to December. A maximum of 81 species bloomed during June, followed by 79 species in July and 75 species in August. During June 44% of the total species were flowering (Fig. 3.2).

At subalpine, there was no flowering during December to January. Maximum flowering occurred during July when 43 species (59%) bloomed, followed by 38 species (52%) during June and 29 species (40%) during August (Fig.3.2).

Flowering in the alpine pasture started just after the snow-melted in March and ended in November when winter began. Most of the plant species flowered during the months of June, July and August, with a peak in August when 104 species were in bloom, where as 72 and 86 species bloomed in June and August, respectively. This is the period of highest rainfall and maximum temperature. Individuals of *Bergenia ciliata* (Saxifragaceae) started flowering just after snow melt in March and continued flowering until July; *Hemiphragma heterophyllum* of the Scrophulariaceae family also started flowering then, but blooming ended in August. *Primula glomerata* (Primulaceae) started flowering only in August and continued until very late into November. About 48% of the species flowered for three months, 41% flowered for two months, 10% for four months and only one species (*Bergenia ciliata*) flowered for five months (Fig. 3.2).

3.3.4 Life and Growth Forms

The life forms study of the species at temperate zone showed 69.2% phanerophyte, 17.6% chaemephyte, 4.1% therophyte, 2.2% geophyte and only 1.1% hemigeophyte. At subalpine, phanerophyte was highest (38.4%), followed by chaemephyte (30.1%), therophyte (15.1%), hemigeophyte (9.6%) and the least geophyte (6.8%), whereas at alpine zone chaemephyte (57%) was dominant, followed by hemigeophyte (15%), phanerophyte (12%), therophyte (9%) and geophyte (7%) (Table 3.7).

The growth forms study revealed that at temperate zone 36.3% was tree, 20.9% shrub/undershrub, 15.4% tall forb, 6.7% cushion and spreading forb, 6% each for climber and epiphyte, 5.5% short forb, 2.7% graminoid and least being the creepers (0.5%). At the subalpine zone, climber, creeper and epiphytes were absent. Some of the epiphytes could be grown on ground also, hence regarded as other suitable growth forms. Tall forb (27.4%) dominated at the subalpine zone which was followed by shrub/undershrub (20.5%), cushion and spreading forbs (16.4%), short forb (15.1%) and the graminoid (6.9%) was the least. At the alpine zone, tree stratum were absent and was dominated by short forb (31%) followed by cushion and spreading forb (28%), tall forb (25%), shrubs (10%) and the graminoid (6%) the least.

Woody plants dominate in the temperate and subalpine zones. Lower per cent of herbaceous vegetation might be due to certain pressure especially by livestock grazing and collection of non-timber forest products. As the elevation increased woody components decreased and in contrary forbs increased, and change further higher elevation comprised of cushion and spreading forbs. This change is an adaptive mechanism to severe climate in the higher elevation. Phanerophyte (69.2%) in temperate zone is fairly higher than that of Raunkier's normal spectrum (46%). This is an indication of more arboreal structure. But 1.1% hemigeophyte, 2.2% geophyte and 4.1% therophyte in the present study is much lower than Raunkier's normal spectrum (26% hemigeophyte, 6% geophyte and 13% therophyte).

Higher percentage of chaemephyte (57%) compared to 31% in Rudranath flora, 46.7% in snowline vegetation of Central Himalaya, 46.4% in Yusmarg Kashmir alpine and 4.7% in Kumaun Himalaya indicates that the plants were surviving under stresses such as physical, climatic or biotic (Ram *et al.* 1988). Members of Rosaceae and Ericaceae appeared to have the widest adaptability to the alpine environment. Most of the species of these families are least palatable to livestock grazing.

Compared to the Central and Western Himalaya the present study area has more woody plants. Per cent geophyte is closely comparable with that of Raunkiaer's normal spectrum but 4 times fold less than the report from Rudranath flora (28.9%) (Ram *et al.* 1988), this indicates that rhizomatous plants are less in number in the present study areas and forbs are dominating. Maximum plants were forbs (56%), which is an indicator of favourable climate for annual plants, while graminoid represented by 6% only and no tree stratum was found, instead 10% shrubs and undershrubs were recorded which is comparable with other reports from the western and central Himalaya. Higher percentage of cushion and spreading forbs of plants (28%) indicates a hard physical and climatic surroundings. Continuous and heavy grazing might change the growth forms of the plants to a large extent. A lack of trees and big shrubs and the low stature of vegetation in the alpine region was ascribed both to winter desiccation and ice abrasion and to a low annual carbon gain which is inadequate to build and maintain large woody support structures (Billings & Mooney 1968; Savile 1972; Tranquillini 1979). From the growth and life forms study, it revealed that the alpine area faces harsh climatic conditions. This makes the growth of the plants slower. As we ascend from timberline to snowline, the severity of the environment increased, which leads to a progressive decline in the abundance and diversity of plant species. In the severe climate the morphology of plants changed to woolly or cotton rosettes, striking dwarfness, perennial root stocks and surface level spreading probably due to the need of thermal heat liberated by the rock or soil surface for survival and need physiological process.

3.3.5 Ethnobotanical Plant Wealth

The ethnobotanical plant wealth of temperate and subalpine zone is presented in Table 3.8. At temperate zone 13 species (under 12 families and 13 genera) were found to have medicinal use (Table 3.8). Nearly 23 species (belonging to 16 families and 23 genera) were frequently collected by the villagers from the surrounding forests as wild edibles. Besides, fibre and paper (4 species under 2 families and 4 genera), dye (1 species), and incense (2 species under 2 families and 2 genera) yielding plants were also collected by local people from the surrounding forests. Local communities commonly used 17 species for timber and other construction purposes. Forty-one species are used as fodder and either collected from wild or animals graze on them. Details of fodder and forage resources are presented separately in chapter IV. The local residents commonly used 26 different plant species as fuelwood.

The ethnobotanical plant wealth of alpine meadows is presented in Table 3.9 and 28 species have been reported for different usage. Only 11 species (8 families) were recorded to have medicinal value, their uses are given in Table 3.9. Species of *Rhododendron*, *Juniperus* and *Crementhodium* (6 species under 3 families) were used as traditional incense especially by

Buddhists and at the Monasteries. *Rheum emodi* (syn. *R. australe*) is used as tea-substitute by grazers and porters at high altitudes. Six species of *Rhododendron* are used as fuelwood by the yak herders. *Rheum nobile*, locally called as "Kenjoh" or "Sikkim cabbage", is edible as pickle and also used as medicine. Species of *Primula* are frequently collected as decorative and garden plants (Table 3.9). A few medicinal plants are presented in Photoplate 2.

Collection of various plant materials by local porters and villagers is a common practice. The collection of plants for medicine (e.g. *Aconitum hookeri, Allium wallichii, Picrorhiza kurrooa, Orchis latifolia, Rheum nobile, R. australe, Nardostachys jatamansi, Bergenia ciliata, Swertia multicaulis*, etc.), fuelwood (*Rhododendron anthopogon, R. lepidotum, R. setosum, R. fulgens, Juniperus recurva, J, indica*, etc.), tea substitute (*Rheum emodi*), decorative pieces (*Primula* spp. *Bergenia ciliata*) and edible species (*Rheum nobile*) have exerted continued pressure on these species at the alpine pasture affecting the vegetation composition and structure. A code of conduct for visitors have been made by a local NGO (Khangchendzonga Conservation Committee) which stresses on stopping illegal collections of plant species especially from alpine areas. ■

Table 3.1 Livestock types and their numbers during 1987 and 1992 in the Sikkim State.

Livestock	1987		1992		Per cent change from 1987 to 1992
	Number	(%)	Number	(%)	
Cattle	15,7546	53.98	200035	51.88	26.97 (+)
Buffaloes	5438	1.86	2932	0.76	46.08 (-)
Sheep	16104	5.52	16268	4.22	1.02 (+)
Pig	18596	6.37	44477	11.54	139.18 (+)
Goat	88986	30.49	114707	29.75	28.90 (+)
Horse	1186	0.41	1789	0.46	50.84 (+)
Yak/dzo	3995	1.37	5349	1.39	33.89 (+)
Total	291851	100	385557	100	66.02 (+)

Source: Forest Department, Government of Sikkim 1995.

Table 3.2 Grazing livestock types and numbers for the study period in Yuksam Block

Village/livestock type	Livestock number			Per cent change from 1996 to 1998
	1996	1997	1998	
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 (+)
Total for block	1324	1365	1523	15.03 (+)

Source: Primary data

Table 3.3 Rearing pattern and seasonal mobility of different grazing animals along the Yuksam-Dzongri trail in Khangchendzonga Biosphere Reserve

Animal types	Season	Grazing mobility and characteristic pattern
Cattle	Summer	Only a few cattle grazed in alpine pastures at Dzongri while rest grazed in lower forest around Yuksam except milking cows and calves. In Tshoka village all the cattle are free-grazed except milking cows and calves, for them fodder are lopped from the nearby forest and fed with other agricultural byroducts like 'pina' (oil cake) which they purchase from market @ Rs 8-10/- per kg.
	Rainy	Only a few cattle graze in alpine pastures while rest graze in forest pastures except milking cows and calves.
	Winter	Both stall-fed and free-grazing inside forest.
Yak	Summer	Yaks grazed in alpine pastures and near timberline. Never come down to temperate areas due to its adaptation in cold climate.
	Rainy	Graze in alpine pastures close to snow line.
	Winter	Graze near timberline and lower alpine pastures.
Dzo	Summer	Dzos are used as pack animals by tourist trekkers and mountaineers. At resting stations like Yuksam, Sachen, Tshoka, Phedang, Deorali, Dzongri, Thangsing, Basecamp free grazing is observed. At Yuksam, Tshoka and Dzongri these pack animals are provided some common salt and mustard oil. Salt and mustard oil are believed to strengthen the knee of the animals for trekking.
	Rainy	Graze in both alpine pastures as well as inside the temperate forests.
	Winter	Graze freely inside temperate forest.
Horse	Summer	Free grazing inside lower elevation forest grounds and used for carrying loads.
	Rainy	Most graze in alpine pastures.
	Winter	Free grazing inside temperate forest.
Sheep	Summer	Graze in alpine pastures.
	Rainy	Graze in alpine pastures
	Winter	Free grazing inside temperate forest.
Goat	Summer	70% stall-fed while remaining freely graze inside the forest.
	Rainy	Both stall-fed and free grazing in temperate forest was recorded.
	Winter	Both free grazing and stall-feeding (around 70% stall-fed).

Table 3.4 Income generated from grazing livestock along the Yuksam-Dzongri trail

Income source	Animal types (items)	Price rate (Rs)*	Quantity		Revenue (Rs)		Per cent change from 1997 to 1998
			1997	1998	1997	1998	
Pack animals	Dzo	120	6084	4834	730080	580080	20.55 (-)
	Horse	110	77	69	8470	7590	10.39 (-)
	Total	-	-	-	738550	587670	20.43 (-)
Milk	Cattle (milk)	10	8170	9500	81700	95000	16.28 (+)
	Yak (milk)	10	7000	7000	70000	70000	No change
	(chhurpi)	120	1000	1000	120000	120000	No change
	Sheep (milk)	15	667	1094	10005	16410	64.07 (+)
	(butter)	160	282	344	45120	55040	21.99% (+)
	Total	-	-	-	326825	356450	9.09 (+)
Wool	Yak (raw)	80	119	125	9520	10000	5.04 (+)
	(rope)	35	50	70	1750	2450	40.00 (+)
	(sofa cover)	120	40	50	4800	6000	25.00 (+)
	Sheep (raw)	120	333	444	39600	48000	21.21 (+)
	(blanket)	650	20	23	13000	14950	15.00 (+)
	Total	-	-	-	68670	81400	18.54 (+)
Skin	Yak (shoe)	45	25	30	1125	1350	20.00 (+)
	(sofa cover)	250	10	10	2500	2500	No change
	Total	-	-	-	3625	3850	6.21 (+)
Grand total	-	-	-	-	1137670	1029370	9.52 (-)

* Price rate (hiring charge for pack animals on per day basis, milk on per litre basis, chhurpi, butter and wool on per kg basis, sofa cover on per piece basis, shoe on per pair basis. Rates during 1997 and 1998 were same.

Table 3.5 Vegetation characteristics at different ecological zones along the Yuksam-Dzongri trail in Khangchendzonga Biosphere Reserve

Ecological zones	Dominant vegetations		
	Tree	Shrub	Herb
Temperate-warm (1600-2000 m)	*Castanopsis* spp., *Cedrela toona*, *Cinnamomum* spp., *Symplocos* spp., *Michelia lanuginosa*, *Macaranga* sp., etc.	*Rubus ellipticus*, *Edgeworthia gardneri*, *Oxyspora paniculata* *Pentapanax* sp., *Girardinia dicursifolia*, *Melastoma normale*, *Casearia* sp., etc.	*Eupatorium cannabinum*, *Cyanotis vaga*, *Hydrocotyle javanica*, *Pilea umbrosa*, *Impatiens* sp., *Brachiaria* sp., *Persicaria capitata*, *Plantago erosa*,etc.
Temperate-cool (2000-3000 m)	*Rhododendron arboreum*, *Quercus lamellosa*, *Acer campbellii*, *A. oblongum*, *Castanopsis tribuloides*, *Magnolia campbelli*, *Eurya acuminata*, etc.	*Maesa* sp., *Rubus paniculatus*, *Zanthoxylum acanthopodium*, *Daphne retusa*, *Aconogonum molle*, *Arundinaria maling*, *Viburnum* spp., *Caesaria* sp., etc.	*Tupistra nutans*, *Viola* sp., *Silaginella* sp., *Elatostema sessile*, *Urtica dioica*, *Rumex nepalensis*, *Drymaria cordata*, *Diplazium umbrosum*, *Impatiens* sp., *Laportia terminalis*, Ferns, etc.
Subalpine (3000-3800 m)	*Rhododendron barbatum*, *R. hodgsonii*, *Abies densa*, *Betula alnoides*, *Acer* sp., *Tsuga dumosa*, etc.	*Rhododendron cinnabarinum*, *R. wightii*, *Viburnum* sp., *Arundinaria maling*, *Rosa sericea*, *Daphne* spp., etc.	*Potentilla* spp., *Selinum tenuifolium* *Fragaria* sp., *Platystemma violoides*, *Prunella vulgaris*, *Gaultheria* spp., *Thalictrum* sp., *Primula* spp., etc.
Alpine (>3800 m)	-	*Rhododendron anthopogon*, *R. lowndesii*, *R. setosum*, *R. lepidotum*, *R. fulgens*, *Spiraea arcuata*, *Juniperus recurva*, *Rosa sericea*, etc.	*Aletris pauciflora*, *Primula* spp., *Potentilla* spp., *Rheum emodi*, *R. nobile*, *Pedicularis* spp., *Gentiana* spp., *Saxifraga* spp., *Hemiphragma heterophyllum*, *Cassiope fastigiata*, *Poa* spp., *Anaphalis* sp.

Table 3.6 Number and per cent contribution of species, genera and families of different plant groups in three ecological zones along the Yuksam-Dzongri trail

Ecological zones/ Plant groups	Families		Genera		Species	
	Number	(%)	Number	(%)	Number	(%)
Temperate						
Dicotyledon	57	86.4	109	82.0	148	81.3
Monocotyledon	7	10.6	22	16.5	32	17.6
Gymnosperm	2	3.0	2	1.5	2	1.1
Total	66	100	133	100	182	100
Subalpine						
Dicotyledon	27	84.4	38	79.2	60	82.2
Monocotyledon	4	12.5	8	16.7	11	15.1
Gymnosperm	1	3.1	2	4.1	2	2.7
Total	32	100	48	100	73	100
Alpine						
Dicotyledon	26	76.5	59	84.3	105	87.5
Monocotyledon	7	20.6	10	14.3	13	10.8
Gymnosperm	1	2.9	1	1.4	2	1.7
Total	34	100	70	100	120	100

Table 3.7 Per cent representation of life and growth forms of plants at different ecological zones along the Yuksam-Dzongri trail

Plant forms	Per cent		
	Temperate	Subalpine	Alpine
Life forms			
Phanerophyte	69.2	38.4	12.0
Chaemephyte	17.6	30.1	57.0
Hemigeophyte	1.1	9.6	15.0
Geophyte	2.2	6.8	7.0
Therophyte	4.1	15.1	9.0
Growth forms			
Tree	36.3	13.7	-
Shrub/undershrub	20.9	20.5	10.0
Climber	6.0	-	-
Creeper	0.5	-	-
Tall forb	15.4	27.4	25.0
Short forb	5.5	15.1	31.0
Cushion & spreading forbs	6.7	16.4	28.0
Graminoid	2.7	6.9	6.0
Epiphyte	6.0	-	-

Table 3.8 Ethnobotanical plant wealth of temperate and subalpine zones along the Yuksam-Dzongri trail in Khangchendzonga Biosphere Reserve of Sikkim Himalaya

Uses/Species	Vernacular name	Plant parts, used and mode of uses
Medicinal		
Artemisia vulgaris Linn.	'Titepatey'	Shoot and leaves are given in nervous and spasmodic affections connected with debility in asthma and diseases of brain. Hot fomentation of stem is used for treatment of eye cataract.
Astilbe revularis Ham.	'Buro-okhati'	Dried root boiled with milk is taken to get relief from body pain.
Drymaria cordata Willd.	'Abhijalo'	Hot fomentation of shoot is used to cure sinusitis and nasal blockade.
Eupatorium cannabinum Linn.	'Banmara'	Fresh leaf decoction juice is applied as blood coagulant.
Heracleum nepalense D. Don	'Chimphing'	Fruit is used as anti-typhoid treatment, nausea and vomiting.
Kaempfera rotunda Linn.	'Bhui-champa'	Tubers are used as poultice in fracture, swelling and healing.
Oroxylum indicum Linn.	'Totala'	Root bark is aphrodisiac tonic, as appetizer, in fever, dysentery. Seeds are used to cure pneumonia.
Piper longum Linn.	'Pipla'	Root is used in healing, stomachae, and laxative, improve appetite, bronchitis, abdominal pain. Roots are anti-diarrhoetic, anti-dysenteric, fever, tumour, piles, leprosy, jaundice, etc.
Plantago erosa Linn.	'Nasey jhar'	Root and leaves are astringent and used in fever. Seeds are used in dysentery.
Rhododendron arboreum Sm.	'Lali-gurans'	Flower is sour and used to cure dysentery and preserve the flower

		petals as de-obstruction of fish spines in the throat.
Rubia cordifolia Linn.	'Majheto'	Root is used as antidyreutric, antipyretic. It cures diseases of uterus, vagina, eyes, ulcer, urinary disorder, jaundice, piles, etc. Fruit is used in spleen disorder.
Rumex nepalensis Spreng	'Halhaley'	Root extracts are used for hepatitis and for hair loss.
Swertia chirata Ham.	'Chirowto'	The plant decoction is having coolen effect, anthelmintic, antipyretic, laxative, biliousness, leucoderma, inflammation, body-ache, urinary disorder, ulcer, asthma bronchitis, piles, etc.
Wild edibles		
Agaricus sp.	'Kalungey chew'	Fruiting body is one of the most delicious vegetables. Sun dried is also preserved for off-season.
Arundinaria hookeriana Munro.	'Pareng'	Tender shoots eaten as vegetables.
Bassia butyracea Roxb.	'Chewri'	Fruit are eaten. Seeds yield edible oil.
Bauhinia variegata Linn.	'Koiralo'	Flowers are making curry.
Castanopsis tribuloides A. DC.	'Patley katus'	Seeds are taken after fried.
Cinnamomum impressinervium Meissn.	'Sisi'	Seeds are fried and eaten.
Citrullus colocynthis Schrad.	'Indreni'	Fried seeds are eaten.
Dendrocalamus hamiltonii Nees. & Arnolt.	'Choya bans'	Tender shoot eaten as vegetables and made into pickles. Fermented shoot can be preserved and used in off-season to add flavour and taste to curry.
Dioscorea hamiltonii Hook.	'Ban tarul'	Tuber boiled eaten.
Diplazium umbrosum Willd.	'Ningro'	Tender shoot is one of the best delicious vegetables.
Evodia fraxinifolia Hook. f.	'Khanakpa'	Fruit into pickles.

Ficus infectoria Roxb.	'Kabra'	Shoots into pickles
Girardinia dicusifolia (Link) Friss	'Bhangrey sisnoo'	Leaves and tender shoot cooked with dal (*Phaseolus* sp.) is regarded as most delicious curry.
Juglans regia Linn.	'Okhar'	Seed kernels eaten.
Litsaea citrata Blume	'Siltimur'	Fresh fruit made into pickles.
Machilus edulis King.	'Kaulo'	Mature fruit are cured for some days in earthen pits and the pulp eaten.
Pleurotus sajor Caju.	'Kanney chew'	One of the best mushroom. Dried fruiting body is preserved for off-season use.
Prunus nepalensis Hook. f.	'Arupatey'	Ripe fruit pulp eaten.
Pyrus pashia Ham	'Mehel'	Fruit eaten raw, also made into pickles.
Rhus semialata Murray	'Bakhimlo'	Ripe fruit eaten.
Rubus ellipticus Smith.	'Aiselu'	Ripe fruit eaten.
Tupistra nutans Wall.	'Nakima'	Inflorescence is eaten as vegetable and fetch high prices.
Urtica dioica Linn.	'Patley sisnoo'	Leaves and tender shoot cooked with dal (*Phaseolus* sp.) is regarded as most delicious curry.

Fibre/ paper yielding plants

Daphne cannabina Wall.	'Syanu argeley'	Bark is used for making paper and rope.
Edgeworthia gardneri Meissn.	'Thulo argeley'	Bark is used for making paper and rope.
Urtica dioica Linn.	'Patley sisnoo'	Stem fibre is used for making fine threads.

Dye yielding plants

Rubia cordifolia Linn.	'Majheto'	Fruit yield reddish-orange dye.

Incense

Cryptomeria japonica D. Don	'Dhupee'	Branchlets used as incense in Buddhist monasteries.
Juniperus sp.	'Dhupee'	Branchlets used as incense in Buddhist monasteries.

Timber

Abies densa Griffith ex Parker	'Salla'	Trailing, roofing, walling and other heavy construction.
Alnus nepalensis D. Don	'Uttis'	House and other construction.
Beilschmiedia sikkimensis King.	'Tarshing'	House and bridge construction.
Castanopsis spp.	'Katus'	House and other heavy constructions.
Elaeocarpus sikkimensis Mast.	'Bhadrasey'	Heavy construction.
Cedrela toona Roxb.	'Tooni'	Furniture and household constructions.
Juglans regia Linn.	'Okhar'	Furniture and house construction.
Machilus edulis King.	'Phunsey'	House, cow shed and furniture.
Magnolia campbelli Hook. f.	'Ghogey chanp'	House and heavy construction
Michelia champaca Linn.	'Rani chanp'	Best wood for furniture.
Michelia lanuginosa Wall.	'Phusrey chanp'	Best wood for furniture
Quercus lamellosa Smith	'Bajrant'	Heavy construction.
Symingtonia populnea R. Br.	'Pipli'	Cowshed construction and firewood.

Fuelwood species

Abies densa Griffith ex R. Parker	'Salla'	†††
Acer campbellii Hook. f. & Thoms.	'Kapasey'	††
A. cappadocicum Gled.	'Kapasey'	††
A. laevigatum Wall.	'Kapasey'	††
A. oblongum Wallich. ex DC.	'Kapasey'	††
Albizzia procera Benth.	'Siris'	††
Alnus nepalensis D. Don	'Uttis'	††
Amoora wallichii King.	'Badar'	†††
Beilschmiedia roxburghiana Nees.	'Tarshing'	†††
Bucklandia populnea R. Br.	'Pipli'	†††
Casearia glomerata Roxb.	'Barkaunle'	††
Castanopsis hystrix Miq.	'Katus'	†††
Castanopsis tribuloides A. DC.	'Katus'	†††
Cedrela toona Roxb.	'Tooni'	††
Cinnamomum cecidodaphne Meissn	'Sinkauli'	††
C. impressinervium Meissn	'Sinkauli'	††
C. obtusifolium Nees.	'Sinkauli'	††
Elaeocarpus sikkimensis Mast	'Bhadrasey'	†††
Engelhardtia spicata Blume	'Mahuwa'	††
Eurya acuminata DC.	'Jhinguni'	†††
Gamblia ciliata C.B. Clarke	-	†
Garuga pinnata Roxb.	-	††
Glochidion acuminatum Muell.	'Latikat'	††
Macaranga pustulata King.	'Mallata'	†††
Maesa chisia Buch.-Ham. ex D. Don	'Bilaune'	††
Magnolia campbellii Hk. f & Thoms	'Chanp'	†††
Quercus lamellosa Smith.	'Bajrant'	†††
Rhododendron arboreum Linn.	'Lali gurans'	†††
R. barbatum Wallich ex G. Don	'Gurans'	†††
Symplocos theifolia Don.	'Kharane'	†††
Viburnum colebrookianum Wall.	'Asare'	†††
V. erubescens Wallich ex DC.	'Asare'	†††

††† = highly preferred, †† = medium preferred and † = least preferred

Table 3.9 Ethnobotanical plant wealth of Dzongri alpine pasture along the Yuksam-Dzongri trail.

Uses/Species	Vernacular name	Parts, uses and mode of uses
Medicinal		
Aconitum ferox Wall.	'Bikhma'	Fresh root decoction juice is taken in fever. Higher concentration can be given in food poisoning. Dried root is used in jaundice and diabetes.
Aconitum heterophyllum Wall.	'Bikhma'	Fresh root decoction juice is taken in fever. Higher concentration can be given in food poisoning. Dried root is used in jaundice and diabetes.
Bergenia ciliata (Haw.) Sternb.	'Pakhanbed'	Soup of fried root in boiling water is taken in fever and diarrhoea. Higher concentration can be recommended in fever.
Heracleum wallichii DC.	'Chim-phing'	Tender shoot and leaf is cooked and eaten in gastric problems. Dry fruit powder is also used in influenza.
Nardostachys jatamansi DC.	'Jatamansi'	Soup of dried root in boiling water is taken in malaria fever. Dried root powder can be applied in hair loss. It has also been reported used in epilepsy.
Orchis chusua Linn.	'Syanu panch-aungley'	Fresh root paste is used applied in cut, wound, bruise and injuries.
Orchis latifolia Linn.	'Panch-aungley'	Fresh root paste with root of *Rheum nobile*, *Rheum australe* and *Swertia multicaulis* is used in bone fracture. It is also applied in cut, wound, bruise and injuries and in bodyache.
Picrorhiza kurrooa Royle ex Benth	'Kutki'	Fresh/dry root boiled in water is taken in cold, cough and fever. For

		fever higher dose can be used.
Rheum australe D. Don	'Khokim'	Root paste is used as bandage in minor fracture. The root paste is also administered externally in chest-pain. The soup prepared from the root is taken in bodyache.
Rheum nobile Hook. f. & Thoms.	'Kenjoh'	Fresh root paste is administered externally in chest pain. Root soup boiled with water can also be taken.
Swertia multicaulis D. Don	'Sarma-guru'	Fresh root paste is used in cut, wound and injuries. It is also very effectively used in bone-fracture.
Incense		
Cremanthodium reniforme Benth.	'Dhup'	Branchlet along with leaves
Juniperus indica Bertol.	'Dhupee'	Branchlet along with leaves, used extensively in Buddhist Monasteries.
Juniperus recurva D. Don	'Dhupee'	Branchlet along with leaves, used extensively in Buddhist Monasteries.
Rhododendron anthopogon D. Don	'Sunpate'	Branchlet along with leaves
R. lepidotum Wallich ex G. Don	'Sunpate'	Branchlet along with leaves
Rhododendron setosum D. Don	'Sunpate'	Branchlet along with leaves
Tea substitute		
Rheum emodi Wallich ex Meissner (syn. *R. australe* D. Don)	'Khokim'	Root used both fresh and dried. One cube of 1 x 1 cm is sufficient for one cup of tea.
Fuel wood		
Rhododendron anthopogon D. Don	'Sunpate'	Whole plant.
R. fulgens Hook. f.	'Chimal'	Whole plant.
R. setosum D. Don	'Sunpate'	Whole plant.
R. thomsonii Hook. f.	'Chimal'	Whole plant.
Juniperus indica Bertol.	'Dhupee'	Whole plant.
J. recurva D. Don	'Dhupee'	Whole plant.

Edible		
Rheum nobile Hook. f. & Thom.	'Khokim'	Tender shoot prepared as ickles.
Miscellaneous uses		
Bergenia ciliata Hook. f.	'Pakhanbet'	Growing in home garden.
Primula spp.	'Primula'	Growing in home garden.
Rhododendron fulgens Hook. f.	'Chimal'	Made field implement handle from wood.

Table 3.10 Plant species number belonging to different utilization groups from three ecological zones along the Yuksam-Dzongri trail.

Utility type	Temperate	Subalpine	Alpine
Number of species recorded	182	73	120
Number of species of different utility*			
Fodder	41	4	-
Fuelwood	26	6	6
Timber	17	2	-
Medicinal plants	12	1	11
Wild edibles	23	-	1
Aesthetic plant	6	4	4
Dye yielding plants	1	-	-
Paper	2	-	-
Fibre	4	-	-
Thatch	2	2	-
Agricultural implements	-	-	1
Incense	2	-	6
Tea-substitute	-	-	1

*Some species have multiple uses

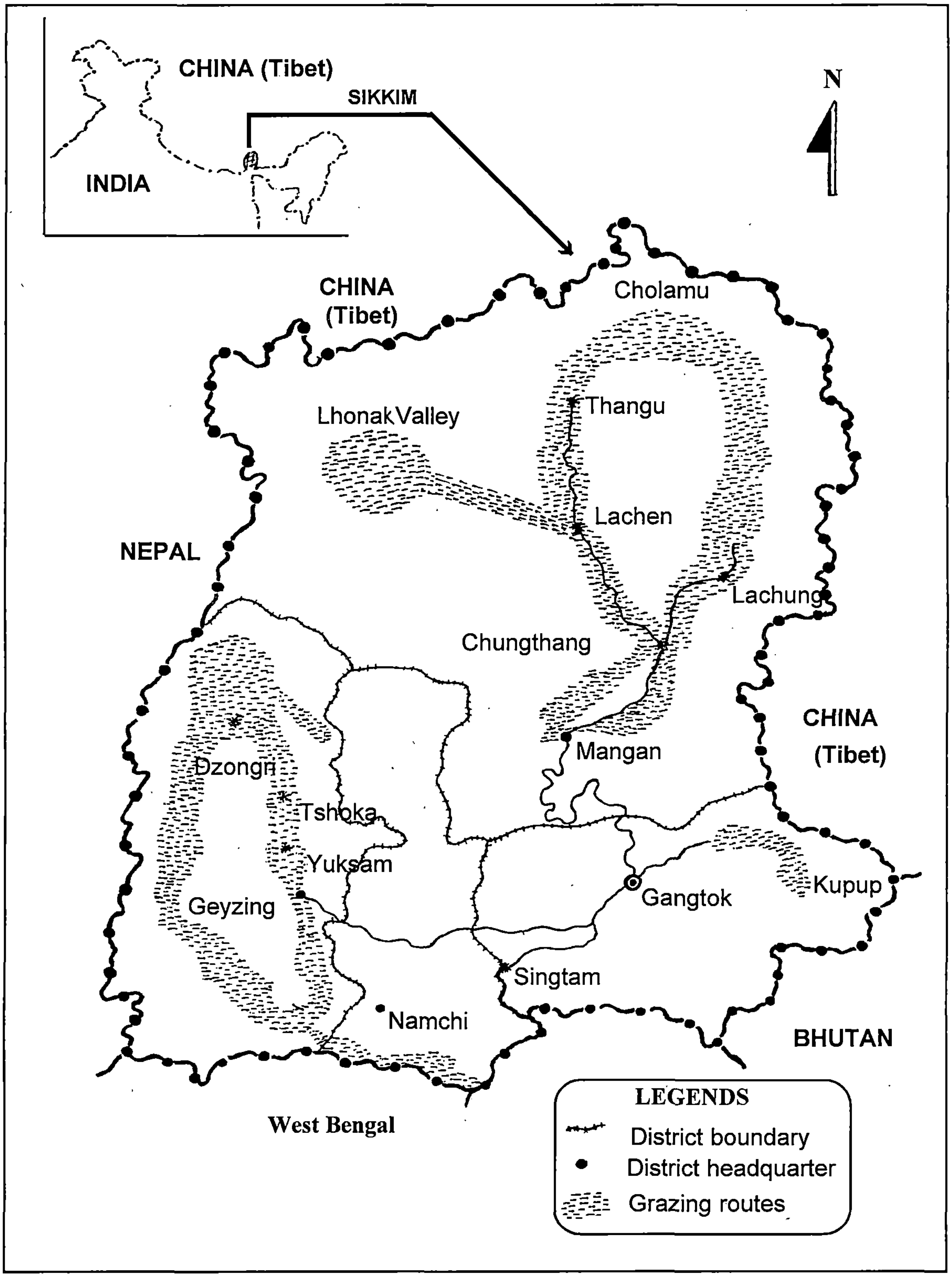

Fig. 3.1 Map showing major livestock grazing routes in the Sikkim Himalaya

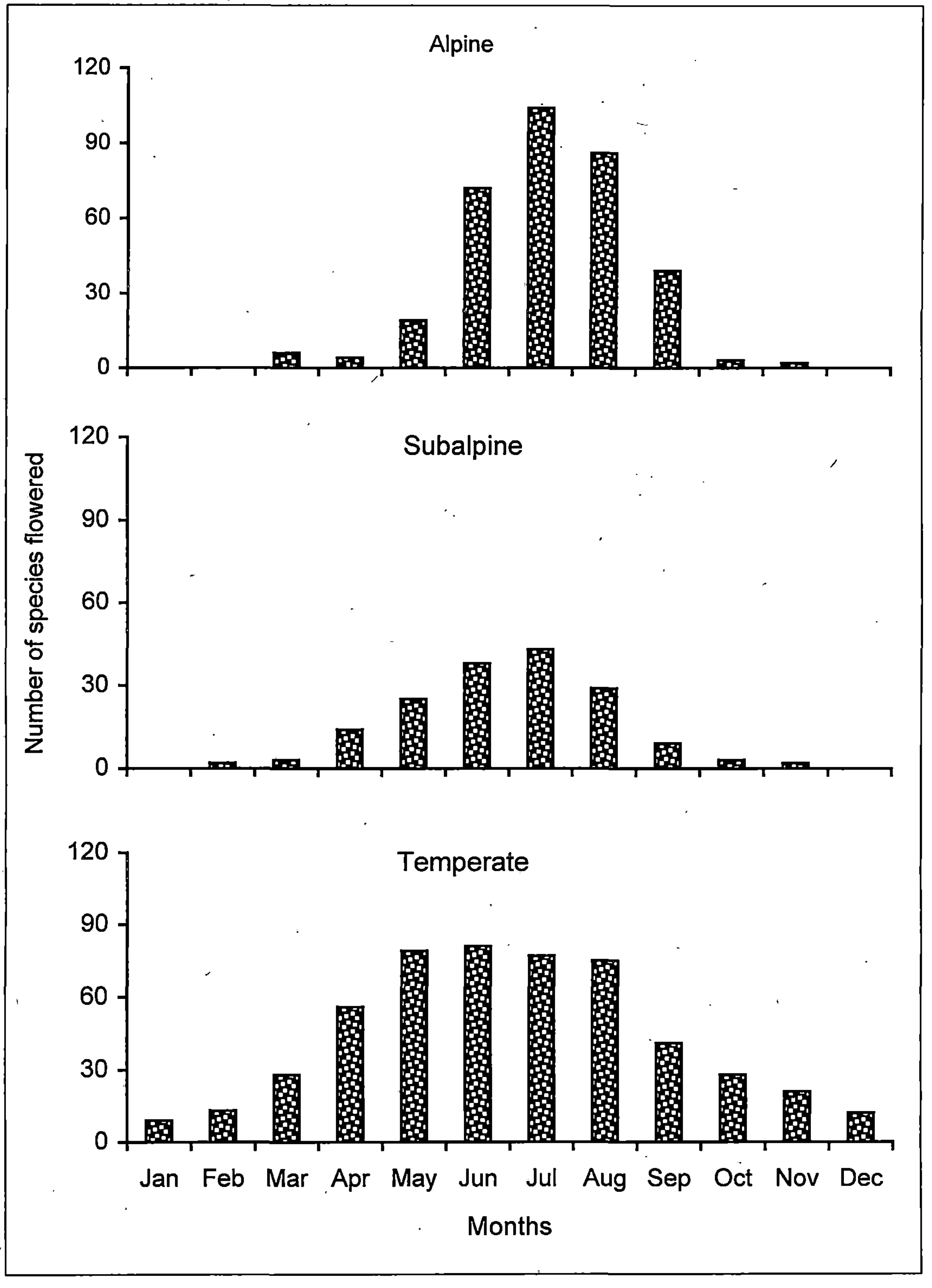

Fig. 3.2 Temporal distribution of flowering at three ecological zones along the Yuksam-Dzongri trail in Khangchendzonga Biosphere Reserve

CHAPTER IV

FORAGE RESOURCES AND LIVESTOCK FORAGING BEHAVIOUR

4.1 INTRODUCTION

An important aspect for forage evaluation is to augment fodder quantity and quality, primarily through the yield assessment of different species, as well as nutritive compositions of forage (Grovum 1988). A large variety of tree species, forest floor phytomass and agricultural by-products are used as animal fodder in the Himalaya (Sundriyal 1995). Digestion and metabolism trails on fodder and grasses contribute to their metabolic evaluation (Van Soest 1994). Palatability of a species depends on its chemical constituents, growth stage and plant-compositions (Heady & Child 1994). Palatability is best understood as the interaction between taste and post-ingestive feedback, which is determined by an animal's physical condition relative to a plant's chemical characteristics. Thus if food is useful, palatability increases, and conversely, if the food is harmful, palatability decreases (Heady & Child 1994; Provenza 1995). The chemical composition of forage changes with maturity of plants (Phillips *et al.* 1954; Loper & Smith 1961; Decker *et al.* 1967; Brown *et al.* 1968) and in different plant components, i.e. inflorescence, leaves and stem (Fleming 1963; Davey & Mitchell 1968; Krueger *et al.* 1969; Smith 1970). Attempts have been made to know comparative botanical and chemical composition of the grazing animals' dietary composition (Cook 1954; Cook *et al.* 1963; Van Dyne & Heady 1965a, 1965b; Sundriyal 1995). The factors governing palatability of range forages and preference by grazing animals are complex and are not well understood, because of the difficulty of accurately measuring dietary composition (Cook & Stoddart 1953; Heady 1964). Calcium and phosphorous are required for normal growth of animals. Crop residues and dry fodder are fibrous in nature due to the presence of structural carbohydrates like cellulose, hemicellulose and pentosans. These structural carbohydrates are in physical association with lignin in the plant cell walls. With maturity of plants the amount of lignin is closely bounded to cellulose by means of linno-cellulosic bonds. Thus lignin reduces the digestibility of dry fodder.

The Sikkim State is recognised as a potential region for intensive livestock production (Balaraman & Golay 1991). A large number of species are used as fodder resources in Sikkim State, out of which a few are considered good quality fodder. However, limited attempt has been made to augment the fodder resources in the state, which can go a long way in translating this potentiality into a practical reality. A recent assessment of feed and fodder availability position for livestock in the state indicate an acute shortage in terms of green fodder, dry forage and concentrates (Balaraman & Golay 1991; Paljor 1998). Generally, stall feeding of animals is popular at low and mid-hills, which is slowly converting to free grazing due to easy access to forest areas. At higher elevations, however, free grazing by locals and nomads is most popular and traditional.

In the core zone of the Khangchendzonga Biosphere Reserve, free grazing is officially banned, however the locals still practise free grazing in forested pastures and alpine and subalpine areas. The mid-elevations support animals throughout the year, while the higher elevations are visited during summer and rainy seasons only. Khangchendzonga Biosphere Reserve has a large variety of fodder resources, which includes herbs, shrubs and trees, and some of these are highly palatable and rich in nutrient content. However, till date no attempt has been made to evaluate all these fodder resources quantitatively as well as qualitatively. The present chapter provides details about the available fodder resources and their annual production, and an estimation of the nutritive values of some potential species. An attempt has also been made to study animal foraging behaviour in the process of free grazing. It is considered that the information will have larger implications for livestock management in this Biosphere Reserve.

4.2 METHODS

Detailed surveys were made with reference to the availability of fodder resources, types of plant species used, mode of feeding at different elevations from Yuksam to Dzongri in the Khangchendzonga Biosphere Reserve. Formal and informal interviews were made with the villagers and graziers, and fodder collections sites as well as livestock rearing places were visited physically to verify the fodder source. The total number of grazing livestock was counted through household survey. Fodder collected from the forest were quantified on back-load basis, as this is most common expression by the villagers and graziers throughout the state (Balaraman & Gollay 1991; Sundriyal *et al.* 1994). Different households collect such back-loads on daily basis, and 52 representative sample households were investigated. The fresh weight of fodder per back-load was quantified and thus a mean value was derived.

Local residents were interviewed with reference to animal preference of fodder. Animals were fed with composite samples of many fodder plants. Observations were made on number of bites for each fodder. It was assumed that the fodder received higher number of bites is most preferred by an animal. The ranking of preference (high, medium and least preferred) was developed. The average quantity of forage consumption per animal per day was estimated by feeding an animal with the known quantity of fodder, and thus total consumption was recorded for different types of animals. Observations on duration of grazing time by livestock at different elevations, bite frequency, size and composition of each diet, forage preference, availability of food and degree of herbage exploitation was noted through field study.

Forage production

The forage biomass production of agroforestry fodder species was calculated by recording tree measurements, mainly height, canopy covers, bole height and number of branches. Thereafter branches of different sizes were lopped for all available fodder, which was quantified and calibrated for whole tree considering total number of branches. Such method is considered of high accuracy and is preferred for all agroforestry tree species (Sharma *et al.* 1992; Sundriyal *et al.* 1994). As the grasslands meet most annual fodder demand, a detailed description of the forage quantity and productivity along the trekking trail is presented separately in Chapter V and VI.

Animal grazing behaviour

Total days foraged in temperate, subalpine/near timberline and alpine pastures were counted for different grazing animal types. Foraging period, grazing bite rate, bite size and daily forage consumption rate by the different animal types in different ecological zones were calculated for the estimation of total forage demand or animal requirement (Sundriyal & Joshi 1989). Since alpine and subalpine have almost similar foraging characteristics, only one value is presented.

Foraging period

Time period of grazing by animals was noted by recording time for free grazing in the pasture. Time was recorded for animals removed for free grazing in the morning and collected from free grazing in the evening. Time spent by single marked individuals of different animal groups for various activity e.g. walking, resting, and other activities during the grazing hours of a day was noted. The grazing hours per day per animal group i.e. the period for which animals remain in the field for grazing was recorded during different months. Hours spent on grazing per day by different animal group were calculated as;

Foraging hours (hrs day^{-1}) = Grazing hour day^{-1} – (time spent on walking + time spent on resting + time spent on other activities).

Bite rate

Bite rate means the number of bites per unit time. The number of grazing bites per animal group was counted in a fixed time interval of 15 minutes. Animals were observed closely and calmly from a very near distance to note the bite cut of plants, which gives an audible sound. The intensity of grazing vary from morning to evening hours, therefore number of bites was noted at 10 a.m., 1.00 p.m. and 3.00 p.m. on each sampling date. Data were recorded for each individual animal ($n = 4$) and values were averaged and converted as bite per animal per hour or per day.

Bite size

To note the bite size of different animal groups, two patches of 30×30 cm, almost similar in species composition were selected before grazing. A number of such patches were selected at each sampling date. Individuals of different animal groups were allowed to graze one of such patches and numbers of bites were counted. Thereafter, intact patch was harvested at ground level, oven dried and weighed. Similarly, grazed patch was also harvested and dried mass was weighed. No data were recorded when animals grazed both of the adjacent patches. Bite size was calculated as;

$$\text{Bite size} = (W_2 - W_1)/N$$

Where, W_2 = biomass weight of the intact patch, W_1 = biomass weight of grazed patch, N = number of bites on grazed patch.

Forage dry matter consumption per animal per day = Bite size × total number of bites per day during total hours of grazing.

Nutrient analyses

Alpine and subalpine plants were surveyed to estimate nutritive values of the most commonly and preferably grazed species. Samples were collected in August, when biomass peaked and species was most available for grazing. Chemical analyses were done in the laboratory for leaves of fodder tree species and for whole aboveground material in case of alpine/subalpine herbaceous species. The leaves of most palatable fodder species were brought to laboratory, and oven dried at 60°C till constant weight. The dried samples of different species were ground into powder by an electrical grinding machine and sieved through 1 mm wire gauge for uniform particle size. Such material was used for estimation of nutrients following standard methods (Allen 1989; Anderson & Ingram 1993).

Crude fibre

Crude fibre is essentially the residue left after subsequential hot digestion with H_2SO_4 and NaOH. It mainly consists of cellulose together with a little lignin. Crude fibre was determined by acid and alkali digestion method using Tecator Fibretec apparatus.

Acid detergent lignin

Acid detergent lignin (ADL) was determined using Fibretec apparatus by de-fatting a known weight of plant sample (W_1) with acetone (cold extraction) and with acid detergent solution (hot extraction), and washed with hot water. The sample was mixed with H_2SO_4 for three hours, again washed to free from acid. It was dried, weighed (W_2) and ashed in muffle furnace at 525°C for three hours and again weighted (W_3). The ADL was calculated as per following formula:

$$\text{ADL (\%)} = \frac{(W_2 - W_3) \times 100}{W_1}$$

Cellulose and hemicellulose

Cellulose was determined by de-lignification of plant samples, which yield the product consisting of cellulose plus various other polysaccharides, mainly hemi-cellulose. Cellulose was determined by difference of acid detergent fibre minus acid detergent lignin. Hemi-cellulose was determined as the difference of nutrient detergent fibre and acid detergent fibre using Fibretec apparatus.

Nitrogen and crude protein

Nitrogen was estimated following modified Kjeldahl method by digesting the samples with sulphuric acid and catalysts (copper sulfate, mercuric oxide, selenium powder and potassium sulfate) (Allen 1989). Crude protein was obtained by multiplying with a factor 6.25 to the nitrogen per cent which is based on the assumption that plant protein consist of 16% nitrogen.

Phosphorus

Phosphorus was estimated by the colorimetric determination using molybdate reagent and the ascorbic acid (Anderson & Ingram 1993). Absorbance was taken at 880 nm in the UVS spectrascan.

4.3 RESULTS

Fodder resources varied at different elevations along the Yuksam-Dzongri trail. At Yuksam, the fodder demand was met from forest floor phytomass, trees, agroforestry species and agricultural byproducts. With the increasing elevation the contribution of forest floor phytomass incresaed upto almost 100%. At subalpine and alpine sites the pasture meet the total fodder demand of the animals. This chapter reports on the fodder from forest, agricultural lands, and alpine and subalpine pastures. A checklist of fodder species along with preference ranking and availability period in temperate, agriculture land, alpine and subalpine areas has been presented (Table 4.1).

4.3.1 Fodder from the Forests and Agriculture Land

Fodder from forests

At Yuksam settlement, the doorstep to the buffer zone of the Khangchendzonga Biosphere Reserve, an average family maintains 5-6 animals, which consists of cattle, sheep, goat, dzo and pig. A total of 43 fodder species were collected from forest (Table 4.1), out of them 24 species were trees, 11 shrubs, 4 herbs, 3 climbers and one epiphyte (Table 4.2). These plants belong to 35 genera of 25 families. Species representation from the families Moraceae (7 spp.), Araliaceae (4 spp.), Aceraceae (3 spp.), and Poaceae (3 spp.), were more. In terms of fodder-preference ranking, 17 species were recorded as highly preferred, 19 with medium-preference, while remaining 7 species were relatively less preferred (Table 4.2). Community collected fodder from forest during different seasons, and an average family collected 38 kg fodder per day from forest. Thus annually 13,500 kg fodder was collected by each household at the Yuksam Block. Total grazing animal numbering 1559 was reared by 274 households at Yuksam (399 cattle, 435 sheep, 320 goat, 120 dzo, 31 horse and 254 pig). Based on individual household fodder requirement, a total of 1303 ton fodder was needed annually averaging 3.57 tons household^{-1} yaer^{-1} at the Yuksam Block. Around 83% of the fodder requirement come from the forest and the remaining from agroforestry and agriculture residues (Table 4.4).

Tshoka is the last settlement in this trail and 10 families reared animals like cow, dzo and horse. Animals were generally left for free grazing except small calves and a few lactating animals. Most animals were given small quantity of fodder at the sheds once in the late evening. Fodders belonging to a few species, viz. *Acer campbellii* (Milo Kapasey), *Arundinaria maling* (Malingo), *Schefflera impressa* (Bhalu chindey) and *Pentapanax leschenaultii* (Chindey) were collected and fed to animals.

Fodder from the agriculture land

Farmers at Yuksam block also maintain a few species in their farms as forage bank, particularly for dry and lean season (i.e. January-March). Ten fodder tree species were recorded being maintained for lean season (Table 4.2). Eight species (*Arundinaria maling*, *Bambusa* sp., *Brassaiopsis mitis, Ficus cunia, F. nemoralis, F. roxburghii, Saurauia napaulensis* and *Thysanolaena maxima*) were most preferred. Each household was maintaining on an average of 30 fodder trees in their farms. Among agroforestry fodder species, *Ficus roxburghii* produced highest forage biomass, which doubled than any other fodder trees, and this species is most preferred by animals. On an average each household produced 445 kg annum^{-1} fodder from *Ficus roxburghii* (c. 45 kg tree^{-1} annum^{-1}). Contrarily, the forage production for *Ficus nemoralis* was recorded less amounting to 49 kg annum^{-1} household^{-1} (c. 12 kg tree^{-1}

annum^{-1}). Other species had intermediate range of fodder production (Table 4.3). Household estimates revealed that each family could generate at least 793 kg of dry fodder per annum from agroforestry species in the Yuksam Block (Table 4.3). The annual fodder from the agricultural land was estimated to be 217 ton raised in 274 households. This amounts to around 17% of green fodder requirement as contributed by the agroforestry fodder trees (Table 4.4).

4.3.2 Fodder from Subalpine and Alpine Pastures

In alpine and subalpine areas all the graziers practise free grazing, and the pastures composed a large variety of lush green species, which is a mixture of both dicot and monocot species. The animals visit all accessible locations and generally cow, yak, dzo and horse prefer plateau, while sheep can graze effectively even in steeper regions. Though the animals graze a large number of species, on the experimental basis high preference was recorded for *Poa* spp., *Juncus thomsonii*, *Aletris pauciflora, Potentilla coriandrifolia, Geranium nakaoanum*, etc. Generally, livestock grazed 17 common forage species in alpine/subalpine pastures, out of which 41.2% were highly palatable, 29.4% medium preferred and remaining 29.4% were least preferred (Table 4.2).

4.3.3 Animal Foraging Behaviour

In temperate pasture dzo has the highest bite rate (51.5 bite min^{-1}) whereas sheep had the least (41.2 bite min^{-1}). Dzo also showed maximum bite size (105.6 mg bite^{-1}) and minimum bite size (53.0 mg bite^{-1}) by goat. Highest foraging hour was recorded in dzos (11.9 hrs day^{-1}) and least in goat (9.3 hrs day^{-1}). Cow and goat grazed throughout the year in temperate zone except a few cows that grazed briefly (3 months) in alpine areas. Sheep grazed about 255 days in temperate pastures. The forage intake rate on dry weight basis was maximum for dzo (3.88 kg day^{-1}) and least for sheep (1.27 kg day^{-1}). In temperate pastures, cow consumes 1250 kg of dry forage per annum whereas least by sheep (323 kg yr^{-1}) (Table 4.5).

The foraging characteristics of cow, dzo, yak, horse, sheep and goat at different ecological zones are given in Table 4.5. In alpine/subalpine zones, dzo has the highest grazing bite rate (59.5 bites min^{-1}) whereas least by sheep (48.5 bites min^{-1}). The biggest bite size was recorded for dzo (99.8 mg bite^{-1}) whereas least for sheep (52 mg bite^{-1}). Foraging hours was highest for horse (11.5 hrs day^{-1}) whereas least for sheep (7.75 hrs day^{-1}). Total foraging period was highest for yak (365 days yr^{-1}) whereas least for cow (90 days yr^{-1}) in alpine/subalpine pastures. Forage intake rate was highest by dzo (4.03 kg day^{-1}) and least by sheep (1.17 kg day^{-1}). The total forage intake was highest in yak (1214 kg yr^{-1}) whereas least by sheep (129 kg yr^{-1}) in alpine pasture (Table 4.5).

4.3.4 Nutritive Values of Fodder Species

4.3.4.1 Cellulose, hemicellulose, crude fibre and lignin content

Cellulose, hemicellulose, crude fibre and lignin contents of 21 temperate forest species, 8 agroforestry species and 10 alpine and subalpine species was estimated and presented (Table 4.6). Among temperate species, cellulose content was highest in *Acer campbellii* (37.32%) while least in *Silaginella* sp. (7.3%); among agroforestry species it was highest in *Saurauia napaulensis* (27.9%) and least in *Ficus cunia* (10.7%); and among alpine and subalpine species the cellulose content was highest in *Poa* sp. I (27.53%) while least in *Bistorta affinis* (4.59%) (Table 4.6).

Hemicellulose content was highest in *Brachiaria* sp. (26.9%) and least in *Ficus foveolata* (12.2%) among temperate forest species; highest in *Prunus cerasoides* (17.23%) and least in *Saurauia napaulensis* (6.0%) among agroforestry species, whereas it was highest in *Hemiphragma heterophyllum* (35.84%) and least in *Potentilla coriandrifolia* (19.71%) of alpine/subalpine pastures (Table 4.6).

Crude fibre content was highest in *Urtica dioica* (30.43%) while least in *Commelina benghalensis* (8.55%) among the temperate forest species; highest in *Thysanolaena maxima* (31.21%) and least in *Ficus cunia* (16.47%) among agroforestry species and was highest in *Potentilla peduncularis* (28.21%) and least in *Poa* sp. III (11.41%) among alpine and subalpine species (Table 4.6).

Lignin content was highest in *Acer oblongum* (35.89%) and least in *Pteris* sp. (6.56%) among temperate forest species; highest in *Prunus cerasoides* (17.36%) and least in *Brassaiopsis mitis* (10%) among agroforestry species; and it was highest in *Potentilla peduncularis* (26.72%) and least in *Poa* sp. III (9.32%) among alpine/subalpine species (Table 4.6).

4.3.4.2 *Nitrogen, phosphorus and crude protein concentration*

Nitrogen, phosphorus and crude protein of 21 temperate forest species, 8 agroforestry species and 10 alpine and subalpine species have been estimated (Table 4.6). Among the forest species, highest concentration of nitrogen was recorded in *Diplazium umbrosum* (3.68%) while least in *Aconogonum molle* (1.04%). Among agroforestry species, nitrogen concentration was highest in *Ficus cunia* (4.97%) and least in *Prunus cerasoides* (1.17%). In alpine and subalpine pastures, highest nitrogen concentration was recorded in *Poa* sp. II (1.87%) while least in *Aletris pauciflora* (1.06%) (Table 4.6).

Phosphorus concentration among temperate forest species was highest in *Hedychium ellipticum* (0.229%) and least in *Litsaea polyantha* (0.038%); it was highest in *Ficus nemoralis* (0.282%) and least in *Prunus cerasoides* (0.122%) among agroforestry species and was highest in *Poa* sp. III (0.377%) and least in *Aletris pauciflora* (0.185%) among alpine and subalpine species (Table 4.6). Crude protein content ranged from 6.25 to 23% among temperate species, 7.31 to 31.06% among agroforestry species and from 6.63 to 11.69% among alpine and subalpine species (Table 4.6).

4.4 DISCUSSION

The fodder need of livestock at low and mid-elevations throughout the Sikkim state is presently met through natural resources like forest floor phytomass, fodder tree, agroforestry species and crop residues and byproducts (Sundriyal *et al.* 1994). Fodder trees can be used as multipurpose trees (fruits, fuelwood, timber, medicine, etc.) and regarded as a 'forage bank' for the villagers of Sikkim. These fodder trees have high potential for further development and uplifting the economy of the people. Fuel and fodder are two most important basic requirements of the mountain society that are met from the forests, but with increasing population pressure, these resources are rapidly depleting in natural habitats (Nautiyal *et al.* 1987). The rising human population and improved living standards have increased the demand for various livestock products and high yielding animals that require a high quality and quantity of fodder and sustainable management systems. Animal population is growing continuously in the recent past due to family fragmentation and involvement of livestock in tourism sector, therefore grazing may cause a threat to forest regeneration in the future (Sundriyal *et al.* 1994).

Generally *Ficus* leaves possess lower values of cellulose and lignin content and therefore preferred most. *Ficus* species from agroforestry showed moderate to higher protein content. Higher content of cellulose, crude fibre and lignin (e.g. *Brassaiopsis mitis* and *Saurauia napaulensis*) by species are indicator of less preferred fodder. Reduction of lignin, cellulose and fibre content in plants of grazed areas can be attributed to growth of new tissue, which is always replaced, thus reduces the total fibre content. In the present study temperate plants were generally having higher crude protein than the alpine plants, which is in contrary to the alpine plants of Central Himalaya as reported to contain more nitrogen and consequently higher crude protein than the plants of lower elevations (Ram 1988).

Nitrogen content was more in grass than forbs, which is in contradiction to the findings from the Garhwal Himalaya (Ram 1988) where 1.99 to 2.71% nitrogen concentration in grasses and 1.39 to 3.71% in forbs reported was comparatively higher than the present study (1.02 to 1.87% in grasses and 1.03 to 1.35% in forbs.

Animal nutritional requirements, particularly for lactating animals, cannot be met by free grazing alone. Grasses found in forest during October to March are nutritionally poor and may contain only 2-18 per cent of crude protein (Verma 1988). Currently, cultivated forage and pasture-lands are the major sources of inexpensive, good quality feed for livestock. Therefore plantation of fodder trees is compulsory to supplement the fodder needs during scarcity period (Sundriyal 1995). The improvement of forage resources in the Himalaya implies a simultaneous development of both pastures and cultivated fodder, as both of these resources are used continuously or sequentially across the spectrum of animal husbandry system.

In alpine and subalpine areas, free grazing may be allowed with a frequent shifting of animals from place to place, which will avoid overgrazing at a single place. In temperate areas, however, dependence on the forests should be reduced through promotion of some alternatives such as by maintaining more agroforestry forage banks, and sustained production of other agricultural crop residues. As local inhabitants practise free grazing, certain pockets have already been becoming bare lands, particularly surroundings of animal herds and concentration areas. There is a need to regulate such activities. Free grazing inside the forest should be controlled and regulated because free grazing not only affects the ground vegetation but also hampers growth of young seedlings and saplings particularly in temperate zones. Fodder collection from these areas, though a labour intensive exercises, should be the best option for management efforts. While in stall-fed, the fodder should be kept in proper designated place, otherwise large amount of fodder will be destroyed due to faecal dirty. Putting huge amount of fodder at a time make the animal choosy. Therefore, less quantity should be kept and after completion of it, more can be put according to the requirement. Less palatable fodder should be fed mixed with other more palatable fodder species. Over 81% of total fodder demand are met from the forest areas and thus these areas provide a cheapest source of fodder availability for rearing animals. Though the local state Government has fixed a nominal fee for pack animals operating along the Yuksam-Dzongri trail.

A large number of tree species have been recorded as potential fodder species, which are collected for fodder purpose from the temperate forests. However, most of these species provided fodder during summer and rainy seasons. Only 13 species provided fodder during winter. Therefore the animals move to temperate zone. It was recorded that there was no dearth of fodder during rainy season, however during winter months the good quality fodder comes from agroforestry species only. Thus strengthening of agroforestry species at farm particularly those provide fodder during winter months will have larger implications and acceptance from villagers point of view.

Bite rate, bite size and foraging hours of horse and sheep are closely comparable with the reports from the Central Himalaya (Negi *et al.* 1993). Each animal was having relatively low bite rate per unit time in temperate zone than the alpine areas, which can be attributed to lower grazing hours at higher elevations. Also may be the forage of the alpine areas have more number of palatable species, thus animals may require less time in food search and their per unit time bite frequency increases. However, the less bite frequency in the temperate zone is substantiated by bigger bite size as all animals recorded a higher bite size in this zone. Further more fodder species are taller in height, which also increased the bite size in temperate zone. All animals except yak move to lower elevation during winter season, and among all, cow move first, followed by horse, sheep and dzos. As the climatic conditions were very severe at alpine during winter, and there is hardly any fodder available, most of the yak fed on small bushes especially rhododendron twigs by coming down slightly to subalpine areas. Often yaks suffer causalities during this period. Winter season is a fodder scarcity period and at this period all animals rely on poor quality fodder. Therefore the villagers maintain forage bank in the form of agroforestry trees, which provide fodder during winter months. Plantation of better quality fodder species (like *Ficus* spp.) in wasteland, community lands and other agricultural lands would bring opportunity of more high quality fodder availability during winter months. The State Forest Department (1995) has estimated the annual requirement of fodder for the livestock of the state and according to them as against the requirement of 2.08 million tons of green fodder only 1.32 million tons of green fodder are available leaving a deficit of 0.76 million tons or 36.54% (Paljor 1998). Out of the total 709,600 ha area of Sikkim, about 162,392 ha (23%) is available for fodder production and pasture development in the state compared to 15% of the total land available for cultivation (Paljor 1998). Still there is high potential for fodder production and pasture development because of its vast area. Scientific intervention on the development of fodder species and pasture management can excel the livestock production as well as pasture conservation. ■

Table 4.1 Common fodder species collected from forest and agriculture lands at Yuksam village and in alpine (Dzongri) and subalpine (Deorali) pastures

Species	Vernacular name	Habit	Ranking	Availability
Forest				
Acer campbellii.	'Kapasey'	Tree	††	Aug-Nov
Acer laevigatum	'Kapasey'	Tree	††	Aug-Nov
Acer oblongum	'Putley'	Tree	††	Aug-Nov
Aconogonum molle	'Thotney'	Shrub	††	Jun-Sep
Artocarpus lakoocha	'Badar'	Tree	†††	Jul-Oct
Arundinaria maling	'Malingo'	Shrub	†††	Round
Bassia butyracea	'Chewri'	Tree	††	Jun-Aug
Betula cylindrostachys	'Saur'	Tree	††	May-Oct
Brachiaria sp.	'Bonsoghans'	Herb	†††	Apr-Nov
Brassaiopsis mitis	'Chuletro'	Shrub	†††	Round
Castanopsis tribuloides	'Katus'	Tree	†	Jun-Aug
Commelina benghalensis	-	Herb	††	May-Sep
Cyperus sp.	-	Herb	†††	Round
Diplazium umbrosum	'Ningro'	Herb	††	Round
Pteris sp.	'Unyo'	Shrub	††	May-Dec
Erythrina indica	'Falado'	Tree	†††	Apr-Oct
Ficus clavata	'Lute-khanew'	Tree	†††	Apr-Sep
Ficus cunia	'Khanew'	Tree	†††	Apr-Nov
Ficus foveolata	'Dudilhara'	Climber	†††	Mar-Dec
Ficus hirta	'Khasrey''	Shrub	††	May-Nov
Ficus nemoralis	'Dudhilo'	Tree	†††	Round
Ficus roxburghii	'Nebhara'	Tree	†††	Round
Gamblia ciliata	'Khursimal'	Shrub	†	May-Sep
Garuga pinnata	'Dabdabe'	Tree	††	May-Sep

Glochidion acuminatum	'Latikat'	Tree	†††	May-Oct
Heynea trijuga	'Ankha-tarua'	Tree	††	Apr-Oct
Litsaea polyantha	'Kutmero'	Tree	†††	May-Sep
Macaranga pustulata	'Malata'	Tree	††	Apr-Nov
Machilus edulis	'Kawla'	Tree	†††	May-Dec
Maesa chisia	'Bilaune'	Shrub	†	May-Sep
Morus laevigata	'Kimbu'	Tree	††	May-Sep
Mussaenda frondosa	'Dhobi'	Shrub	††	Jun-Sep
Pentapanax racemosa	'Chindey'	Climber	††	Mar-Dec
Prunus cerasoides	'Payun'	Tree	††	May-Oct
Quercus lamellosa	'Bajrant'	Tree	†	Jul-Sep
Rhaphidophora divursiva	'Kanchirna'	Climber	†	Round
Saurauia napaulensis	'Gagoon'	Tree	†††	Round
Schefflera impressa	'Balu-chinde'	Tree	†††	May-Oct
Thysanolaena maxima	'Amliso'	Shrub	†††	Round
Turpinia nepalensis	'Thali'	Tree	††	May-Sep
Vaccinium serratum	-	Epiphyte	†	Apr-Dec
Vitex heterophylla	'Panchpate'	Shrub	†	Jun-Sep
Zanthoxylum alatum	'Timboor'	Shrub	††	May-Oct
Agroforestry				
Alnus nepalensis	'Uttis'	Tree	†	Round
Arundinaria maling	'Malingo'	Shrub	†††	Round
Bambusa sp.	'Bans'	Tree	†††	Round
Brassaiopsis mitis	'Chuletro'	Shrub	†††	Round
Ficus cunia	'Khanew'	Shrub	†††	Round
Ficus nemoralis	'Dudhilo'	Shrub	†††	Round
Ficus roxburghii	'Nebhara'	Tree	†††	Round
Prunus cerasoides	'Payun'	Tree	††	May-Oct
Saurauia napaulensis	'Gagoon'	Shrub	†††	Round

Thysanolaena maxima	'Amliso'	Shrub	†††	Round
Alpine/Subalpine				
Aletris pauciflora	-	Graminoid	†††	May-Sep
Anemone tetrasepala	-	Forb	†	May-Aug
Bistorta affinis	-	Cushion	†	Apr-Oct
Corydalis juncea	-	Forb	†††	Jun-Aug
Gentiana phyllocalyx	-	Spreading	††	May-Aug
Geranium nakaoanum	-	Cushion	††	Jun-Aug
Hemiphragma heterophyllum	-	Spreading	†	Apr-Oct
Juncus thomsonii	-	Graminoid	†††	May-Sep
Pedicularis hoffmeisteri	-	Forb	††	Jun-Aug
Phaeonychium parryoides	-	Cushion	†††	Jun-Aug
Poa sp. I	'Booki'	Graminoid	†††	Apr-Oct
Poa sp. II	'Booki'	Graminoid	†††	Apr-Oct
Poa sp. III	'Booki'	Graminoid	†††	Apr-Oct
Potentilla coriandrifolia	-	Cushion	††	Jun-Sep
Potentilla microphylla	-	Cushion	†	May-Sep
Potentilla peduncularis	-	Forb	†	Apr-Oct
Primula primulina	-	Forb	††	Jun-Aug

*Preference ranking as cited by the villagers and also by personal observation (††† = most preferred, †† = medium preferred and † = least preferred).

Table 4.2 Number of species of each category of plant habit and preference levels of fodder species from forest, agriculture land of Yuksam and alpine and subalpine pastures along the Yuksam-Dzongri trail.

Habit/Preference	Number of species		
	Temperate forest	Agriculture land	Alpine/subalpine
Habit			
Tree	24	4	-
Shrub	11	6	-
Herb	4	-	17
Climber	3	-	-
Epiphyte	1	-	-
Total	43	10	17
Preference			
High	17	8	7
Medium	19	1	5
Least	7	1	5
Total	43	10	17

Table 4.3 Species wise fodder production in agriculture land on household basis at Yuksam. Data based on the basis of 52 households' survey.

Fodder species	Average number of trees per household	Dry weight forage production (kg tree^{-1} year^{-1})	Total forage production (kg household^{-1} year^{-1})
Brassaiopsis mitis	4	16.68	67
Ficus cunia	5	19.20	96
Ficus nemoralis	4	12.18	49
Ficus roxburghii	10	44.46	445
Saurauia napaulensis	7	19.38	136
Total	30	111.90	793

Fresh weight = 3.5 × dry weight

Table 4.4 Quantity of forage collected from the forest and the agriculture land at Yuksam village. Data on fodder are presented on fresh weight basis.

Parameters	Quantity
Total number of households	274
Number of fodder trees in the agriculture land (household^{-1})	30
Forage production from the agriculture land (kg household^{-1} year^{-1})	793
Total forage production from the agriculture land (kg year^{-1})	217282
Forage collected from the forest (kg household^{-1}day^{-1})	10.86
Forage collected from the forest (kg household^{-1} year^{-1})	3964
Total forage collected from the forest (kg year^{-1})	1086136
Total forage collected from the forest and agriculture land (kg year^{-1})	1303418
Forage contributed from the forest (%)	83.33
Forage contributed from the agriculture land (%)	16.67

Fresh weight = 3.5 × dry weight

Table 4.5 Bite rate, bite size, foraging hours and foraging days of livestock grazing animals in temperate and alpine pastures along the Yuksam-Dzongri trail (± standard error).

Pasture site/ Animal types	Bite rate (bite min^{-1})	*Apparent bite size (mg $bite^{-1}$)	Foraging hours (hours day^{-1})	Total foraging period (days $year^{-1}$)	*Forage intake rate (kg day^{-1})	**Forage intake rate (kg day^{-1})	*Total forage intake (kg $animal^{-1}$ $year^{-1}$)
Temperate							
Cow	49.7±6.2	102.3±0.35	11.2±2.5	365	3.43	16.46	1250
Dzo	51.5±2.5	105.6±0.5	11.9±1.7	185	3.88	18.62	718
Horse	50.1±3.5	100.0±0.75	11.7±2.5	265	3.52	16.90	932
Goat	42.6±1.2	53.0±0.15	9.3±2.5	365	1.28	6.14	469
Sheep	41.2±3.5	53.3±0.20	9.6±1.7	255	1.27	6.10	323
Alpine/subalpine							
Cow	56.5 ± 7.50	97.5 ± 0.25	10.8 ± 2.5	90	3.55	12.83	320
Dzo	59.5 ± 1.25	99.8 ± 0.20	11.3 ± 0.5	180	4.03	14.11	725
Yak	54.0 ±7.00	92.5 ± 0.15	11.1 ± 0.8	365	3.33	18.32	1214
Horse	54.0 ± 9.00	96.0 ± 0.14	11.5 ± 0.5	100	3.58	12.53	358
Sheep	48.5 ± 5.50	52.0 ± 0.20	7.8 ± 2.5	110	1.17	4.10	129

* dry weight, ** fresh weight

Table 4.6 Nutrient concentration of the common fodder species from forest and cropland farming system in Yuksam (dry weight basis)

Species	Nutrient concentration (%)						
	Crude fibre	Cellulose	Hemi-cellulose	Lignin	Total nitrogen	Total phosphorus	*Crude protein
Forest species							
Acer campbellii	19.73±1.02	37.32±2.12	17.21±2.11	32.66±0.96	2.21±0.06	0.101±0.021	13.81
Acer oblongum	17.23±1.29	32.81±1.03	13.45±0.09	35.89±1.13	2.02±0.06	0.132±0.028	12.63
Aconogonum molle	15.90±0.02	13.10±0.09	_	11.33±1.17	1.04±0.03	0.060±0.032	6.25
Bassia butyracea	13.34±0.06	33.21±0.08	_	32.92±0.79	1.32±0.08	0.076±0.031	8.25
Brachiaria sp.	18.40±1.03	16.70±0.09	26.90±1.23	16.37±0.83	3.01±0.06	0.203±0.045	18.79
Commelina benghalensis	8.55±0.08	19.56±0.06	_	12.56±0.92	1.96±0.06	0.219±0.037	12.25
Diplazium umbrosum	18.56±0.19	11.32±0.04	_	12.50±0.75	3.68±0.09	0.211±0.031	23.00
Elatostema sessile	14.21±0.11	15.11±0.04	_	12.66±0.39	2.01±0.06	0.159±0.028	12.56
Eupatorium cannabinum	11.20±0.08	22.56±0.13		12.92±0.86	2.40±0.12	0.173±0.023	15.00
Ficus clavata	19.45±0.09	11.85±0.12	_	20.75±0.97	1.41±0.07	0.088±0.021	8.81
Ficus foveolata	17.44±1.21	10.72±0.11	12.20±0.09	17.34±1.01	2.67±0.05	0.141±0.021	16.69
Ficus hirta	17.33±1.04	15.26±0.09	_	16.89±1.29	2.32±0.07	0.052±0.036	14.50

Hedychium ellipticum	26.31±1.23	19.20±2.11	17.80±0.08	13.87±0.39	2.92±0.12	0.229±0.023	18.25
Impatiens sp.	12.54±2.10	18.42±1.20	_	11.08±0.76	1.83±0.03	0.153±0.011	11.44
Litsaea polyantha	16.87±0.08	11.54±1.02	_	9.86±0.59	2.53±0.05	0.038±0.008	15.81
Pilea scripta	18.10±1.03	17.21±1.75	_	15.56±1.11	2.19±0.04	0.113±0.012	13.69
Pteris sp.	18.23±1.10	11.56±0.03	_	6.56±0.08	3.05±0.08	0.131±0.014	19.06
Silaginella sp.	14.61±0.09	7.30±0.03	16.30±1.24	11.30±1.03	2.63±0.07	0.224±0.012	16.45
Urtica dioica	30.43±0.09	14.00±0.05	_	12.55±0.27	2.63±0.06	0.135±0.013	16.44
Viola sp.	16.21±0.08	11.16±0.08	_	18.31±0.85	2.52±0.11	0.116±0.015	15.75
Vitex heterophylla	18.32±1.12	14.75±0.09	_	13.20±0.74	1.09±0.05	0.154±0.041	6.81
Agroforestry species							
Arundinaria maling	29.76±1.13	16.22±1.09	-	9.78±1.13	2.11±0.06	0.199±0.031	13.20
Brassaiopsis mitis	29.20±1.16	13.12±0.56	10.00±0.63	13.61±1.15	1.75±0.04	0.208±0.013	10.94
Ficus cunia	16.57±0.91	10.70±0.72	11.30±0.43	10.22±0.93	4.97±0.05	0.216±0.022	31.06
Ficus nemoralis	24.10±0.72	21.03±0.88	12.70±0.92	11.73±1.06	1.82±0.06	0.282±0.013	11.38
Ficus roxburghii	16.98±2.56	11.79±0.93	12.00±0.87	11.21±0.43	3.14±0.05	0.209±0.027	19.65
Prunus cerasoides	21.13±0.93	13.07±0.11	17.23±0.66	17.36±0.87	1.17±0.04	0.122±0.008	7.31
Saurauia napaulensis	28.70±2.80	27.90±1.20	6.00±0.33	12.23±0.25	1.69±0.18	0.185±0.011	10.58

Thysanolaena maxima	31.21±1.78	21.32±0.97	-	11.34±1.10	1.83±0.11	0.191±0.009	11.41
Alpine & subalpine species							
Poa sp. I	23.71±0.91	27.53±0.87	35.54±0.13	16.81±0.23	1.12±0.03	0.209±0.012	7.00
Poa sp. II	21.16±0.32	27.08±0.12	27.51±0.08	13.23±0.38	1.87±0.03	0.234±0.009	11.69
Poa sp. III	11.41±0.09	24.35±0.12	35.44±0.09	9.32±0.08	1.32±0.05	0.377±0.007	8.25
Potentilla peduncularis	28.45±0.19	12.65±0.11	24.28±0.13	26.72±0.09	1.32±0.07	0.209±0.022	8.25
Aletris pauciflora	14.27±0.37	33.19±0.11	27.43±0.32	11.31±0.11	1.06±0.03	0.185±0.013	6.63
Bistorta affinis	19.73±0.21	4.59±0.08	22.53±0.07	23.11±0.26	1.12±0.01	0.201±0.023	7.00
Hemiphragma heterophyllum	26.33±0.09	18.72±0.08	35.84±0.12	19.89±0.11	1.35±0.06	0.190±0.008	8.44
Potentilla microphylla	24.12±0.18	6.98±0.18	20.62±0.18	22.11±0.12	1.21±0.06	0.212±0.016	7.56
Potentilla coriandrifolia	16.38±0.35	5.17±0.15	19.71±0.25	16.23±0.11	1.35±0.09	0.213±0.011	8.44
Juncus thomsonii	22.46±0.31	26.18±0.08	26.74±0.32	18.72±0.09	1.63±0.06	0.226±0.019	10.19

* Crude protein (%) = Total nitrogen (%) × 6.25; This is based on the assumption that plant protein contains 16% nitrogen.

CHAPTER V

IMPACT OF GRAZING ON VEGETATION STRUCTURE, SPECIES RICHNESS, DIVERSITY AND DISTRIBUTION

5.1 INTRODUCTION

The Khangchendzonga Biosphere Reserve supports various types of livestock (cows, yaks, dzos, horses, sheep, goats) and these animals graze mainly at alpine pastures during summer (May to October) and at mid-elevation during winter (November to April) season. In the process of grazing the animals move freely from one area to another. Grazing by large herbivores is generally recognized as a major ecological factors in grasslands and has been suggested as an important evolutionary force (Harper 1961; McNaughton 1979, 1984; Mack & Thompson 1982). The complexity arises on grasslands due to livestock herbivory are mainly based on grazer population fluctuations and migrations, and from the greater opportunity that there may have been for evolution of mutual adaptations between certain herbivores and certain plants over a longer period of ecological interaction (McNaughton 1979). Livestock have preferential selectivity of fodder and differ from animal to animal types. It is widely accepted that, as a result of grazing by herbivores, less palatable plants increase at the expense of more palatable ones (Ellision 1960; Sundriyal *et al.* 1988; Thurow & Hussein 1989; Curry & Hacker 1990). Individual plants are not completely consumed by herbivore, differences among the plant species in their response to herbivory in terms of survivorship, growth, reproduction, and competitive ability can also be critical determinant of community structure (McNaughton 1983). Noy-Meir *et at.* (1989) observed that the tall perennial and tall annual grasses dominated in ungrazed sites, whereas small prostrate annuals were abundant in the heavily grazed sites. Plant responses to herbivory are conditioned by past history, current environmental conditions, and interactions among the biotic components (Mack & Thompson 1982; Milchunas *et al.* 1988; Trlica & Rittenhouse 1993). Many studies have demonstrated that selective herbivore by livestock on palatable grasses allows forbs to invade or increase in the community (Jones 1933; Sala *et al.* 1986; Facelli 1988; Augustine & McNaughton 1998). Management (assessment of condition and trend) of much of the world's grazing lands is primarily based upon changes in species composition (Joyce 1989; Lauenroth & Laycock 1989). Differences in the degree of grazing palatability and selective grazing by animal groups, different grazing pressures are exerted on different species, resulting changes in species composition. Individual species have been used as indicators of the condition of grazed rangeland since the inception of the "increase-decrease-invader" concept (Sampson 1919) made us interesting to study in the response of dominant species to grazing.

Low grazing intensity resulting higher species diversity is well-documented (Gupta 1985; Sundriyal 1995). Contrarily, free and heavy grazing has adversely affected the species richness and diversity in Himalaya as well as other grasslands (Gupta 1986; Negi *et al.* 1993; Sundriyal 1994). Most of the current management of much of the world's grazing lands based on species composition (Joyce 1989; Lauenroth & Laycock 1989; Milchunas & Lauenroth 1993). Heavy grazing reduces the density of plant species and decrease in the growth that attributed to the reduction in both biomass and productivity in grazed plots (Bement 1969; Sundriyal & Joshi 1990; Rikhari *et al.* 1992).

Alpine areas provide important pasturage for local and transhumance herders who graze their animals on common pastures along with entrepreneurs owning pack animals who earn significant income from renting animals to trekking groups and mountaineering expeditions. Sustainable management of these rangelands cannot be achieved without an understanding of the changing pattern of its vegetation, and the factors affecting the grazing carrying capacity. In India, a few studies on different ecological aspects of the alpine of North-West Himalayan region have been reported (Semwal *et al.* 1981; Sundriyal *et al.* 1987; Joshi *et al.* 1988; Sundriyal & Joshi 1989, 1990). No report is available on the impact of livestock grazing on vegetation composition and structure in the Eastern Himalayan regions especially in the Sikkim Himalaya. This chapter aims to analyse the impact of grazing by livestock along the Yuksam-Dzongri trekking corridor at different ecological zones on vegetation structure, density, species richness, diversity, palatability and tree regeneration status inside the forest.

3.2 METHODS

Four sites were selected along the Yuksam-Dzongri trail and details of the selection of these sites are provided in Chapter II under description of the study sites section. These sites (Yuksam, Sachen, Deorali and Dzongri) were fenced with barbed wire (10×10 m size each and $n = 4$ at a site). The exclosures were sampled in the months of April, June, August and October during the study period, using randomly placed 1×1 m quadrats (n = 20×4). Each species were listed and the total number of individuals of all species was counted in each plot. Identical samplings were also conducted in nearby representative open-grazed pasture areas. Basal cover was quantified for all the species by measuring 10 representative size individuals with the help of a screwgauge. For grasses each tillers was considered as an individual plant entity.

Density, frequency and abundance (Misra 1968) and A/F ratio (Whitford 1949) were analysed for all the species and given below;

$$\text{Density} = \frac{\text{Total number of individuals of one species}}{\text{Total number of quadrats studies}}$$

$$\text{Total basal area} = \pi r^2 \times D$$

Where, r = radius at stem, D = density

$$\text{Abundance (A)} = \frac{\text{Total number of individuals of one species}}{\text{Number of quadrats of occurrence of that species}}$$

$$\text{\% frequency (F)} = \frac{\text{Number of quadrats of occurrence of a species} \times 100}{\text{Total number of quadrats studied}}$$

$$\text{Relative frequency} = \frac{\text{Number of quadrats of occurrence of a species} \times 100}{\text{Number of quadrats of occurrence of all the species}}$$

$$\text{Relative density} = \frac{\text{Number of individuals of a species in all quadrats} \times 100}{\text{Number of individuals of all the species in all quadrats}}$$

$$\text{Relative dominance} = \frac{\text{Total basal area of a species in all quadrats} \times 100}{\text{Total basal area of all the species in all quadrats}}$$

Importance Value Index (IVI) was determined as the sum of relative dominance, relative frequency and relative density (Phillips 1959).

IVI = Relative dominance + relative frequency + relative density

Species richness (Margalef 1957), diversity (Shannon 1948), evenness or equitability (Buzas & Gibson 1969) and dominance (Simpson 1949) were determined for both the exclosures and the open-grazed areas. Dominance-diversity curves were drawn after Whittaker (1972). The following formulae were used for the calculation of different parameters;

Species richness (Margalef's index) (d) = $\frac{(S-1)}{ln\ (N)}$

Species diversity (Shannon's index) (H') = $-\sum pi\ ln\ (pi)$

Beta diversity ($\beta' d$) = Sc/s

Dominance index (Simpson's index) (C) = $\sum(ni/N)^2$

Evenness or Equitability (Buzas and Gibson's index) (E) = e^{H}/S

Where, S = the total number of species, N = total number of individuals of all the species, pi = proportion value of *i* species, Sc = total number of species in a set of sample at one plot, s = average number of species per individual sample (average species per quadrat), ni = total number of individuals of particular *i* species and H' = Shannon's index.

Enumeration of tree seedlings and saplings status as affected by livestock grazing and anthropogenic pressure was made in the temperate forest pastures (both warm and cool temperate) during the month of August by putting 1×1 m random quadrats (n = 20) inside the fence exclosure as well as outside open-grazed areas of identical situations. All the tree/shrub species <10 cm diameter at breast height were considered as regenerating individuals (Sundriyal & Bisht 1988; Sundriyal & Sharma 1996). The regenerating individuals were classified into two groups (seedling = height not more than 20 cm; sapling = height more than 20 cm but girth at breast height less than 10 cm). The total numbers of seedlings as well as saplings were counted separately for different species. The density of seedlings and saplings were calculated on per hectare basis.

5.3 RESULTS

5.3.1 Plant Community Structure

At Yuksam (warm temperate), a total of 45 species were recorded, out of which 42 occurred in exclosure plots and 38 species in grazed plots. Thirty-two species were common in both grazed and exclosure plots which showed 80% similarity between these plots. After two years of exclosure a few species were exclusively recorded in exclosure sites only (viz. *Rhaphidophora dicursiva*, *Lonicera glabrata*). In contrary, *Hemiphragma heterophyllum* were present in grazed plots only.

At Sachen (cool temperate), *Urtica dioica*, *Galium* sp., *Viola* sp., ferns, *Laportia terminalis*, *Girardinia dicursifolia*, *Piper* sp., *Elatostema sessile* were present throughout the sampling months and in both grazed and exclosure plots. *Daphne involucrata*, *Stellaria medica*, *Drymaria cordata*, *Ficus foveolata* and *Commelina benghalensis* were totally absent in the grazed plots whereas *Begonia* sp., *Tupistra nutans*, *Rhaphidophora dicursiva*, *Stellaria medica*, *Arisaema griffithii* were absent in the exclosure plots (Table 5.1).

At Deorali (subalpine) *Poa* spp., *Potentilla coriandrifolia*, *Potentilla peduncularis* and *Geranium nakaoanum* were present throughout the sampling months and in both grazed and exclosure plots. *Gentiana* sp., *Prunella vulgaris*, *Scrophularia* sp. and *Parnassia nubicola* were totally absent in the exclosure plots whereas *Primula calderana*, *Aconitum heterophylum*, *Corydalis juncea*, *Meconopsis paniculata*, *Pedicularis hoffmeisteri*, *Primula sikkimensis*, *Cyananthus lobatus*, *Euphorbia* sp. and *Potentilla plurijuga* were absent in the grazed plots (Table 5.1).

At Dzongri (alpine zone), *Poa* spp., *Potentilla peduncularis*, *Potentilla coriandrifolia*, *Gentiana phyllocalyx* and *Bistorta affinis* were present throughout the sampling months in both grazed and exclosure plots. *Primula calderana* was absent in the exclosure plots whereas *Parnassia nubicola* and *Juncus thomsonii* were absent in grazed plots (Table 5.1)

Out of the 45 species recorded from the study plots at Yuksam, 13.3% were shrub, 11.1% undershrub, 11.1% climber, 2.2% lianas and remaining herbs. At Sachen 67.6% were herb, 16.2% undershrub, 8.1% were shrub, 8.1% climber. At Deorali, all the species were herbs except one undershrub species. At Dzongri, only *Juniperus recurva* was shrub in the sampling plots while the rest were herb.

At Yuksam, most of the herbaceous plants were annual (58%) and propagated through seed (78%). Similarly, at Sachen, most of the plants were annual (51%) and propagated through seed (86%). At Deorali and Dzongri, all the plants were annual and the aerial parts were perished during winter season and propagated through underground parts vegetatively except *Juniperus recurva* at Dzongri, which is perennial and mainly propagated through cone (Table 5.1).

5.3.2 Vegetation Structure

At Yuksam, in the beginning of growing season in April higher plant density in grazed plots were *Pilea scripta* (27 plant m^{-2}) and *Silaginella* sp. (11 plants m^{-2}) whereas in exclosure plots by *Silaginella* sp. (62 plant m^{-2}) and *Elatostema sessile* (39 plant m^{-2}). During June, the two dominant plants in grazed plots were *Pilea scripta* (96 plant m^{-2}) and *Hydrocotyle javanica* (21 plant m^{-2}) whereas in exclosure plots by *Silaginella* sp. (69 plant m^{-2}) and *Pilea scripta* (42 plant m^{-2}). During August, the dominant plants in grazed plots were *Pilea scripta* (96 plant m^{-2}) and *Brachiaria* sp. (71 plant m^{-2}) whereas in exclosure plots by *Brachiaria* sp. (111 plant m^{-2}) and *Elatostema sessile* (62 plant m^{-2}). During October, the dominant plants were *Eupatorium cannabinum* (66 plants m^{-2}) and *Pilea scripta* (66 plant m^{-2}) in grazed plots whereas *Pilea scripta* (43 plant m^{-2}) and *Elatostema sessile* (40 plant m^{-2}) in exclosure plots (Table 5.3).

At Sachen the dominant species during April were *Pilea scripta* (49 plants m^{-2}) and *Rumex nepalensis* (9 plants m^{-2}) in grazed plots whereas *Pilea scripta* (100 plants m^{-2}) and *Viola* sp. (11 plants m^{-2}) in exclosure plots. During June, the dominant species in grazed plots were *Plantago erosa* (68 plants m^{-2}) and *Girardinia dicursifolia* (17 plants m^{-2}) whereas in exclosure plots by *Brachiaria* sp. (88 plants m^{-2}) and *Stellaria midica* (70 plants m^{-2}). During August, *Silaginella* sp. (85 plants m^{-2}) and *Hydrocotyle javanica* (17 plants m^{-2}) were dominated in grazed plots whereas by *Silaginella* sp (154 plants m^{-2}) and *Elatostema sessile* (25 plants m^{-2}) in exclosure plots. Towards the end of the growing season in October the dominant plants in grazed plots were *Pilea scripta* (23 plants m^{-2}) and *Elatostema sessile* (15 plants m^{-2}) whereas in exclosure plots by *Pilea scripta* (50 plants m^{-2}) and *Elatostema sessile* (10 plants m^{-2}) (Table 5.2).

At Deorali in the beginning of growing season in April the most dominant plants in grazed plots were *Poa* sp. I (477 plants m^{-2}) and *Potentilla peduncularis* (140 plants m^{-2}) whereas in exclosure plots by *Poa* sp. I (630 plants m^{-2}) and *Poa* sp. II (153 plants m^{-2}). With the advancement of growing season in June the most dominant species was by *Poa* sp. III (282 plants m^{-2}) in grazed plots whereas by *Poa* sp. I (439 plants m^{-2}) in the exclosure plots. During the peak-growing season in August the most dominant species in grazed plots were *Poa* sp. II (407 plants m^{-2}) and *Poa* sp. I (333 plants m^{-2}) whereas in exclosure plots by *Poa* sp. II (1005 plants m^{-2}) and *Poa* sp. I (888 plants m^{-2}). Towards the end of the growing season in October the most dominant plant species in grazed plots were *Poa* sp. II (223 plants m^{-2}) and *Potentilla peduncularis* (203 plants m^{-2}) whereas by *Poa* sp. I (451 plants m^{-2}) and *Poa* sp. II (327 plants m^{-2}) in exclosure plots (Table 5.3).

At alpine Dzongri, as snow started melting in April the most dominant species in grazed plots were *Poa* sp. I (447 plants m^{-2}) and *Potentilla peduncularis* (178 plants m^{-2}) whereas in exclosure plots by *Poa* sp. I (718 plants m^{-2}) and *Poa* sp. II (195 plants m^{-2}). With the advancement of growing season in June the dominant plants in grazed plots were *Bistorta affinis* (387 plants m^{-2}) and *Potentilla coriandrifolia* (343 plants m^{-2}) whereas in exclosure plots by *Bistorta affinis* (402 plants m^{-2}) and *Poa* sp. II (317 plants m^{-2}). During peak-growing season in August the dominant plants were *Poa* sp. I (604 plants m^{-2}) and *Potentilla peduncularis* (450 plants m^{-2}) in grazed plots whereas by *Poa* sp. II (1583 plants m^{-2}) and *Poa* sp. I (395 plants m^{-2}) in exclosure plots. Towards the end of growing season in October the dominant plants in grazed plots were *Poa* sp. I (534 plants m^{-2}) and Poa sp. II (222 plants m^{-2}) whereas in exclosure plots by *Poa* sp. I (452 plants m^{-2}) and *Poa* sp. II (404.2 plants m^{-2}) (Table 5.4).

Abundance/Frequency (A/F) ratio study of the plants in throughout the season and at all the sites were mostly contagious distribution; some showed random distribution while only one species i.e. *Hypericum japonicum* in exclosure plots at Yuksam during April showed regular distribution. At Yuksam A/F ratio ranged from 0.01 to 1.700 (Table 5.1); at Sachen (0.038 to 1.900) (Table 5.2); at Deorali (0.036 to 3.100) (Table 5.3) and at Dzongri (0.041 to 4.000) (Table 5.4).

At Yuksam, in the beginning of the growing season in April highest Importance Value Index (IVI) in grazed plots were by *Pilea scripta* (44) and ferns (31) whereas in exclosure plots by *Elatostema* *sessile* (59) and *Silaginella* sp. (53). With the advancement of growing season in June the highest IVI in grazed plots were contributed by *Pilea scripta* (86) and *Galium* sp. (34) whereas in exclosure plots by *Galium* sp. (42) and *Silaginella* sp. (34). During the peak growing season in August the highest IVI in grazed plots were contributed by *Eupatorium cannabinum* (62) and *Pilea scripta* (62) whereas in exclosure plots by *Silaginella* sp. (80) and *Eupatorium cannabinum* (40). (Table 5.1). At Sachen in the beginning of the growing season in April the highest IVI was contributed by *Pilea scripta* (65) and *Impatiens* sp. (22) in grazed plots whereas by *Pilea scripta* (96) and *Urtica dioica* (28) in exclosure plots. With the advancement of growing season in June the highest IVI contribution in grazed plots were by *Rumex nepalensis* (87) and *Plantago erosa* (43) whereas in exclosure plots by *Brachiaria* sp. (44) and *Stellaria medica* (39). During the peak growing season in August, highest IVI in grazed plots were contributed by ferns (45) and *Pilea scripta* (36) whereas in exclosure plots by *Pilea scripta* (69) and ferns (46) (Table 5.2). At Deorali in the beginning of the growing season in April the highest IVI was contributed by *Poa* sp. I (115) and *Potentilla peduncularis* (76) in grazed plots whereas by *Poa* sp. I (110) and *Potentilla peduncularis* (67) in exclosure plots. With the advancement of growing season in June, the highest IVI in grazed plots were contributed by *Potentilla peduncularis* (80) and *Poa* sp. III (54) whereas in exclosure plots by *Potentilla peduncularis* (59) and *Poa* sp. I (45). During peak growing season in August, the highest IVI in grazed plots were contributed by *Potentilla peduncularis* (97) and *Poa* sp. I (44) whereas in exclosure plots by *Poa* sp. I (60) and *Poa* sp. II (49). Towards the end of the growing season in October, highest IVI in grazed plots were contributed by *Potentilla peduncularis* (92) and *Poa* sp. I (38) whereas in exclosure plots by *Poa* sp. I (65) and *Potentilla peduncularis* (60) (Table 5.3).

At Dzongri, in the beginning of growing season in April the highest IVI in grazed plots were contributed by *Poa* sp. I (113) and *Potentilla peduncularis* (67) whereas in exclosure plots by *Poa* sp. I (145) and *Poa* sp. II (42). With the advancement of growing season in June, highest IVI in grazed plots were contributed by *Potentilla coriandrifolia* (82) and *Bistorta affinis* (44) whereas in exclosure plots by *Potentilla coriandrifolia* (75) and *Juncus thomsoni* (49). During peak growing season in August, highest IVI in grazed plots were contributed by *Potentilla peduncularis* (86) and *Poa* sp. I (51) whereas in exclosure plots by *Poa* sp. II (67) and *Poa* sp. I (37). Towards the end of growing season in October, highest IVI in grazed plots were contributed by *Poa* sp. I (97) and *Potentilla peduncularis* (47) whereas in exclosure plots by *Poa* sp. I (89) and *Poa* sp. II (52) (Table 5.4).

Number of species decreased with increasing altitude in both exclosure and grazed plots. Grazing reduced species number significantly in all the sampling period ($P<0.0001$) in temperate, subalpine and alpine. Plant density increased with increasing altitude ($P<0.0001$) in both grazed and exclosure plots. Highest plant density was attained in August at all the altitudinal sites. Plant density ranged from 96-502 plants m^{-2} (grazed) and 105 to 550 plants m^{-2} (exclosure) at temperate sites, 906 to

1645 plants m^{-2} (grazed) and 1158 to 3249 plants m^{-2} (exclosure) at subalpine sites and from 920-2290 plants m^{-2} (grazed) and 1090 to 3747 plants m^{-2} (exclosure) at alpine sites, and their interaction was significant (P<0.0001). Values in grazed and exclosure plots and between stands at different elevation was significant with least standard deviation of 60.4. Grazing decreased basal coverage of plants significantly at temperate sites (16-52%), but increased in subalpine (13 to 28%) and alpine (0.7 to 83%) (P<0.0001). Basal coverage of plants increased with increasing altitude in both grazed and exclosure plots (P<0.0001) and their interactions were also significant. Basal coverage was ranged from 16 to 124 cm^2m^{-2} in forested pastures, 128-238 cm^2m^{-2} in subalpine and 141 to 439 cm^2m^{-2} in alpine zone.

5.3.3 Species Richness, Diversity and Distribution

Species richness

At Yuksam, plant species richness decreased with the advancement of growing season in both grazed and exclosure plots. In the beginning of the growing season grazed plots have more species richness but with the advancement of growing season it was more in exclosure plots. Species richness (Margalef's index) value ranged from 2.93 to 3.75 in grazed plots whereas 3.01 to 3.36 in exclosure plots. At Sachen also similar trend was observed. The value ranged from 2.34 to 3.07 in grazed plots whereas 2.36 to 2.37 in exclosure plots. Contrary to it, at Deorali, species richness increased with the advancement of growing season in both grazed and exclosure plots. The value ranged from 1.19 to 1.22 in grazed plots while 1.27 to 1.65 in exclosure plots. Similar trend was also observed in Dzongri with the value ranged from 0.71 to 1.30 in grazed plots and 0.93 to 1.32 in exclosure plots (Table 5.5). Species richness decreased with elevation in both exclosure (P<0.0001) and grazed (P<0.0001) plots (Fig. 5.3).

Species diversity

At Yuksam, species diversity decreased slightly with the advancement of growing season in grazed plots whereas it was increased in exclosure plots. Grazing increased plant diversity throughout the growing season. The value ranged from 2.69 to 2.700 in grazed plots and 2.03 to 2.66 in exclosure plots. At Sachen, diversity increased with the advancement of growing season in both grazed and exclosure plots. Grazing increased plant diversity throughout the growing season. The value ranged from 2.25 to 2.49 in grazed plots and 1.52 to 2.29 in exclosure plots. At Deorali, plant diversity increased with the advancement of growing season in both grazed and exclosure plots. Plant diversity was more in grazed plots in the beginning of growing season but reverse during growing peak season. The value ranged from 1.54 to 1.89 in grazed plots and 1.42 to 1.93 in exclosure plots. At Dzongri also plant diversity increased with growing season in both grazed and exclosure plots. Grazing increased plant diversity throughout the growing season. The value ranged from 1.48 to 1.99 in grazed plots and 1.14 to 1.77 in exclosure plots (Table 5.5). Plant diversity decreased with elevation in both exclosure (P<0.02) and grazed plots (P<0.02) (Fig. 5.3).

The rate of change of species composition (beta diversity) was highest in temperate zone, followed by alpine zone and least in subalpine zone in both grazed and exclosure plots (Fig. 5.4). This is very interesting result where rate of change of species composition at subalpine zone was recorded least. The subalpine zone is more of transition zone migrating livestock where the grazing intensity is observed high with heavy trampling.

Equitability

At Yuksam, equitability or evenness of plants increased with advancement of growing season. Grazing increased equitability of plants throughout the growing season. The value of equitability ranged from 0.50 to 0.53 in grazed plots and 0.27 to 0.49 in exclosure plots. Similar trend was also observed at Sachen (0.38 to 0.57 in grazed plots and 0.23 to 0.45 in exclosure plots) and at Deorali (0.42 to 0.55 in grazed plots and 0.34 to 0.41 in exclosure plots). At Dzongri, plants were less equitable with growing season in grazed plots but reversed in exclosure plots and the value ranged from 0.56 to 0.63 in grazed plots and 0.35 to 0.42 in exclosure plots (Table 5.5). Equitability of plants increased with elevation in grazed plots ($P<0.05$) but no correlation was observed in exclosure plots (Fig. 5.3).

Concentration of dominance

At Yuksam concentration of plants decreased with growing season in both grazed and exclosure plots. Grazing reduced concentration of plant growth throughout the growing season. The dominance index value ranged from 0.098 to 0.099 in grazed plots and 0.101 to 0.235 in exclosure plots. Similar trend was also observed at Sachen, Deorali and

Dzongri except in Deorali where plants were more dominant in grazed plots during peak growing season. Dominance index value ranged from 0.141 to 0.192 (grazed) and 0.204 to 0.430 (exclosure) at Sachen; from 0.177 to 0.322 (grazed) and 0.153 to 0.348 (exclosure) at Deorali and from 0.174 to 0.302 (grazed) and 0.255 to 0.472 (exclosure) at Dzongri (Table 5.5). There was no correlation between dominance with elevation in both grazed and exclosure plots (Fig. 5.3).

Dominance-diversity curve study showed slight concave-shaped in both grazed and exclosure plots at (Yuksam and Sachen), negative exponential at subalpine (Deorali) and (Dzongri) (Fig. 5.2).

5.3.4 Tree Seedling and Sapling Enumeration

Species-wise density of seedling and sapling in grazed and exclosure plots in different temperate forested pastures has been enumerated (Table 5.6). The comparison of seedling and sapling between grazed and exclosure plots in the cool and the warm temperate forested pasture along the trekking corridor has been presented in Fig. 5.5. Grazing exclosure just for one year (one season) has resulted the increase of 29% seedling in cool temperate forest (9000 and 7000 seedlings ha^{-1} in exclosure and grazed plots, respectively). After two years the exclosure plots recorded 10750 seedlings ha^{-1}, which showed a further increase of 19% over the previous year. Slight increase of sapling in the exclosure plots whereas slight decreased in the open-grazed plots (from 1998 to 1999). In the warm temperate forest the seedlings in the exclosure plots has increased 46% from 1998 to 1999 (6000 seedling ha^{-1} in 1998 and 8750 seedling ha^{-1} in 1999) whereas in the open-grazed plots 20%

increase was recorded (3750 seedling ha^{-1} in 1998 and 4500 seedling ha^{-1} in 1999). Slight increase in sapling was observed in the exclosure plots though no change was recorded in the grazed plots.

5.4 DISCUSSION

Herbivory can have a variety of direct and indirect effects on plant communities (Huntley 1991; Davidson 1993; Jefferies *et al.* 1994; Hixon & Brostoff 1996). Herbivores visibly damage relatively few plant species (Ritchie *et al.* 1998). The damage species is best identified as the palatable species and with more magnitude in highly palatable species. At Yuksam such phenomenon was shown by *Silaginella* sp., *Elatostema sessile*, etc., at Sachen by *Persicaria capitata*, *Viola* sp., at Deorali by *Poa* spp., *Geranium nakaoanum* and at Dzongri by *Poa* spp., *Euphorbia* sp., etc. On the other hand unpalatable species showed reverse trend such as *Plantago erosa*, *Artimissia vulgaris*, etc. at Yuksam, *Girardinia dicursifolia*, *Rumex nepalensis*, etc. at Sachen, *Potentilla peduncularis*, *Hemiphragma heterophylla*, etc. at Deorali and *Potentilla peduncularis*, *Potentilla microphylla* at Dzongri. As a result of grazing, less palatable plants increased at the expense of more palatable ones (Ellision 1960; Thurow & Hussein 1989; Curry & Hacker 1990) supports the findings of the present study where rapid decrease of palatable species in the grazed pastures and contrary to it, the least palatable species increased in the same intensity but reverse order; (see Photoplate 5) this support McNaughton (1983) that individual plants are not completely consumed by herbivore, differences among the plant species in their response to herbivory in terms of survivorship, growth, reproduction, and competitive ability can be a critical determinant of community changes. Therefore, livestock grazing will change the vegetation composition and that shifts the community patterns (Photoplate 7). In the present study, monocot plants were detrimentally affected by grazing; due to its preference by grazing animals.

Plant diversity increased with growing season and peaked during June (Ram *et al.* 1989) coincides with the findings of the present study. The selected grazing change in species association and distribution pattern with higher magnitude in higher elevation (alpine/subalpine) than lower elevation forested pastures probably due to environmental arrest of plant growth and other metabolic activities. Plant communities and species reacting differently to varying degrees of grazing pressures (Milchunas & Lauenroth 1993; Sundriyal 1995). In a recent view, Milchunas & Lauenroth (1993) indicate change in species composition with grazing is primarily a function of aboveground net primary production and the evolutionary history of grazing at the site. Changes in species composition increase with productivity and with longer, more intense, evolutionary history. Although species considerations are clearly central to fundamental studies attention must also be given to the long-term ability of a system to sustain productivity (Milchunas & Lauenroth 1993).

The findings of the present study favours that (i) the main effect of grazers on grasslands is the removal of living parts, which is selective and hence differential between plant species. (ii) Grazing shifts the balance of relative species, abundance, which is established in the ungrazed ('climax') grassland mainly by competition for light, water and nutrients, towards a new stable balance ('grazing disclimax') which also depends on differential defoliation and regrowth. (iii) Changes in species composition in response to changes in grazing intensity ('degradation', 'succession') are consistent, reversible and continuous; hence (apart from weather-induced fluctuations) grassland composition closely reflects the current grazing regime, once it has been established for some time. (iv) The relative abundance of some plants in a community decreases consistently in response to increased grazing intensity ('decreasers'), while that of others increases consistently ('increasers'); some species only appear above a certain grazing intensity ('invaders'). It has strongly believed that change in species composition will affect other structural and functional parameters of pastures/ grasslands positively or negatively with different magnitude in different time scale.

Tree regeneration study reveals that grazing has certain pressure on the regeneration of tree species inside the forest. Browsing by large herbivores can affect both tree structure and regeneration (Fox 1998). Overall seedling density was increased by 29% in cool temperate forest and 46% in warm temperate forest just after two years of livestock grazing exclosure is a significant change in regeneration status. Simple protection of the forested areas enhanced regeneration. It has been observed that in grazed pastures secondary and least palatable species was higher density. This is an indication of vegetation change and possible dominant species in future. Protection of forested pasture from livestock grazing will definetely improve the status of forest in due course and will provide better forest structure. Since complete protection is difficult to achieve, a deferred grazing regime of 3-4 years if developed would promote tree regeneration especially in temperate areas of North-East India where humidity, rainfall and temperature are not limiting environmental factors ■

Table 5.1 Vegetation structure during growing months at grazed and exclosure (parenthesis) sites at warm temperate Yuksam (1700 m asl).

Species	April			June			August			October		
	Density	A/F	IVI	Density	A/F	IVI	Density	A/F	IVI	Density	A/F	IVI
Eupatorium cannabinum	7.65	0.106	26.76	6.65	0.118	20.32	20.1	0.314	20.49	65.5	0.222	62.08
	(8.05)	(0.099)	(19.80)	(6.00)	(0.122)	(7.80)	(35.9)	(0.561)	(40.04)	(24.2)	(0.242)	(86.9)
Elatostema sessile	10.3	0.161	22.68	19.4	0.24	22.06	10.45	0.213	13.76	5.8	0.192	19.09
	(38.65)	(0.477)	(59.03)	(20.3)	(0.281)	(19.81)	(62)	(0.969)	(28.58)	(40.3)	(0.403)	(32.83)
Viola sp.	7.75	0.073	16.7	4.95	0.088	9.21	16.65	0.394	10.34	-	-	-
	(7.9)	(0.123)	(14.37)	(9.45)	(0.105)	(11.26)	(6.75)	(0.083)	(11.85)	(9.6)	(0.096)	(12.79)
Impatiens sp.	3.65	0.051	11.94	2.8	0.049	8.69	3.25	0.107	6.133	0.9	0.036	4.85
	(5.3)	(0.073)	(14.35)	(4.05)	(0.083)	(7.30)	(12.05)	(0.398)	(8.68)	(2.05)	(0.068)	(5.31)
Rubia cordifolia	0.20	0.05	1.57	-	-	-	-	-	-	0.30	0.133	1.61
	(0.9)	(0.044)	(4.69)				(0.85)	(0.213)	(2.41)	(0.8)	(0.04)	(3.79)
Osbeckia stellata	1.70	0.106	10.11	-	-	-	-	-	-	-	-	-
	(0.4)	(0.064)	(2.79)									
Arisaema jackquemontii	0.30	0.048	3.92	-	-	-	-	-	-	-	-	-
	(0.6)	(0.067)	(5.92)									
Silaginella sp.	10.9	0.109	19.97	6.83	0.162	9.29	33.65	0.526	15.75	4.25	0.68	6.74
	(62.4)	(0.624)	(52.67)	(69.35)	(0.768)	(33.57)	(59.25)	(0.105)	(80.99)	(39.35)	(0.394)	(28.61)
Brachiaria sp.	2.75	0.136	6.28	7.45	1.76	16.2	70.75	1.105	25.81	5.45	0.097	10.54
	(5.7)	(0.116)	(10.24)	(21.05)	(0.26)	(14.97)	(111.25)	(2.27)	(35.07)	(7.55)	(0.076)	(10.69)
Cyperus sp.	8.3	0.092	16.25	5.05	1.20	13.31	7.1	0.126	8.86	4.90	0.087	11.66

	(2.6)	(0.032)	(10.58)	(8.25)	(0.168)	(10.24)	(4.55)	(0.15)	(7.98)	(3.5)	(0.076)	(10.69)
Cissus repanda	2.7	0.037	9.33	4.4	1.76	7.75	8.25	0.129	9.66	3.9	0.193	7.38
	(3.35)	(0.11)	(7.37)	(10.3)	(0.183)	(13.99)	(11.6)	(0.237)	(10.56)	(5.0)	(0.089)	(8.13)
Galium sp.	1.95	0.046	7.04	6.75	0.138	33.71	-	-	-	3.45	0.082	7.84
	(3.55)	(0.099)	(8.34)	(28.25)	(0.669)	(41.49)	(11.35)	(0.375)	(8.5)	(4.9)	(0.077)	(8.48)
Rhaphidophora dicursifolia	(0.10)	(0.10)	(1.52)	-	-	-	(9.2)	(0.751)	(6.45)	(0.35)	(0.39)	(3.21)
Hypericum japonicum	0.15	0.067	1.26	-	-	-	-	-	-	-	-	-
	(0.05)	(0.01)	(0.41)							(0.15)	(0.067)	(1.14)
Lonicera glabrata	(0.20)	(0.089)	(1.39)	-	-	-	-	-	-	-	-	-
Plantago erosa	3.05	0.038	12.23	2.0	0.163	4.26	29.75	0.298	20.84	2.45	0.392	3.90
	(0.3)	(0.033)	(2.78)	(4.3)	(0.119)	(8.1)	(-)	(-)	(-)	(-)	(-)	(-)
Fern	4.75	0.059	30.55	6.65	0.118	20.32	11.6	0.181	38.65	1.70	0.106	14.15
	(1.85)	(0.029)	(19.48)	(9.7)	(0.12)	(11.04)	(6.9)	(0.163)	(18.39)	(3.5)	(0.083)	(6.97)
Persicaria capitata	4.7	0.111	10.38	7.75	0.158	11.34	14.6	0.202	11.94	1.35	0.6	2.12
	(2.55)	(0.126)	(7.15)	(13)	(0.203)	(11.44)	(7.7)	(0.30)	(7.59)	(-)	(-)	(-)
Fragaria nubicola	(0.9)	(0.4)	(2.48)	-	-	-	-	-	-	-	-	-
Pothos scandens	(0.35)	(0.088)	(2.35)	-	-	-	-	-	-	-	-	-
Arisaema intermedium	0.5	0.222	4.38	-	-	-	-	-	-	-	-	-
	(5.85)	(0.366)	(23.0)	(0.3)	(0.048)	(3.26)						
Pilea scripta	26.8	0.371	43.76	96.15	0.962	86.2	95.8	0.958	43.47	65.5	0.907	62.08
	(7.55)	(0.616)	(14.98)	(41.5)	(0.574)	(31.68)	(50.85)	(0.509)	(29.95)	(42.75)	(0.528)	(29.65)
Rubus paniculatus	(0.3)	(0.133)	(1.9)	-	-	-	(1.55)	(0.388)	(2.81)	-	-	-

Gynura cushimboa	0.7 (0.95)	0.112 (0.059)	2.6 (5.76)	- (0.7)	- (0.078)	- (6.1)	-	-	-	0.25 (0.25)	0.111 (0.111)	1.58 (1.22)
Centella asiatica	7.05 (0.25)	0.125 (0.25)	12.68 (1.28)	-	-	-	-	-	-	-	-	-
Aconogonum molle	0.2 (1.1)	0.089 (0.059)	1.44 (2.53)	- (2.05)	- (0.328)	- (8.33)	-	-	-	-	-	-
Piper sp.	0.55 (0.15)	0.244 (0.25)	1.51 (1.36)	0.47 (-)	0.1 (-)	2.7 (-)	-	-	-	- (0.3)	- (0.048)	- (1.86)
Rubus ellipticus	0.7 (0.35)	0.078 (0.489)	2.81 (1.48)	0.25 (-)	0.063 (-)	3.2 (-)	0.9 (-)	0.144 (-)	3.07 (-)	0.25 (-)	0.111 (-)	2.58 (-)
Artimissia vulgaris	1.6 (-)	0.064 (-)	2.47 (-)	- (0.8)	- (0.128)	- (6.68)	0.9 (-)	0.144 (-)	3.07 (-)	0.25 (-)	0.111 (-)	2.58 (-)
Commelina benghalensis	-	-	-	0.5 (0.65)	0.08 (0.104)	4.03 (8.9)	3.7 (7.7)	0.411 (0.481)	3.53 (8.36)	3.45 (1.95)	0.082 (0.096)	7.84 (4.49)
Hedychium ellipticum	1.2 (-)	0.133 (-)	3.32 (-)	- (9.0)	- (0.298)	- (7.42)	3.35 (12.0)	0.111 (0.284)	7.01 (13.89)	- (2.2)	- (0.18)	- (4.76)
Hydrocotyle javanica	-	-	-	20.6 (18.5)	0.572 (0.256)	18.2 (12.67)	69.35 (9.75)	0.96 (0.173)	24.87 (10.48)	6.35 (4.1)	1.76 (0.202)	9.46 (5.23)
Mazus sp.	0.35 (-)	0.156 (-)	1.36 (-)	1.9 (2.0)	0.304 (0.099)	5.07 (7.53)	7.7 (-)	0.182 (-)	8.02 (-)	-	-	-
Melastoma normale	1.65 (-)	0.081 (-)	6.94 (-)	1.8 (2.0)	0.089 (0.32)	6.58 (5.57)	0.6 (8.85)	0.15 (0.983)	2.36 (5.66)	0.35 (1.45)	0.088 (0.4)	2.51 (5.42)

Stephania rotunda	(-) 0.2	(-) 0.2	(-) 0.88	(2.85) -	(0.317) -	(10.85) -	-	-	-	- (0.4)	- (0.064)	- (1.91)
Amaranthus sp.	-	-	-	-	-	-	9.5 (8.7)	0.117 (0.43)	10.71 (7.79)	-	-	-
Pilea umbrosa	-	-	-	-	-	-	8.05 (12.8)	0.657 (0.228)	6.25 (11.16)	7.25 (6.95)	0.129 (0.193)	14.5 (8.41)
Adenostems viscosum	-	-	-	-	-	-	- (2.8)	- (0.448)	- (3.83)	-	-	-
Stellaria medica	-	-	-	-	-	-	- (13.85)	- (0.721)	- (9.19)	-	-	-
Astilbe revularis	-	-	-	-	-	-	1.6 (1.2)	0.044 (0.133)	6.73 (4.93)	0.9 (6.35)	0.073 (0.064)	5.86 (11.56)
Oxyspora paniculata	-	-	-	-	-	-	- (1.3)	- (0.325)	- (4.93)	0.9 (6.35)	0.073 (0.064)	5.86 (11.56)
Cyanotis vaga	-	-	-	-	-	-	- (8.0)	- (0.264)	- (7.93)	1.15 (-)	0.511 (-)	3.27 (-)
Drymaria cordata	-	-	-	-	-	-	45.5 (-)	0.455 (-)	20.91 (-)	3.85 (-)	(-) 0.616	4.64 (-)
Edgeworthia gardneri	-	-	-	-	-	-	-	-	-	(0.2)	(0.05)	(1.95)
Hemiphragma heterophyllum	-	-	-	-	-	-	-	-	-	1.4 (-)	0.114 (-)	4.05 (-)

A/F= Abundance/Frequency, IVI= Importance Value Index

Table 5.2 Vegetation structure during growing months at grazed and exclosure (parenthesis) sites at cool temperate Sachen (2700 m asl).

Species	April			June			August			October		
	Density	A/F	IVI	Density	A/F	IVI	Density	A/F	IVI	Density	A/F	IVI
Pilea scripta	48.75	0.54	64.51	-	-	-	-	-	-	22.7	0.252	35.97
	(99.7)	(0.997)	(95.8)				(16.15)	(0.449)	(11.84)	(50.25)	(0.503)	(68.46)
Urtica dioica	1.85	0.116	13.68	2.7	0.108	20.61	4.8	0.3	11.24	2.4	0.043	14.18
	(7.35)	(0.074)	(27.45)	(4.55)	(1.82)	(11.15)	(10.1)	(0.824)	(6.33)	(3.15)	(0.064)	(14.35)
Galium sp.	4.05	0.113	10.91	5.85	0.193	10.43	16.65	1.041	12.17	3.45	0.082	9.14
	(1.9)	(0.119)	(6.51)	(3.0)	(0.061)	(11.61)	(13.9)	(0.556)	(9.42)	(3.0)	(0.071)	(8.14)
Viola sp.	2.4	0.079	8.93	3.35	0.165	7.7	11.35	1.261	8.96	2.25	0.04	9.17
	(11.15)	(0.116)	(20.45)	(1.4)	(0.056)	(7.22)	(18.2)	(0.506)	(15.47)	(3.25)	(0.058)	(9.49)
Impatiens sp.	6.7	0.119	22.02	-	-	-	-	-	-	4.3	0.067	12.01
	(8.55)	(0.106)	(22.01)							(6.3)	(0.112)	(16.18)
Ferns	3.2	0.076	20.66	1.7	0.068	8.2	8.55	0.238	30.47	7.7	0.12	44.64
	(3.6)	(0.049)	(20.87)	(2.3)	(0.054)	(11.18)	(8.76)	(0.156)	(32.02)	(4.5)	(0.056)	(46.32)
Rubus ellipticus	1.2	0.075	9.18	-	-	-	-	-	-	-	-	-
	(3.1)	(0.086)	(13.96)									
Arisaema intermedium	1.1	0.09	15.73	-	-	-	-	-	-	0.5	0.041	4.68
	(1.8)	(0.089)	(23.42)							(0.5)	(0.031)	(4.74)

Laportia terminalis	1.25	0.078	10.61	0.6	0.049	7.06	5.8	0.232	16.56	1.25	0.041	8.8
	(2.35)	(0.05)	(13.38)	(0.5)	(0.041)	(14.25)	(3.95)	(0.195)	(6.24)	(2.65)	(0.054)	(13.09)
Girardinia	0.55	0.088	4.68	17.3	4.325	15.55	7.05	0.441	13.46	-	-	-
dicursifolia	(0.6)	(0.049)	(8.97)	(0.55)	(0.088)	(31.73)	(1.8)	(0.2)	(3.92)	(1.4)	(0.039)	(9.44)
Rumex nepalensis	8.9	0.556	18.98	49.4	1.168	86.99	13.4	0.372	18.88	9.55	0.316	34.02
	(0.6)	(0.038)	(5.43)	(-)	(-)	(-)	(0.2)	(0.05)	(2.2)	(0.8)	(0.065)	(4.48)
Piper sp.	0.15	0.067	1.88	17.2	2.752	11.18	0.8	0.476	13.35	14.6	0.202	38.15
	(0.2)	(0.089)	(1.71)	(0.3)	(0.133)	(2.22)	(5.4)	(0.338)	(19.3)	(9.95)	(0.177)	(22.54)
Elatostema sessile	8.8	0.291	21.07	3.05	0.122	11.53	11.9	0.476	13.35	14.6	0.202	38.15
	(4.2)	(0.263)	(10.64)	(43.8)	(0.684)	(27.11)	(24.75)	(0.306)	(19.3)	(9.95)	(0.177)	(22.54)
Daphne involucrata	-	-	-	-	-	-	-	-	-	-	-	-
	(0.1)	(0.1)	(1.47)									
Hydrocotyle javanica	2.0	0.576	4.37	3.75	0.089	11.26	16.75	0.67	13.69	1.85	0.296	4.53
	(2.2)	(0.55)	(4.07)	(6.05)	(0.108)	(11.4)	(18.3)	(0.373)	(13.11)	(-)	(-)	(-)
Cissus repanda	-	-	-	-	-	-	-	-	-	2.45	0.058	8.31
	(1.4)	(0.114)	(5.17)							(-)	(-)	(-)
Silaginella sp.	2.7	0.432	4.941	5.2	0.106	11.94	84.9	1.733	45.61	5	0.408	8.55
	(1.1)	(0.275)	(2.94)	(-)	(-)	(-)	(154.45)	(2.138)	(51.97)	(-)	(-)	(-)
Stellaria medica	-	-	-	-	-	-	-	-	-	-	-	-
	(1.2)	(0.192)	(3.55)	(69.5)	(1.236)	(38.85)						
Aconogonum molle	1.9	0.155	10.72	0.3	0.048	3.71	3.1	0.344	12.24	-	-	-
	(2.2)	(0.24)	(10.2)	(1.45)	(0.091)	(8.31)	(7.7)	(0.629)	(32.63)	(2.25)	(0.046)	(14.63)

Drymaria cordata	- (0.45)	- (0.2)	- (2.02)	-	-	-	-	-	-	-	-	-
Brachiaria sp.	0.5 (-)	0.08 (-)	3.16 (-)	4 (87.45)	0.16 (1.555)	8.43 (44.01)	7.55 (20.1)	1.888 (0.314)	6.78 (14.53)	1.6 (6.9)	0.1 (0.096)	5.63 (14.13)
Cyperus sp.	2.1 (-)	0.131 (-)	7.08 (-)	- (28.05)	- (3.117)	- (19.4)	15.9 (11.4)	0.442 (0.317)	16.17 (10.6)	2.4 (2.55)	0.196 (0.071)	6.42 (8.31)
Hedychium ellipticum	0.5 (-)	0.222 (-)	3.22 (-)	-	-	-	-	-	-	1.25 (1.85)	0.078 (0.074)	5.65 (11.95)
Begonia sp.	0.1 (-)	0.1 (-)	1.2 (-)	-	-	-	-	-	-	-	-	-
Persicaria capitata	8.1 (-)	0.4 (-)	14.86 (-)	2.25 (1.3)	0.09 (0.052)	7.52 (12.44)	11.6 (10.55)	0.464 (0.861)	11.72 (7.97)	3.0 (-)	0.148 (-)	7.51 (-)
Tupistra nutans	0.1 (-)	0.1 (-)	2.01 (-)	-	-	-	-	-	-	-	-	-
Rhaphidophora dicursiva	0.3 (-)	0.133 (-)	2.32 (-)	-	-	-	-	-	-	-	-	-
Stellaria medica	15 (-)	3.75 (-)	17.99 (-)	-	-	-	-	-	-	-	-	-
Plantago erosa	1.0 (-)	0.16 (-)	5.28 (-)	68.2 (4.0)	1.392 (0.071)	43.03 (10.11)	14.6 (5.05)	0.406 (0.561)	15.81 (6.48)	0.9 (-)	0.1 (-)	4.03 (-)
Diplazium umbrosum	-	-	-	0.5 (0.7)	0.056 (0.044)	6.8 (14.21)	1.4 (9.0)	0.35 (0.36)	10.28 (17.3)	1.45 (-)	0.072 (-)	10.24 (-)

Eupatorium cannabinum	-	-	-	30.8 (2.05)	1.519 (0.082)	22.92 (11.33)	12.85 (15.2)	0.262 (0.31)	16.78 (16.43)	-	-	-
Rubia cordifolia	-	-	-	0.7 (1.15)	0.112 (0.072)	3.92 (9.79)	1.1 (4.1)	1.1 (0.456)	2.76 (5.55)	-	-	-
Arisaema griffithiii	-	-	-	-	-	-	2.45 (-)	2.45 (-)	14.7 (-)	-	-	-
Achyranthes aspera	-	-	-	- (0.1)	- (0.1)	- (3.66)	3.5 (2.8)	0.875 (0.448)	5.89 (6.07)	1.85 (1.9)	0.074 (0.063)	7.56 (6.67)
Ficus foveolata	-	-	-	-	-	-	- (1.1)	- (0.176)	- (3.83)	- (1.9)	- (0.063)	- (7.52)
Commelina benghalensis	-	-	-	-	-	-	-	-	-	- (2.9)	- (0.096)	- (8.72)
Rubus calycinus	-	-	-	-	-	-	-	-	-	4.05 (0.6)	0.083 (0.049)	12.29 (3.41)

A/F= Abundance/Frequency, IVI= Important Value Index

Table 5.3 Vegetation structure during growing months at grazed and exclosure (parenthesis) sites at subalpine Deorali (3800 m asl)

Species	April			June			August			October		
	Density	A/F	IVI	Density	A/F	IVI	Density	A/F	IVI	Density	A/F	IVI
Poa sp. I	477	1.193	114.5	91.8	0.23	25.26	333.4	0.768	44.3	160	1.128	65.16
	(630.2)	(1.576)	(109.6)	(438.6)	(1.097)	(45.00)	(888.2)	(3.073)	(60.2)	(451)	(0.4)	(37.72)
Poa sp. II	75.6	0.233	26.94	117.4	0.294	22.38	406.8	1.589	40.4	223.2	0.558	36.03
	(152.6)	(0.382)	(37.65)	(383.4)	(0.959)	(43.44)	(1004.6)	(2.783)	(49.2)	(326.6)	(1.008)	(37.88)
Poa sp. III	67.2	0.233	22.25	281.8	0.975	54.19	265.4	0.819	31.4	173.4	0.535	29.14
	(148.8)	(0.412)	(29.91)	(252)	(2.52)	(25.12)	(463.2)	(1.809)	(26.2)	(226.4)	(0.699)	(30.37)
Potentilla peduncularis	140.4	0.389	76.28	145	0.557	80.44	326.8	0.905	97.3	203.4	0.509	92.19
	(149.6)	(0.374)	(67.12)	(109.8)	(0.275)	(58.75)	(182.8)	(0.564)	(34)	(160.4)	(0.401)	(59.9)
Potentilla coriandrifolia	5.0	0.102	6.53	7.6	0.053	7.94	6.2	0.062	7.64	3.6	0.036	6.35
	(6.0)	(0.167)	(5.58)	(23.2)	(0.161)	(7.54)	(163.6)	(0.639)	(32.1)	(104)	(0.104)	(9.86)
Potentilla microphylla	34.6	0.205	15.26	140.8	0.352	35.62	-	-	-	14.6	0.298	8.97
	(5.6)	(0.056)	(8.37)	(56.0)	(0.219)	(11.99)				(31.4)	(0.260)	(12.27)
Gentiana phyllocalyx	4.6	0.184	4.64	-	-	-	7.8	0.217	4.86	14.6	0.121	7.24
	(8.2)	(0.128)	(6.8)	(26.2)	(0.081)	(11.83)	(-)	(-)	(-)	(18.6)	(0.23)	(6.83)
Geranium nakaoanum	26.2	0.155	14.4	16.6	0.098	8.91	100.8	0.448	18.5	39.2	0.109	14.13
	(35.6)	(0.182)	(16.95)	(113.8)	(0.285)	(18.02)	(80.4)	(0.41)	(12.4)	(11.8)	(0.07)	(8.71)
Primula calderana	-	-	-	-	-	-	-	-	-	-	-	-
	(8.2)	(0.328)	(5.52)									

Anemone tetrasepala	- (3.6)	- (0.1)	- (5.54)	19.0 (18.0)	0.074 (0.092)	10.53 (13.99)	33.8 (37.8)	0.15 (0.224)	14.7 (9.5)	8.8 (8.6)	0.045 (0.071)	9.47 (7.6)
Aconitum heterophyllum	- (0.6)	- (0.15)	- (1.54)	-	-	-	-	-	-	-	-	-
Hemiphragma heterophyllum	- (9.0)	- (0.25)	- (5.46)	68.4 (50.6)	0.211 (0.299)	17.18 (15.16)	60 (-)	0.417 (-)	12.5 (-)	17 (13.2)	0.21 (0.206)	6.52 (5.46)
Aletris pauciflora	69.4 (-)	1.084 (-)	15.88 (-)	-	-	-	99.4 (225.4)	0.388 (0.696)	22.7 (22.7)	-	-	-
Gentiana sp.	1.8 (-)	0.072 (-)	4.33 (-)	-	-	-	-	-	-	-	-	-
Prunella vulgaris	4.4 (-)	0.176 (-)	4.7 (-)	-	-	-	-	-	-	-	-	-
Corydalis juncea	-	-	-	- (6.0)	- (0.05)	- (16.21)	-	-	-	-	-	-
Meconopsis paniculata	-	-	-	- (0.8)	- (0.089)	- (3.16)	- (0.8)	- (0.2)	- (1.72)	- (0.8)	- (0.089)	- (2.69)
Pedicularis hoffmeisteri	-	-	-	- (1.8)	- (0.036)	- (12.37)	- (21.4)	- (0.177)	- (6.89)	-	-	-
Phlomis rotata	-	-	-	14.5 (16.2)	0.566 (0.072)	25.59 (11.96)	-	-	-	34 (54.8)	0.133 (0.453)	12.63 (11.97)
Primula sikkimensis	-	-	-	- (2.4)	- (0.049)	- (4.46)	-	-	-	-	-	-

Juncus thomsonii	-	-	-	15.8 (-)	1.58 (-)	7.57 (-)	- (53.2)	- (1.478)	- (6.07)	- (14.2)	- (0.222)	- (6.06)
Heracleum wallichii	-	-	-	3.0 (-)	0.188 (-)	2.65 (-)	- (18.8)	- (0.752)	- (5.86)	2.8 (1.8)	0.057 (0.072)	6.04 (3.66)
Scrophularia sp.	-	-	-	1.6 (-)	0.178 (-)	1.75 (-)	-	-	-	-	-	-
Penzio sp.	-	-	-	-	-	-	4.0 (38.0)	0.16 (0.776)	4.36 (8.95)	-	-	-
Cyananthus lobatus	-	-	-	-	-	-	- (23.0)	- (0.19)	- (8.14)	- (47.6)	- (0.331)	-(11.39)
Euphorbia sp.	-	-	-	-	-	-	- (24.2)	- (0.299)	- (6.11)	- (14.2)	- (0.29)	- (5.18)
Orchis chusua	-	-	-	-	-	-	0.8 (8.4)	0.2 (0.171)	1.42 (4.9)	-	-	-
Potentilla plurijuga	-	-	-	-	-	-	- (15.4)	- (0.616)	- (4.98)	- (67)	- (0.396)	- (15.01)
Parnassia nubicola	-	-	-	-	-	-	-	-	-	4.4 (-)	0.069 (-)	5.14 (-)

Table 5.4 Vegetation structure during growing months at grazed and exclosure (parenthesis) site at alpine Dzongri (3900 m asl)

Species	April			June			August			October		
	Density	A/F	IVI	Density	A/F	IVI	Density	A/F	IVI	Density	A/F	IVI
Poa sp. I	446.6	1.24	113.4	277.8	0.695	38.24	603.6	1.863	50.7	534.2	1.649	97.42
	(718.2)	(1.79)	(144.8)	(312)	(0.78)	(37.34)	(395)	(1.219)	(37.4)	(451.6)	(1.129)	(88.51)
Poa sp. II	123.4	0.38	36.05	122.6	0.626	15.55	276.4	0.853	26.9	222.2	0.556	36.85
	(195)	(0.49)	(42.12)	(316.8)	(0.792)	(27.64)	(1582.8)	(3.957)	(66.8)	(404.2)	(1.011)	(51.78)
Poa sp. III	62	0.19	25.17	-	-	-	58.6	0.407	10.8	126.4	0.316	26.78
	(47.6)	(0.12)	(20.13)				(139.6)	(0.62)	(13.0)	(218.8)	(0.675)	(32.24)
Potentilla peduncularis	178.4	0.55	66.61	129	0.323	39.82	449.8	1.125	86	84.6	0.261	46.92
	(25.2)	(0.17)	(18.93)	(71.8)	(0.199)	(26.21)	(112.4)	(0.347)	(28.7)	(39)	(0.135)	(32.26)
Potentilla coriandrifolia	8.4	0.05	13.1	342.8	0.857	81.48	151.4	0.591	33.1	40.40	0.239	23.84
	(55.4)	(0.15)	(29.91)	(292.4)	(0.731)	(74.85)	(97.8)	(0.382)	(25.3)	(27.8)	(0.096)	(21.44)
Potentilla microphylla	-	-	-	125	0.31	20.85	-	-	-	107.4	0.269	34.05
				(310)	(0.775)	(33.03)				(7.2)	(0.147)	(6.21)
Gentiana phyllocalyx	50.60	0.16	24.4	42.4	0.131	11.97	92.2	0.36	16.5	26.2	0.081	15.42
	(30)	(0.08)	(19.8)	(46.6)	(0.117)	(11.8)	(161.8)	(0.499)	(17.2)	(19)	(0.084)	(10.76)
Bistorta affinis	50.6	0.3	21.24	386.6	0.967	44.34	130.4	0.402	25.9	36	0.184	18.72
	(12)	(0.08)	(11.02)	(401.8)	(1.01)	(39.99)	(132)	(0.673)	(22.2)	(34.4)	(0.153)	(18.32)
Aletris pauciflora	-	-	-	108.4	0.271	19.61	226.4	0.627	29.7	-	-	- (12.89)
	(5.0)	(0.04)	(9.41)	(90.2)	(0.226)	(16.12)	(78.8)	(0.547)	(12.1)	(21.6)	(0.096)	

Parnassia nubicola	- (1.8)	- (0.07)	- (3.85)	-	-	-	-	-	-	-	-	-
Phlomis rotata	-	-	-	5.0 (0.8)	0.078 (0.05)	4.83 (2.11)	-	-	-	-	-	-
Geranium nakaoanum	-	-	-	19 (36.8)	0.074 (0.218)	9.47 (8.61)	-	-	-	-	-	-
Orchis latifolia	-	-	-	4.6 (0.4)	4.6 (0.2)	0.8 (0.94)	-	-	-	-	-	-
Penzio sp.	-	-	-	(26.6) -	(0.092) -	(9.31) -	-	-	-	-	-	-
Cyananthus lobatus	-	-	-	2.8 (0.4)	0.311 (0.1)	1.70 (0.95)	-	-	-	-	-	-
Pedicularis hoffmeisteri	-	-	-	5.2 (4.6)	0.106 (0.072)	4.4 (4.13)	4.8 (-)	0.192 (-)	3.78 (-)	-	-	-
Corydalis juncea	-	-	-	0.2 (1.6)	0.05 (0.044)	1.02 (2.84)	- (17.6)	- (0.275)	- (4.67)	-	-	-
Primula sikkimensis	-	-	-	- (1.2)	- (0.075)	- (2.07)	-	-	-	-	-	-
Juniperus recurva	-	-	-	- (0.4)	- (0.1)	- (1.02)	-	-	-	-	-	-
Arisaema griffithii	-	-	-	12.8 (0.4)	0.128 (0.1)	5.91 (1.02)	-	-	-	-	-	-

Juncus thomsonii	-	-	-	- (908)	- (6.306)	- (48.53)	-	-	-	- (75.6)	- (0.386)	- (17.68)
Euphorbia sp.	-	-	-	-	-	-	4.6 (13.6)	0.184 (0.213)	3.64 (4.83)	-	-	-
Potentilla plurijuga	-	-	-	-	-	-	27.2 (21.4)	0.756 (0.594)	6.33 (5.04)	- (6.0)	- (0.24)	- (3.79)
Anemone tetrasepala	-	-	-	-	-	-	- (14.8)	- (0.411)	- (4.42)	-	-	-
Hemiphragma heterophyllum	-	-	-	-	-	-	42.8 (71)	0.428 (0.42)	8.6 (9.57)	- (5.2)	- (0.144)	- (4.11)
Primula calderana	-	-	-	-	-	-	6.4 (-)	0.4 (-)	4.32 (-)	-	-	-

(-) either absent or did not encountered in sampling quadrats

Table 5.5 Species richness (Margalef's index), diversity (Shannon's index), equitability (Buzas and Gibson's index) and concentration of dominance (Simpson's index) in grazed and exclosure plots at different study sites along the Yuksam-Dzongri trail.

Study sites (Ecological zones)	Parameters	Treatment	Growing months	
			April	August
Yuksam (warm temperate)	Species richness	Grazed	3.75	2.93
		Exclosure	3.36	3.01
	Diversity	Grazed	2.70	2.69
		Exclosure	2.03	2.66
	Equitability	Grazed	0.50	0.53
		Exclosure	0.27	0.49
	Dominance	Grazed	0.10	0.10
		Exclosure	0.24	0.10
Sachen (cool temperate)	Species richness	Grazed	3.07	2.34
		Exclosure	2.37	2.36
	Diversity	Grazed	2.25	2.49
		Exclosure	1.52	2.29
	Equitability	Grazed	0.38	0.57
		Exclosure	0.23	0.45
	Dominance	Grazed	0.19	0.14
		Exclosure	0.43	0.20
Deorali (sub-alpine)	Species richness	Grazed	1.19	1.22
		Exclosure	1.27	1.65
	Diversity	Grazed	1.54	1.89
		Exclosure	1.42	1.93
	Equitability	Grazed	0.42	0.55
		Exclosure	0.34	0.41
	Dominance	Grazed	0.32	0.18
		Exclosure	0.35	0.15
Dzongri (alpine)	Species richness	Grazed	0.71	1.30
		Exclosure	0.93	1.32
	Diversity	Grazed	1.48	1.99
		Exclosure	1.14	1.77
	Equitability	Grazed	0.63	0.56
		Exclosure	0.35	0.42
	Dominance	Grazed	0.30	0.17
		Exclosure	0.47	0.26

Table 5.6 Seedling and sapling numbers of regenerating tree species in the temperate forest (Sachen and Yuksam sites) under grazed and exclosure condition in August 1999).

Tree species	Treatment	Seedlings (ha^{-1})				Sapling (ha^{-1})			
		Sachen		Yuksam		Sachen		Yuksam	
		1998	1999	1998	1999	1998	1999	1998	1999
Symplocos ramosissima	Gr	1750	1750	-	250	1000	1250	-	-
	Ex	2250	2750	250	750	1000	1250	-	-
Viburnum colebrookianum	Gr	2750	3250	750	1000	1000	750	500	250
	Ex	2500	1750	1000	250	750	1750	250	250
Eurya acuminata	Gr	2750	2250	-	-	750	750	-	-
	Ex	1500	1250	-	250	1750	1250	-	-
Alnus nepalensis	Gr	-	-	1750	2250	-	-	-	-
	Ex	-	-	750	250	-	-	-	-
Zanthoxylum acanthopodium	Gr	-	-	-	-	-	-	-	-
	Ex	-	-	-	750	-	-	-	-
Prunus cerasoides	Gr	-	-	-	-	-	-	-	-
	Ex	250	1500	-	-	-	-	-	-

Quercus lamellosa	Gr	-	-	-	-	-	250	-	-
	Ex	-	250	-	-	-	-	-	-
Castanopsis tribuloides	Gr	-	-	-	-	-	250	-	-
	Ex	500	-	-	-	-	-	-	-
Michelia lanuginosa	Gr	250	-	-	-	-	-	-	-
	Ex	750	1250	-	-	250	250	-	-
Macaranga pustulata	Gr	-	-	1000	750	-	-	-	-
	Ex	-	-	1750	3000	-	-	-	250
Juglans regia	Gr	-	-		250	-	-	-	-
	Ex	-	-	750	1250	-	-	-	-
Cinnamomum obtusifolium	Gr	-	250	-	-	-	-	-	-
	Ex	1250	2000	750	1250	-	-	-	-
Cedrela toona	Gr	-	-	250	-	-	-	-	-
	Ex	-	-	750	1000	-	-	-	250

Gr = Grazed, Ex = Exclosure

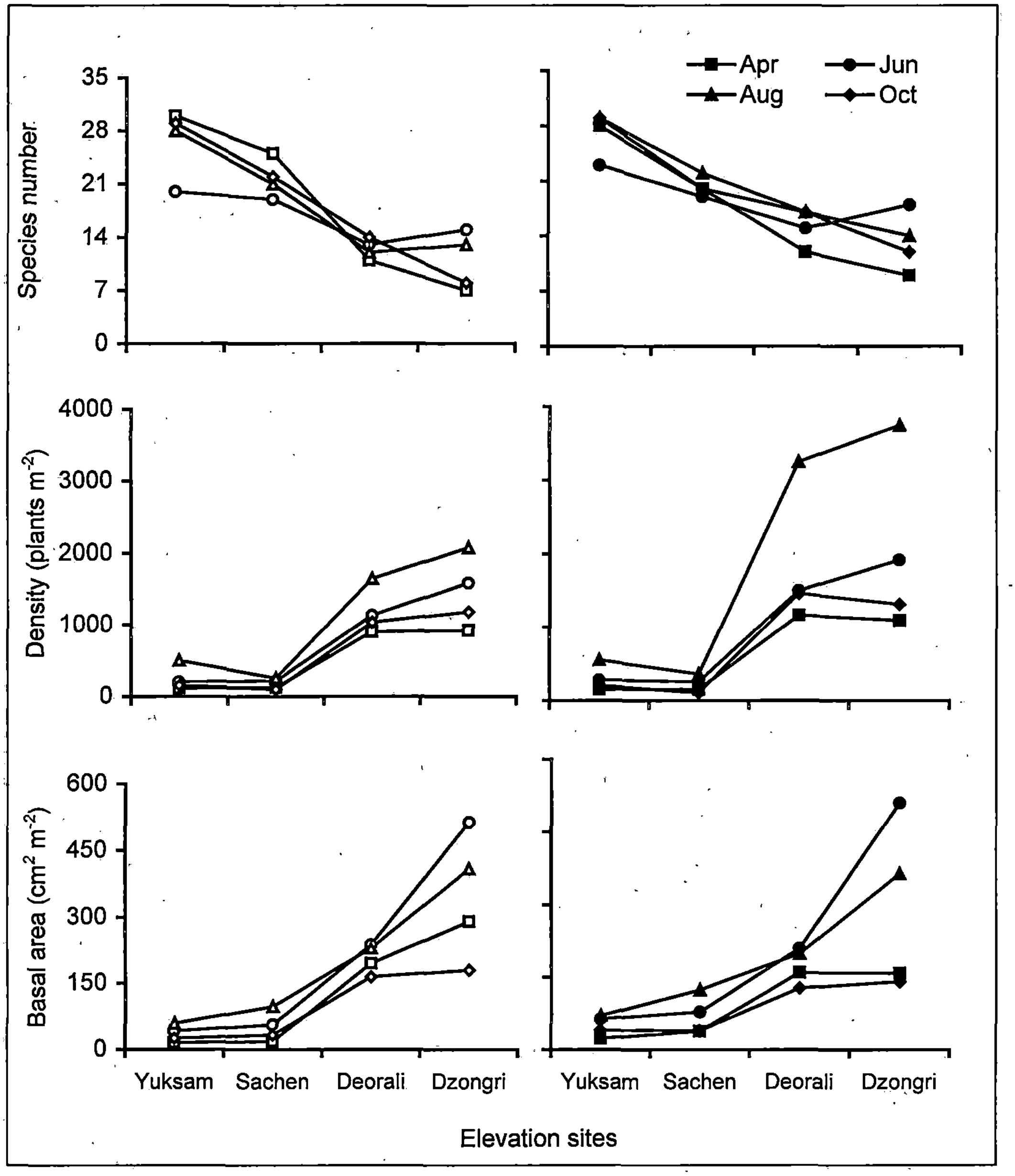

Fig. 5.1 Species number, density & basal area under grazed (empty circle) & exclosure (dark circle) plots at different elevational sites along the Yuksam-Dzongri trail. **ANOVA**: **Species number**- Month $F_{3,608}$=31.5, P<0.0001; Site $F_{3,608}$=260, P<0.0001; Treatment $F_{1,608}$=23.7, P<0.0001; Month x Site $F_{9,608}$=21, P<0.0001, LSD$_{(0.05)}$=0.34; **Density**- Month $F_{3,608}$=178, P<0.0001; Site $F_{3,608}$=497, P<0.0001; Treatment $F_{1,608}$=88, P<0.0001; Month x Site $F_{9,608}$=39.9, Month x Treatment $F_{3,608}$=15.5, $P_{3,608}$=15, P<0.0001; Site x Treatment $F_{3,607}$=20.1, P<0.0001; Month x Site x Treatment $F_{9,607}$=10.4, P<0.0001, LSD$_{(0.05)}$=10. **Basal area**- Month $F_{3,608}$=143, P<0.0001; Site $F_{3,608}$=727, P<0.0001; Treatmet $F_{1,608}$=18.9, P<0.0001; Month x Site $F_{9,608}$=41, P<0.0001; Site x Treatment $F_{3,608}$=24.6, P<0.0001; Month x Site x Treatment interaction not significant.

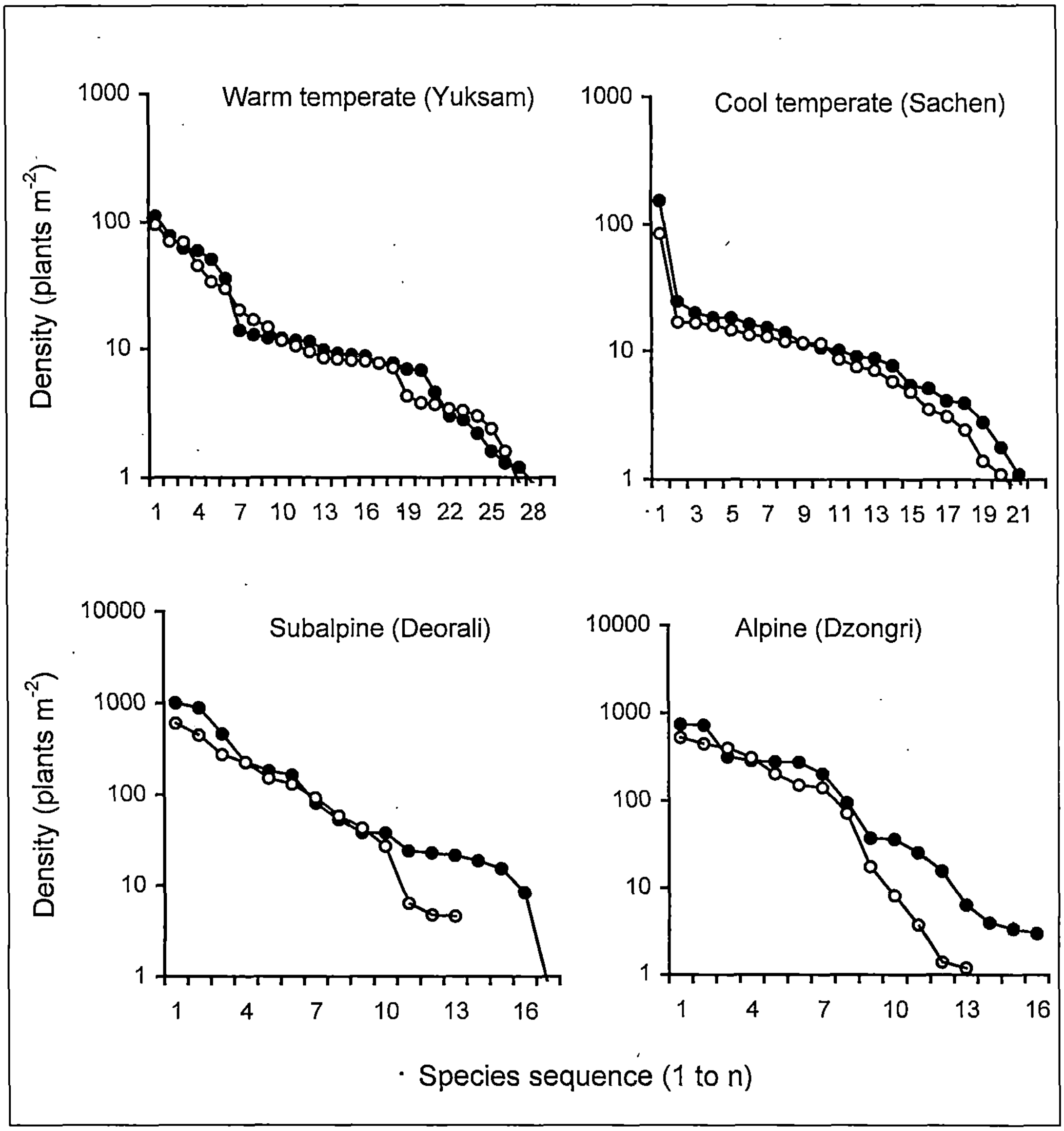

Fig. 5.2 Dominance-diversity curves for grazed (empty circle) and exclosure (dark circle) plots at different elevation study sites along the Yuksam-Dzongri trail of Khangchendzonga Biosphere Reserve

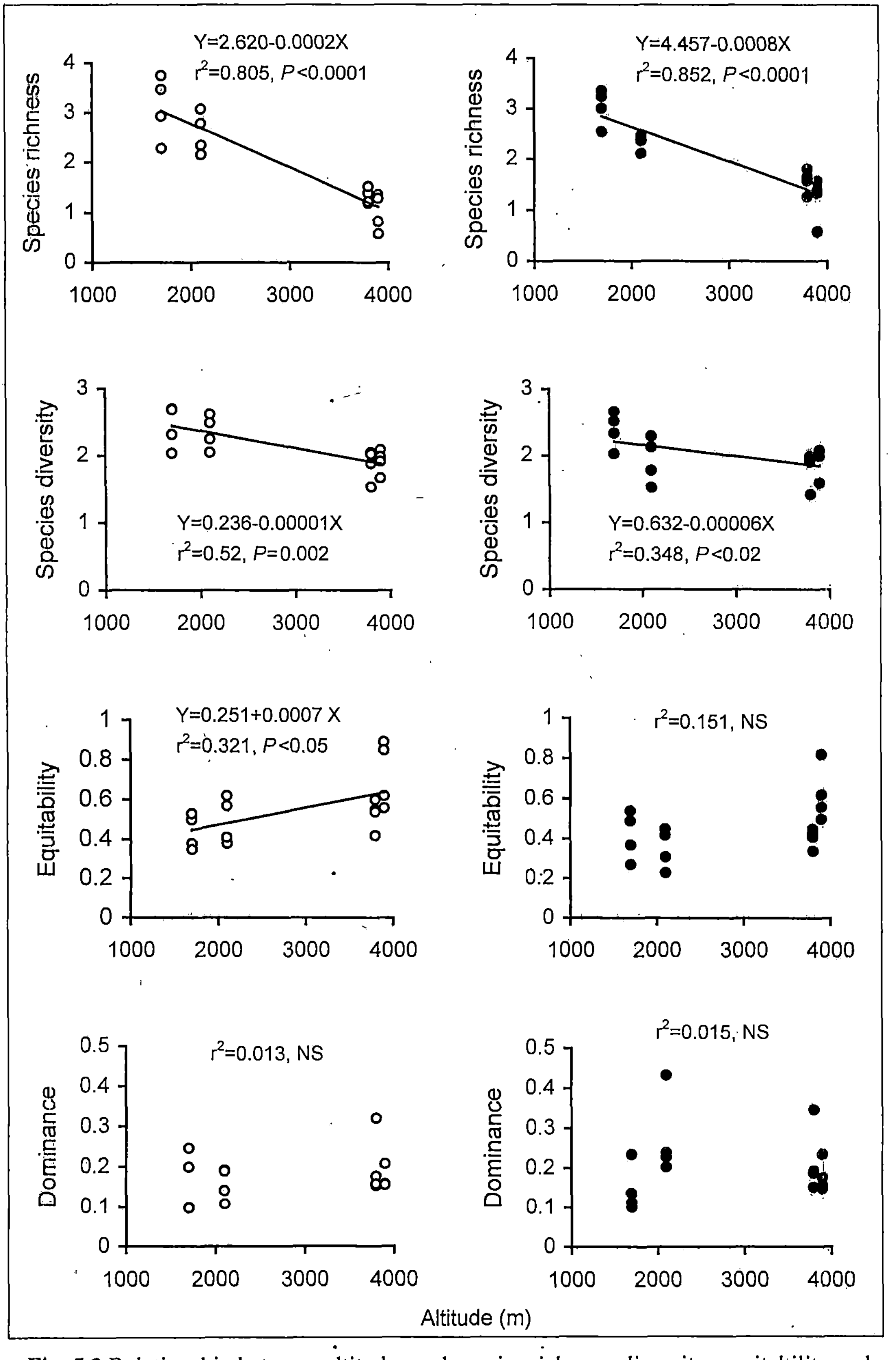

Fig. 5.3 Relationship between altitudes and species richness, diversity, equitability and dominance of herbaceous plants in grazed (empty circle) and exclosure (dark circle) sites along the Yuksam-Dzongri trail.

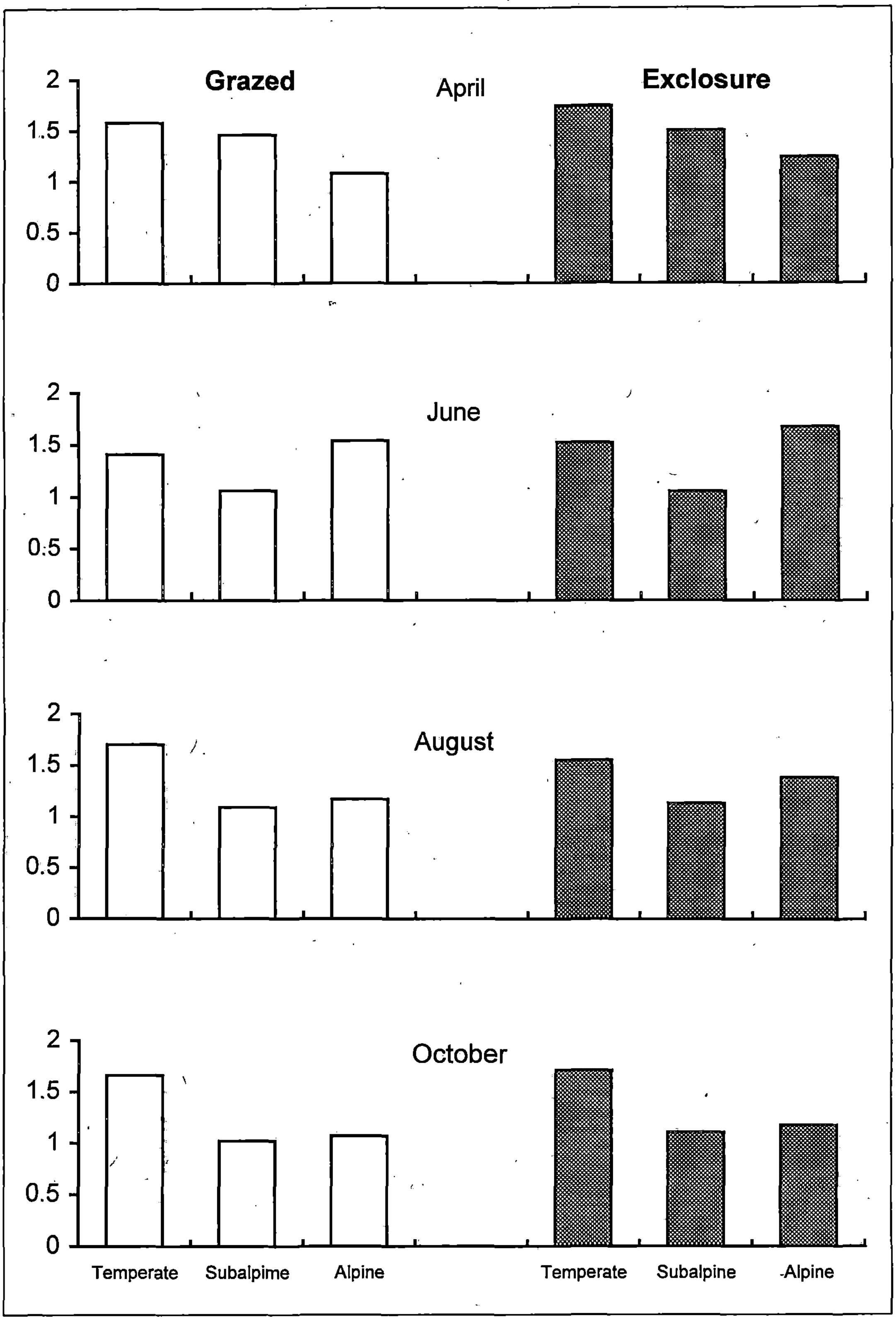

Fig. 5.4 Plant species composition changes (beta diversity-Simpson's index) under grazed and exclosure condition across the environmental gradient along the Yuksam-Dzongri trail in Khangchendzonga Biosphere Reserve

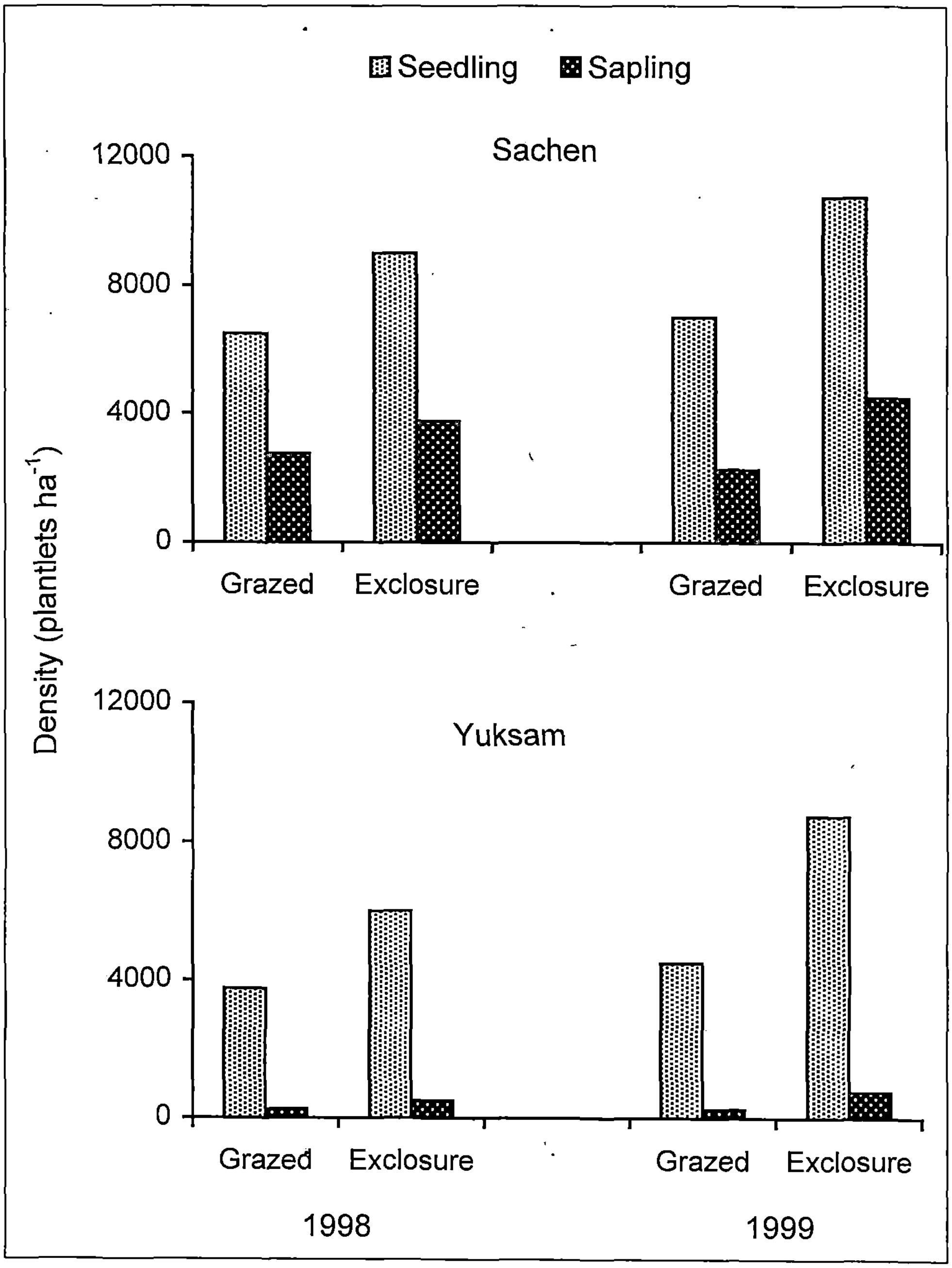

Fig. 5.5 Status of seedling and sapling of tree species in the temperate forest (Sachen and Yuksam sites) as affected by livestock grazing in the Khangchendzonga Biosphere Reserve (Gr = grazed, Ex = exclosure)

CHAPTER VI

IMPACT OF GRAZING ON PLANT BIOMASS AND PRODUCTIVITY

6.1 INTRODUCTION

The grasslands are most important source of fodder for livestock throughout the globe. In India, the grasslands are considered as the easiest means to feed the animals (Yadav & Singh 1977). In Himalaya, the local communities as well as nomadic graziers' practice either free grazing or controlled grazing. Grazing has direct or indirect effect, mainly on plant species composition, above- and belowground plant biomass and productivity and nutrient cycling (Naiman *et al.* 1986; Brown & Heske 1990; Power 1990; DeAngelis 1992; McInnes *et al.* 1992; Pastor *et al.* 1993; Ritchie *et al.* 1998). Extensive reports are available on the inter and intra seasonal dynamics of plant biomass and productivity from outside India (McNaughton 1985; Sala *et al.* 1986; Huntley 1991; Davidson 1993; Milchunas & Lauenroth 1993; Jefferies *et al.* 1994; Hixon & Brostoff 1996; Augustine & McNaughton 1998; Ritchie *et al.* 1998) as well as in Indian grasslands (Dabadghao & Sankarnarayanan 1973; Singh & Yadav 1974; Sundriyal & Joshi 1990; Ram *et al.* 1989; Singh *et al.* 1999). Large number of studies are also carried out in the Himalayan region, particularly in North-West Himalaya (Ram 1988; Bisht & Gupta 1985; 1988; Karunaichamy & Paliwal 1989; Sundriyal & Joshi 1990; Rikhari *et al.* 1992; Sundriyal 1995; Nautiyal *et al.* 1997). It is reported that grazing initially increases primary productivity, and attains a peak at moderate rate of herbivory as stated in "grazing optimization hypothesis" (McNaughton 1979; Hilbert *et al.* 1981; Dyer *et al.* 1986). However with increasing grazing pressure, the plant biomass production is negatively effected (Sundriyal 1995a; Singh *et al.* 1999). Heavy grazing allows little time for herbage replacement, shoot growth and subsequent translocation to root storage, thus resulting in low biomass values of both aboveground and belowground components (Wielgolaski *et al.* 1981; Sundriyal & Joshi 1990).

In Sikkim at low and mid elevations, nearly 65% of the total fodder need is met from forest floor phytomass (Sundriyal & Sharma 1996). The animal census report reveals that the number of livestock is increasing at a fast rate in the state. During recent years, free grazing is becoming as a popular means to feed the animals, which may have detrimental effects on vegetation and soil. No report is available on the dynamics of grasslands and impact of livestock grazing in the Sikkim State. There is an urgent need to extend studies on different pastures to understand the dynamics of plant production in response to grazing. Furthermore, study in the context of grazing will have additional benefits, as it will help in the management of grassland resources by improving productivity and diversity of the rangelands. The present chapter deals with the biomass dynamics and net primary productivity as a response to livestock grazing at different pastures along an altitudinal gradient in the Yuksam-Dzongri trail of the Khangchendzonga Biosphere Reserve.

6.2 METHODS

Standing biomass

At temperate site, standing plant biomass was harvested 5 times (January, April, June, August and October) in a year whereas 4 times (April, June, August and October) at alpine and subalpine sites by randomly placing quadrats of the size 50×50 cm (n = 12×2). At alpine and subalpine sites no samplings were done during January because of snow cover. Samplings were also made in the nearby-demarcated identical open-grazed pastures for comparative assessment. The aboveground biomass was clipped almost at the ground level and packed in polythene bag, which was later separated into species. Litter mass was collected separately and packed in polythene bags. Belowground biomass was collected by digging out the soil monolith of 50×50 cm size upto 30 cm depth (n = 12) at each sampling date and washed by a fine jet of water. The belowground biomass could not be separated into species. All the collected samples were dried in hot-air oven at 80°C till constant weight for dry weight conversion and the weight was recorded separately.

Net primary productivity

"Difference method" has been adapted to measure the productivity in the grasslands (Singh & Yadav 1974). In this investigation, the net aboveground primary productivity was measured through difference method, by subtracting the previous month biomass with current month biomass, and thus accumulating all positive increments (Singh & Yadav 1974). This method for measuring net primary productivity is largely used for most of the temperate and alpine grasslands (Ram 1988; Sundriyal & Joshi 1990; Rikhari *et al.* 1992; Sundriyal *et al.* 1993; Nautiyal *et al.* 1997). For individual species, the productivity was measured at the time of peak biomass as the growth of liveshoot started with the onset of growing season in April. Per cent contributions by each species to total net aboveground productivity are presented. The net belowground primary production was calculated by summing up the positive increments in different successive sampling intervals.

Turnover rate

The turnover rate is the ratio of net production to maximum biomass. It was calculated by the following method (Dahlman & Kucera 1965);

$$\text{Turnover rate} = \frac{\text{Net production}}{\text{Maximum biomass}}$$

6.3 RESULTS

6.3.1 Aboveground Standing Biomass

The aboveground biomass accumulation pattern was almost similar at all the sites, which increased in subsequent sampling dates except in October. At the Yuksam (warm temperate) site, aboveground standing biomass increased at different sampling months and peaked during August and declined in subsequent months. Aboveground biomass ranged from 104-337 g m^{-2} (grazed) and 118-641 g m^{-2} (exclosure) plots. The highest biomass in grazed plots was contributed by fern in 1998 and *Pilea scripta* in 1999 in grazed plots whereas in exclosure plots by fern in both 1998 and 1999. The grazed plots had higher aboveground biomass of dicot species, which decreased after fencing. Contrarily, the contribution of monocot and pteridophyte increased in exclosure plots (Fig. 6.1). As expected, the aboveground biomass contribution by palatable species increased after fencing from 64 to 82% in the year 1998 and from 53 to 83% in 1999 (Fig. 6.2). Among different growth forms undershrub dominated in both grazed (29.4-31.2%) and exclosure (33.2-38.4%) plots (Table 6.3). Grazing exclosure increased the aboveground biomass of graminoids from 5.1 to 10.4% in 1998 and 7.3 to 19.5% in 1999, tall forb from 21.3 to 24.5% in 1998 and 21.5 to 28.5% in 1999, undershrub from

29.4 to 38.4% in 1998 and 31.2 to 33.2% in 1999, whereas contribution of cushion plants decreased from 26.9 to 8.0% in 1998 and 24.8 to 5.3% in 1999 (Table 6.3). Grazing has detrimental effect on tall forbs and graminoids, therefore cushion plants spread in the pasture as an adaptation to grazing.

At Sachen (cool temperate) the aboveground standing biomass ranged from 94-490 g m^{-2} (grazed) and 125-693 g m^{-2} (exclosure) plots (Table 6.1). The highest biomass was contributed by *Urtica dioica* in grazed plots while *Diplazium umbrosum* in exclosure plots (Table 6.2). Maximum biomass was contributed by dicot in both exclosure and grazed plots (Table 6.1). Aboveground biomass of 81-83% was contributed by palatable species in grazed plots while 89-93% in exclosure plots (Fig. 6.2). Maximum aboveground biomass was contributed by short forb (25-26%) in grazed plots while by tall forbs (35-41%) in exclosure plots. Grazing exclosure increased biomass of graminoids from 9.3 to 15.5% in 1998 and 11.2 to 17.5% in 1999; tall forbs 29.7 to 35.1% in 1998 and 21.6 to 41.2% in 1999; undershrub 17.4 to 31.5% in 1998 and 21.3 to 28.5% in 1999 while it was decreased for short forb from 25.1 to 12.4% in 1998 and 26.2 to 8.6% in 1999 and cushion/spreading forbs from 18.5 to 5.5% in 1998 and 19.7 to 4.2% in 1999 (Table 6.3).

At Deorali (subalpine) the aboveground standing biomass ranged from 126-352 g m^{-2} in grazed and 149-537 g m^{-2} in exclosure during the year 1998 and 1999, respectively (Table 6.1). Exclosure has resulted in increase of aboveground biomass by 53-67%. Highest aboveground biomass in grazed plots was contributed by *Potentilla peduncularis*, which was compensated by *Poa* sp. I in exclosure plots (Table 6.2).

Dicots contributed aboveground biomass of 58.26-61.55% in grazed and 40.08-41.33% in exclosure plots (Fig. 6.1). Palatable species contributed 78.54-81.46% in grazed plots while 88.27-89.78% in exclosure plots (Fig. 6.2). Highest biomass was contributed by cushion and spreading forbs (32.8-47.3%) in grazed plots, while by graminoid (34.5-41.2%) in exclosure plots (Table 6.3).

At Dzongri (alpine) aboveground standing biomass ranged from 129 to 310 g m^{-2} in grazed and from 145 to 539 g m^{-2} in exclosure plots (Table 6.1). Highest aboveground biomass was contributed by *Potentilla peduncularis* (111-123 g m^{-2}) in grazed plots while by *Poa* sp. I (106-112 g m^{-2}) in exclosure plots (Table 6.2). Dicot represented highest aboveground biomass (70-74%) in grazed plots while by monocot (50-62%) in exclosure plots (Fig 6.1). Palatable species contributed by 23.0-24.3% in grazed plots while 65.1-78.1% in exclosure plots (Fig. 6.2). Cushion and spreading forbs dominated in grazed plots (49.3-54.3%) whereas in exclosure plots by graminoid (29.7-37.5%) (Table 6.3).

Analysis of variance showed that aboveground standing biomass varied significantly among the sampling intervals and at all the sites ($P<0.0001$) (Table 6.1) but did not show any correlation with elevation (Fig. 6.5). Monthly rainfall have significant positive relationships with aboveground biomass at all the sites; temperate zone ($P<0.002$ for grazed and $P<0.001$ for exclosure), subalpine ($P<0.002$ for grazed and $P<0.001$ for exclosure) and alpine ($P<0.01$ for grazed and $P<0.001$ for exclosure) (Fig. 6.3). Exclosure sites showed stronger correlation than grazed plots with rainfall in all the study sites (Fig. 6.3).

6.3.2 Litter Mass

At Yuksam, litter accumulation ranged from 37-103 g m^{-2} (grazed) and 38-212 g m^{-2} (exclosure); at Sachen from 40-148 g m^{-2} (grazed) and 46-172 g m^{-2} (exclosure); at Deorali from 7-48 g m^{-2} (grazed) and 10-89 g m^{-2} (exclosure) and at Dzongri from 7-40 g m^{-2} (grazed) & 10-86 g m^{-2} (exclosure). Analysis of variance showed that litter accumulation varied among the sampling dates and at all the sites ($P<0.0001$). Grazing significantly reduced litter accumulation at all the sites ($P<0.0001$) (Table 6.4).

6.3.3 Belowground Biomass

At Yuksam, the value of belowground biomass ranged from 315 to 489 g m^{-2} in grazed and 402 to 536 g m^{-2} in exclosure plots; at Sachen from 307 to 593 g m^{-2} (grazed) and 429 to 668 g m^{-2} (exclosure); at Deorali from 848 to 1143 g m^{-2} (grazed) and 794 to 1013 g m^{-2} (exclosure) and at Dzongri from 923 to 1104 g m^{-2} (grazed) and from 845 to 993 g m^{-2} (exclosure) (Table 6.5)

Analysis of variance showed that belowground biomass did not vary significantly among sampling dates but significant among the sites ($P<0.0001$). Belowground biomass showed significant positive correlation with elevation in both grazed and exclosure plots ($P<0.001$) (Fig. 6.5).

6.3.4 Root:Shoot Ratio

Root:shoot ratio value ranged from 1.20 to 2.07 (grazed) and 0.84 to 1.84 (exclosure) at Yuksam, 1.21-1.90 (grazed) and 0.94-1.85

(exclosure) at Sachen, 2.41-6.05 (grazed) and 1.35-4.21 (exclosure) at Deorali and 2.99-6.54 (grazed) and 1.57-5.04 (exclosure) at Dzongri (Table 6.6). Aboveground and belowground biomass ratio showed positive correlation in exclosure plots ($P<0.01$) while it was not significant in grazed plots at Yuksam, positive correlation was recorded in both grazed ($P<0.002$) and exclosure ($P<0.005$) plots at Sachen, negative correlation in both grazed ($P<0.01$) and exclosure ($P<0.01$) plots at Deorali and showed negative correlation in exclosure ($P<0.05$) but was not significant at grazed plots at Dzongri (Fig. 6.4). Root:Shoot ratio showed positive curve correlation with elevation in both grazed ($P<0.001$) and exclosure ($P<0.001$) plots (Fig. 6.5).

6.3.5 Net Primary Productivity

At Yuksam, aboveground net primary productivity (NPP) of plant species ranged from 206-224 g m^{-2} $year^{-1}$ (grazed) and 449-485 g m^{-2} $year^{-1}$ (exclosure), belowground NPP from 96-166 g m^{-2} $year^{-1}$ (grazed) and 73-100 g m^{-2} $year^{-1}$ (exclosure) and total NPP from 302-390 g m^{-2} $year^{-1}$ (grazed) and 549-558 g m^{-2} $year^{-1}$ (exclosure). Highest NPP of aboveground biomass was contributed by fern (11.28-19.68%) in grazed plots and by *Brachiaria* sp. (10.76-23.09%) in exclosure plots (Table 6.8).

At Sachen, aboveground NPP of plant species ranged from 285-302 g m^{-2} $year^{-1}$ in grazed and 329-491 g m^{-2} $year^{-1}$ in exclosure plots, belowground NPP from 275-282 g m^{-2} $year^{-1}$ (grazed) and 192-205 g m^{-2} $year^{-1}$ (exclosure) and total NPP from 567-577 g m^{-2} $year^{-1}$ (grazed) and 534-683 g m^{-2} $year^{-1}$ (exclosure). Highest NPP of aboveground biomass was contributed by *Urtica dioica* (15.98-18.57%) in grazed plots and by *Diplazium umbrosum* (29.73-30.36%) in exclosure plots (Table 6.8).

At Deorali, aboveground NPP of plant species ranged from 149-163 g m^{-2} $year^{-1}$ in grazed and 299-364 g m^{-2} $year^{-1}$ in exclosure plots, belowground NPP from 139-169 g m^{-2} $year^{-1}$ (grazed) and 142-219 g m^{-2} $year^{-1}$ (exclosure) and total NPP from 288-332 g m^{-2} $year^{-1}$ (grazed) and 441-583 g m^{-2} $year^{-1}$ (exclosure). Highest NPP of aboveground biomass was contributed by *Potentilla peduncularis* (23.01-24.86%) in grazed plots and by *Poa* sp. I (22.99-24.19%) in exclosure plots (Table 6.8).

At Dzongri, aboveground NPP of plant species ranged from 50-109 g m^{-2} $year^{-1}$ in grazed and 292-303 g m^{-2} $year^{-1}$ in exclosure plots, belowground NPP from 29-66 g m^{-2} $year^{-1}$ (grazed) & 46-71 g m^{-2} $year^{-1}$ (exclosure) and total NPP from 79-175 g m^{-2} $year^{-1}$ (grazed) and 338-374 g m^{-2} $year^{-1}$ (exclosure). Highest NPP of aboveground biomass was contributed by *Potentilla peduncularis* (39.68-45.68%) in grazed plots and by *Poa* sp. I (20.78%) in exclosure plots (Table 6.8).

6.3.6 Turnover Rate

At Yuksam, turnover rate of aboveground biomass ranged from 0.326 to 0.329 in grazed plots while from 0.584 to 0.593 in exclosure plots. Turnover rate of belowground biomass ranged from 0.196 to 0.345 in grazed plots while from 0.136 to 0.199 in exclosure plots (Table 6.9).

At Sachen, turnover rate of aboveground biomass ranged from 0.584 to 0.616 in grazed plots while 0.475 to 0.593 in exclosure plots. Turnover rate of belowground biomass ranged from 0.464 to 0.479 in grazed plots while 0.307 to 0.309 in exclosure plots (Table 6.9).

At Deorali, turnover rate of aboveground biomass ranged from 0.426-0.463 in grazed plots while 0.559 to 0.620 in exclosure plots. Turnover rate of belowground biomass ranged from 0.137 to 0.148 in grazed plots while 0.143 to 0.216 in exclosure plots (Table 6.9).

At Dzongri, turnover rate of aboveground biomass ranged from 0.206 to 0.352 in grazed plots while 0.562 to 0.573 in exclosure plots. Turnover rate of belowground biomass ranged from 0.029 to 0.060 in grazed plots while 0.047 to 0.072 in exclosure plots (Table 6.9). Turnover rate of aboveground biomass was higher compared to belowground biomass in both grazed and exclosure plots during both 1998 and 1999 samplings. It was much higher in aboveground biomass compared to belowground at the alpine pasture of Dzongri and was more pronounced in exclosure plots (Table 6.9)

6.4 DISCUSSION

In the present investigation, biomass productivity measurements were done for two years in grazed and exclosure plots at four different elevation sites ranging from 1600 to 3900 m. The aboveground biomass accumulation showed an increasing trend from January to August and thereafter decreased in the subsequent months in all the study plots. This is similar to the reports from other Himalayan studies (Ram 1988; Ram *et al.* 1989; Sundriyal & Joshi 1990; Rikhari *et al.* 1992; Nautiyal *et. al.* 1997). Among all the study sites, Sachen (cool temperate) grassland recorded maximum biomass in any given month, which was due to ferns (*Diplazium umbrosum, Pteris* sp.). Two years of grazing exclosure resulted in the increase of aboveground biomass by 83-90%, at Yuksam, 26-42% at Sachen; 53-67% at Deorali and 74-110% at Dzongri, which is very high by any standard. The compensation is much higher at Yuksam, Deorali and Dzongri, which also bears maximum grazing pressure. Therefore, grazing exclosure helps species to recover very fast at these three sites. At Sachen pasture, the grazing pressure was less than any other study sites as the site is used for grazing for only short period in a year. In alpine areas most of the species are perennial, which perpetuates through underground parts. Grazing removes the aboveground palatable parts. However, exclosure brings back the growth and development of aboveground parts that leads to accumulation of biomass. Sundriyal & Joshi (1990) and Rikhari *et al.* (1992) also reported similar findings. As reported by earlier workers (Bisht & Gupta 1988; Karunaichemy & Paliwal 1989; Sundriyal & Joshi 1990), grazing significantly reduced biomass and productivity; this is due to reduction of photosynthetic area (Slatyer 1971) and smaller surface for higher energy accumulation (Sundriyal 1989). The increase of aboveground biomass of palatable species in the exclosure plots has been supported by the earlier reports (Ellision 1960; Thurow & Hussein 1989; Curry & Hacker 1990) and in turn the aboveground biomass of least palatable or unpalatable species increased in grazed plots. It has also been reported that "individual plants are not completely consumed by herbivore, differences among the plant species in their response to herbivory in terms of survivorship, growth, reproduction, and competitive ability can be a critical determinant of community changes" McNaughton (1983). Grazing exclosure has resulted in the increased of aboveground biomass of graminoids (mostly highly palatable). In the present study, grazing has shifted the plant distribution pattern with more magnitude in higher altitude than the lower forested pastures probably due to climatic arrest against compensation (lost due to grazing) in terms of individual and associated plants physiological activities. Although, the distribution pattern of plants does not amplify greatly in the lower elevation temperate pastures, the species composition are dominanted by weeds and other secondary species, which are generally least palatable to livestock grazing. Around 50% aboveground biomass removal by livestock grazing (comparing between exclosure and grazed plots) in the present study is closer with the accepted upper limit (50-60%) of biomass utilization. If the level of pressure crossed the present limit, herbage compensation will be affected severely and non-palatable and secondary species might have proliferated growth extending in higher intensity and to a larger area. Strong steps are needed at Yuksam and Dzongri whose biomass removal has crossed above 60%. Theses two sites are the areas where animals spend most of the time and grazing constituted removal of high biomass. Although, root biomass differed significantly between climatic zones, no strong relationship between grazing and root mass was recorded and this conforms to earlier reports (Milchunas & Lauenroth 1993; Morton *et al.* 1995). But grazing biotic types and intensity of grazing is highly expected to modify this concept to a large extend. Light grazing does not injure root mass physically but heavy grazing and small-mouth herbivores can be destructive to roots at higher extent as compared to big-mouth animals. Therefore, the intensity and effect of grazing on plant can largely be helpful by studying the root mass and its dynamics. Lower litter mass accumulation in grazed plots are indicative of grazing that consumed more green forage and left very little mass for senescence. Grazing reduced root:shoot ratio which was attributed to more reserve food in the root and at the same time lower in aboveground biomass. Higher amount of root biomass has better condition for quick activation of dormant buds to sprout and establish in the forthcoming season especially at higher elevations. Turnover rate of aboveground biomass in the present study area is lower than the report from the Central Himalaya that ranged from 0.66 to 0.76 for aboveground biomass and 0.28-0.41 for belowground biomass (Ram 1988).

The present study supports the concept "productivity of pastures decreases with the increasing elevation" (Bliss 1962; Whittaker 1966; Sundriyal 1995a). The higher rainfall and temperature in the lower elevation are the major factors for higher productivity. The grazing period at lower elevation is also longer. Livestock grazing exclosures resulted in increase of net primary productivity from 13 to 83%. This clearly shows that livestock grazing have strong negative impact on biomass productivity (Photoplate 7) ■

Table 6.1 Monthly variation in aboveground shoot biomass (g m^{-2}) of herbaceous plants during growing season of 1998 and 1999 in grazed and exclosure plots at four elevation study sites along the Yuksam-Dzongri trail.

Study sites (Ecological zones)	Months	1998		1999	
		Gr	Ex	Gr	Ex
Yuksam (Warm temperate)	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 (Cool temperate)	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 (Subalpine)	April	134	157	126	149
	June	297	387	278	389
	August	350	535	352	587
	October	197	253	184	281
Dzongri (Alpine)	April	129	145	134	157
	June	206	381	265	420
	August	243	510	310	539
	October	147	197	161	225

Gr = Grazed, Ex = Exclosure. ***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 6.2 Aboveground biomass (g m^{-2}) as contributed by dominant species during peak season (August) at different elevation study sites along the Yuksam-Dzongri trail.

Study sites (Ecological zones)	Species	1998		1999	
		Gr	Ex	Gr	Ex
Yuksam (Warm temperate)	*Eupatorium cannabinum*	32	26	39	24
	Plantago erosa	31	16	43	-
	Hydrocotyle javanica	44	62	34	78
	Fern	61	106	38	163
	Pilea scripta	46	53	65	81
	Brachiaria sp.	32	61	22	148
	Other species	64	244	97	146
	Total	310	567	337	641
Sachen (Cool temperate)	*Diplazium umbrosum*	78	187	75	206
	Pilea scripta	44	65	52	81
	Elatostema sessile	65	96	71	121
	Urtica dioica	91	58	78	79
	Rumex nepalensis	54	17	75	18
	Brachiaria sp.	23	62	27	87
	Other species	135	131	110	101
	Total	490	616	488	693
Deorali (Subalpine)	*Potentilla peduncularis*	87	64	81	51
	Anemone tetrasepala	51	43	42	55
	Poa sp. I	46	123	51	142
	Poa sp. II	42	91	34	110
	Aletris pauciflora	23	53	28	76
	Potentilla coriandrifolia	21	48	22	56
	Other species	80	113	94	97
	Total	350	535	352	587
Dzongri (Alpine)	*Potentilla peduncularis*	111	97	123	101
	Bistorta affinis	71	80	61	78
	Poa sp. I	12	106	33	112
	Poa sp. II	6	49	27	69
	Aletris pauciflora	9	38	11	51
	Potentilla coriandrifolia	12	56	21	58
	Other species	22	84	34	70
	Total	243	510	310	539

Gr = Grazed, Ex = Exclosure

Table 6.3 Per cent contribution of different growth forms of herbaceous plants to aboveground shoot biomass during biomass peak season (August) at different elevation study sites along the Yuksam-Dzongri trail.

Study sites (Ecological zones)	Growth forms	1998		1999	
		Gr	Ex	Gr	Ex
Yuksam (Warm temperate)	Graminoid	5.1	10.4	7.3	19.5
	Tall forb	21.3	24.5	21.5	28.5
	Short forb	17.3	18.7	15.2	13.5
	Undershrub	29.4	38.4	31.2	33.2
	Cushion/Spreading forbs	26.9	8.0	24.8	5.3
Sachen (Cool temperate)	Graminoid	9.3	15.5	11.2	17.5
	Tall forb	29.7	35.1	21.6	41.2
	Short forb	25.1	12.4	26.2	8.6
	Undershrub	17.4	31.5	21.3	28.5
	Cushion/Spreading forbs	18.5	5.5	19.7	4.2
Deorali (Subalpine)	Graminoid	13.4	34.5	19.6	41.2
	Tall forb	11.5	21.4	12.0	28.1
	Short forb	13.9	12.7	18.3	13.5
	Undershrub	13.9	12.6	17.3	10.1
	Cushion/Spreading forbs	47.3	18.8	32.8	7.1
Dzongri (Alpine)	Graminoid	13.4	29.7	13.0	37.5
	Tall forb	8.5	16.5	9.9	27.3
	Short forb	12.7	16.4	16.3	11.2
	Undershrub	11.1	9.2	11.5	11.2
	Cushion/Spreading forbs	54.3	28.2	49.3	12.8

Gr = Grazed, Ex = Exclosure

Table 6.4 Monthly variation in litter mass accumulation (g m^{-2}) at different elevation study sites along the Yuksam-Dzongri trail.

Study sites (Ecological zones)	Months	1998		1999	
		Gr	Ex	Gr	Ex
Yuksam (Warm temperate)	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 (Cool temperate)	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 (Subalpine)	April	48	89	32	77
	June	23	37	20	56
	August	7	10	7	16
	October	13	66	10	73
Dzongri (Alpine)	April	40	80	28	86
	June	23	41	17	61
	August	9	10	7	20
	October	17	70	13	81

Gr = Grazed, Ex = Exclosure. ***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 (snow-cover).

Table 6.5 Monthly variation in belowground biomass (g m^{-2}) at different elevation study sites along the Yuksam-Dzongri trail.

Study sites (Ecological zones)	Months	1998		1999	
		Gr	Ex	Gr	Ex
Yuksam (Warm temperate)	April	393	402	315	463
	June	416	463	337	483
	August	489	502	481	536
	October	423	461	402	492
Sachen (Cool temperate)	April	318	429	307	463
	June	470	489	423	507
	August	593	621	589	668
	October	461	507	423	529
Deorali (Subalpine)	April	1016	993	1143	923
	June	917	884	958	863
	August	869	816	848	794
	October	1008	958	1017	1013
Dzongri (Alpine)	April	1016	977	1104	993
	June	933	916	986	907
	August	923	902	927	845
	October	962	948	993	916

Gr = Grazed, Ex = Exclosure. ***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 6.6- Monthly variation in root:shoot ratio in grazed and exclosure plots at different elevation study sites along the Yuksam-Dzongri trail.

Study sites (Ecological zones)	Months	1998		1999	
		Gr	Ex	Gr	Ex
Yuksam (Warm temperate)	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 (Cool temperate)	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 (Subalpine)	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 (Alpine)	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

Gr = Grazed, Ex = Exclosure

Table 6.7 Net primary productivity (g m^{-2} $year^{-1}$) of aboveground shoot and belowground parts in grazed and exclosure plots at different elevation study sites along the Yuksam-Dzongri trail.

Study sites (Ecological zones)	Plant components	1998		1999	
		Gr	Ex	Gr	Ex
Yuksam (Warm temperate)	Aboveground shoot	206	449	224	485
	Belowground parts	96	100	166	73
	Total	302	549	390	558
Sachen (Cool temperate)	Aboveground shoot	302	491	285	329
	Belowground parts	275	192	282	205
	Total	577	683	567	534
Deorali (Subalpine)	Aboveground shoot	149	299	163	364
	Belowground parts	139	142	169	219
	Total	288	441	332	583
Dzongri (Alpine)	Aboveground shoot	50	292	109	303
	Belowground parts	29	46	66	71
	Total	79	338	175	374

Gr = Grazed, Ex = Exclosure

Table 6.8 Per cent contribution to the net aboveground biomass primary productivity by dominant species in grazed and exclosure plots at different elevation study sites along the Yuksam-Dzongri trail.

Study sites (Ecological zone)	Species	Net primary productivity (%)			
		1998		1999	
		Gr	Ex	Gr	Ex
Yuksam (Warm temperate)	*Eupatorium cannabinum*	10.32	4.59	11.57	3.74
	Plantago erosa	10.00	2.82	12.76	-
	Hydrocotyle javanica	14.19	10.93	10.09	12.17
	Fern	19.68	18.69	11.28	9.83
	Pilea scripta	14.84	9.35	19.29	12.64
	Brachiaria sp.	10.32	10.76	6.53	23.09
	Other species	20.65	42.86	28.78	22.78
Sachen (Cool temperate)	*Diplazium umbrosum*	15.92	30.36	15.37	29.73
	Pilea scripta	8.98	10.55	10.66	11.69
	Elatostema sessile	13.27	15.58	14.55	17.46
	Urtica dioica	18.57	9.42	15.98	11.40
	Rumex nepalensis	11.02	2.76	15.37	2.60
	Brachiaria sp.	4.69	10.06	5.53	12.55
	Other species	27.55	21.27	22.54	14.57
Deorali (Subalpine)	*Potentilla peduncularis*	24.86	11.96	23.01	8.69
	Anemone tetrasepala	14.57	8.04	11.93	9.37
	Poa sp. I	13.14	22.99	14.49	24.19
	Poa sp. II	12.00	17.01	9.66	18.74
	Aletris pauciflora	6.57	9.91	7.95	12.95
	Potentilla coriandrifolia	6.00	8.97	6.25	9.54
	Other species	22.86	21.12	26.70	16.52
Dzongri (Alpine)	*Potentilla peduncularis*	45.68	19.02	39.68	18.74
	Bistorta affinis	29.22	15.69	19.68	14.47
	Poa sp. I	4.94	20.78	10.65	20.78
	Poa sp. II	2.47	9.61	8.71	12.80
	Aletris pauciflora	3.70	7.45	3.55	9.46
	Potentilla coriandrifolia	4.94	10.98	6.77	10.76
	Other species	9.05	16.47	10.97	12.99

Gr = Grazed, Ex = Exclosure

Table 6.9 Turnover rate of different components of herbaceous plants at four elevation study sites along the Yuksam-Dzongri trail.

Study sites (Ecological zone)	Compartments	1998		1999	
		Gr	Ex	Gr	Ex
Yuksam (Warm temperate)	Aboveground biomass	0.326	0.584	0.329	0.593
	Belowground biomass	0.196	0.199	0.345	0.136
Sachen (Cool temperate)	Aboveground biomass	0.616	0.593	0.584	0.475
	Belowground biomass	0.464	0.309	0.479	0.307
Deorali (Subalpine)	Aboveground biomass	0.426	0.559	0.463	0.620
	Belowground biomass	0.137	0.143	0.148	0.216
Dzongri (Alpine)	Aboveground biomass	0.206	0.573	0.352	0.562
	Belowground biomass	0.029	0.047	0.060	0.072

Gr = Grazed, Ex = Exclosure

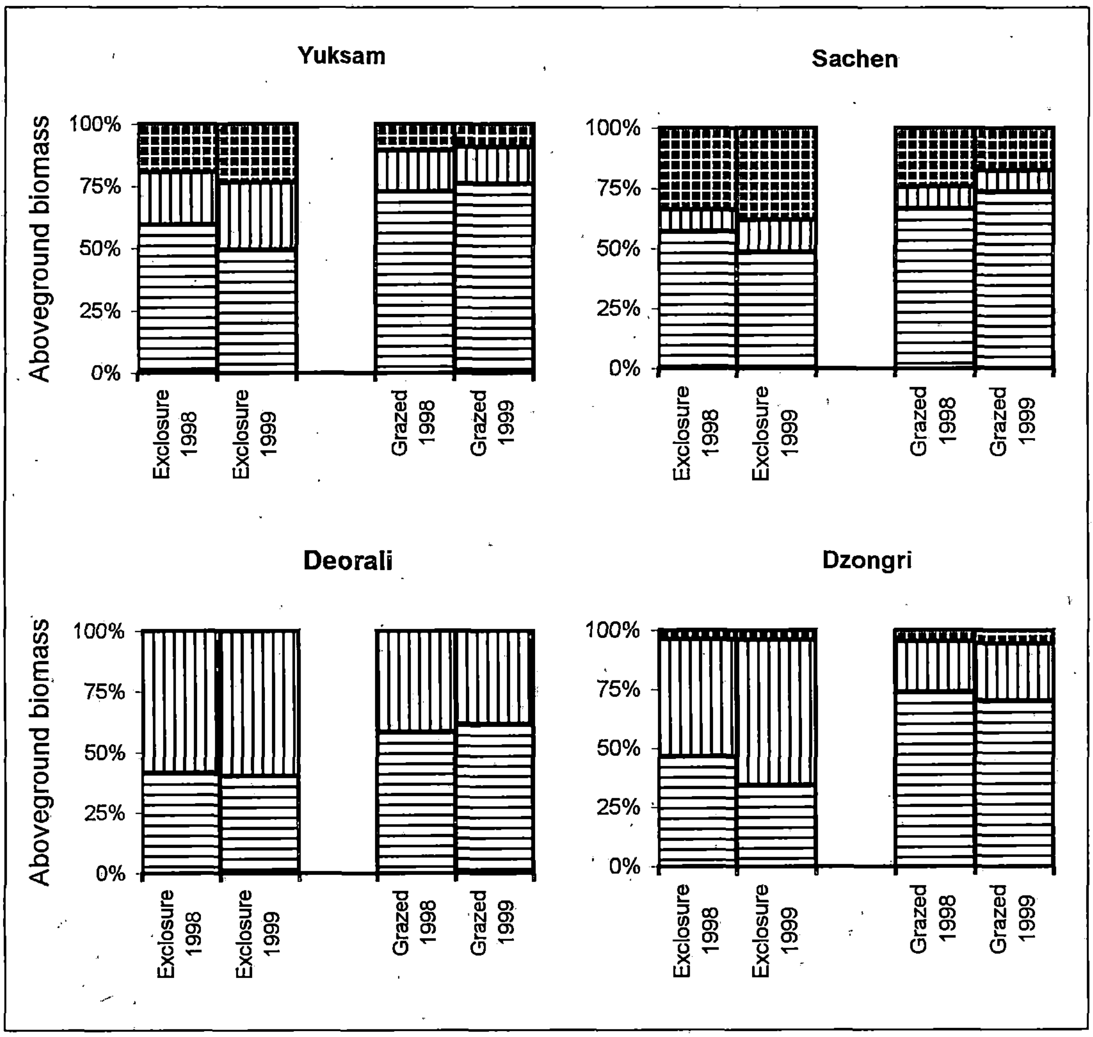

Fig. 6.1 Per cent contribution of aboveground biomass by dicot (horizontal strips), monocot (vertical strips) and others (check) plant in exclosure and grazed pots along the Yuksam-Dzongri trail.

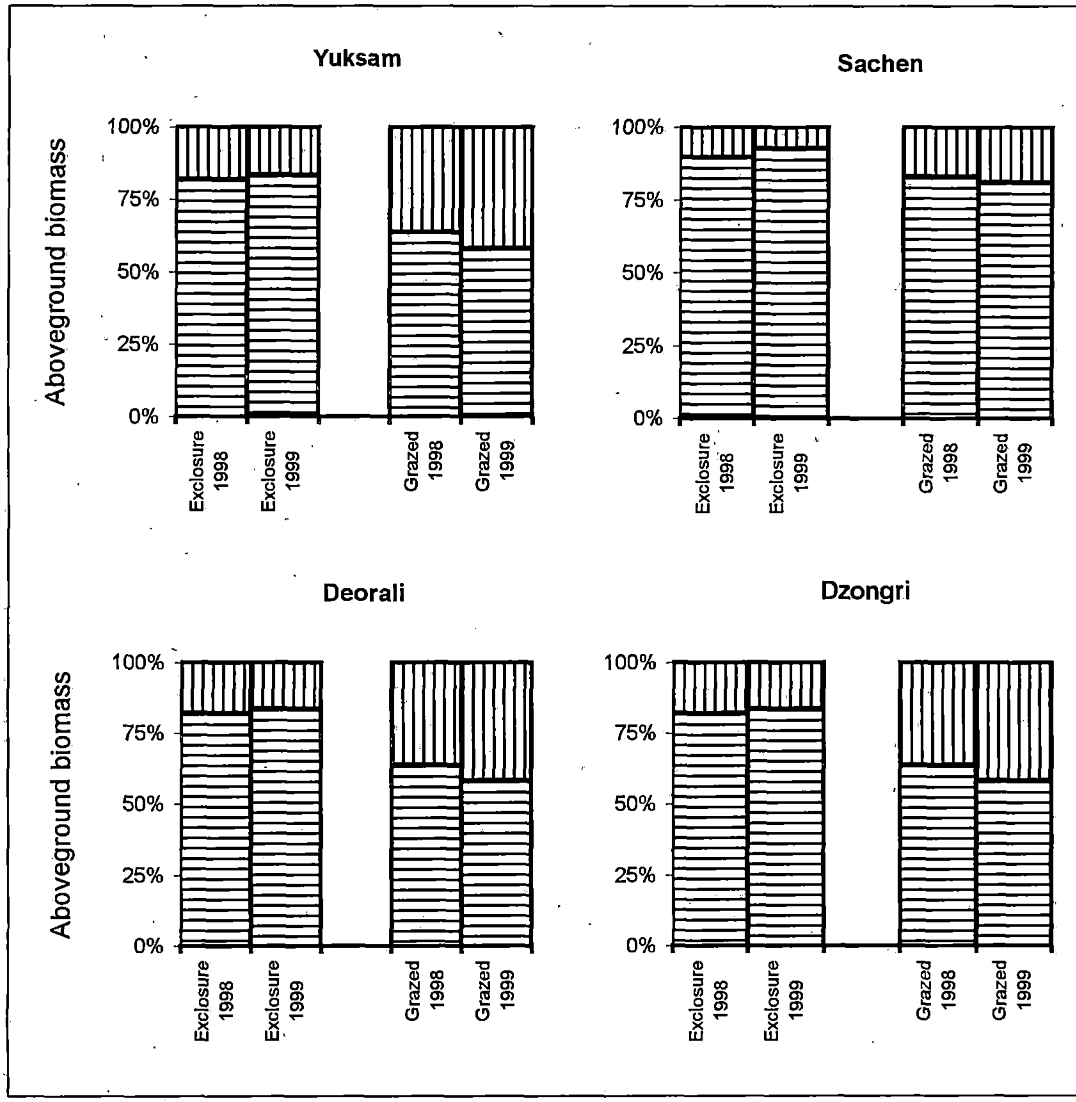

Fig. 6.2 Per cent contribution of aboveground biomass by palatable (horizontal strips) and unpalatable (vertical strips) plant species in exclosure and grazed plots at different study sites along the Yuksam-Dzongri trail.

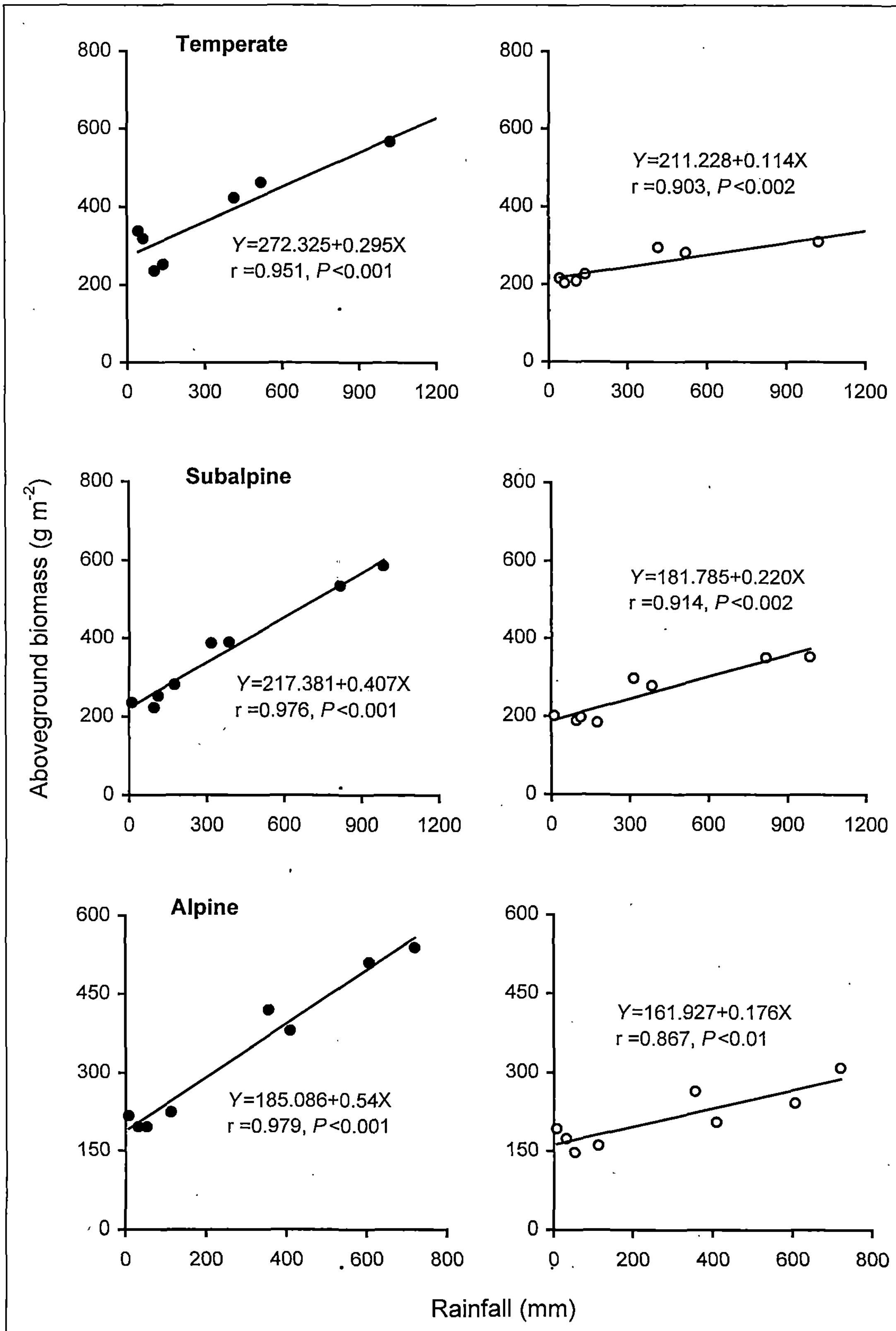

Fig. 6.3 Relationship between monthly rainfall and aboveground biomass in exclosure (dark circle) and grazed (empty circle) plots at different ecological zones along the Yuksam-Dzongri trail of Khangchendzonga Biosphere Reserve

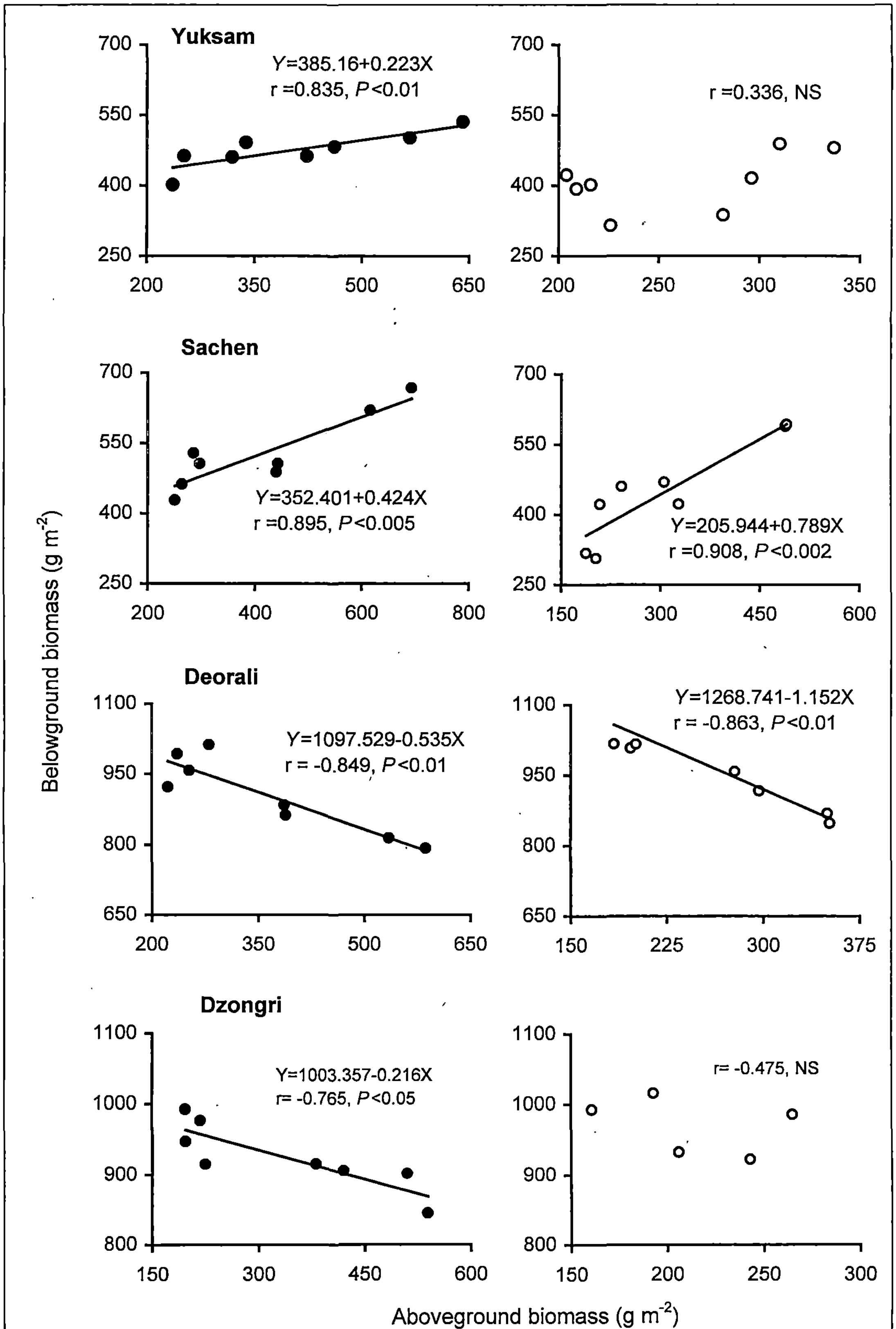

Fig. 6.4 Relationship between aboveground and belowground biomass in exclosure (dark circle) and grazed (empty circle) plots at different ecological sites along the Yuksam-Dzongri trail of Khangchendzonga Biosphere Reserve.

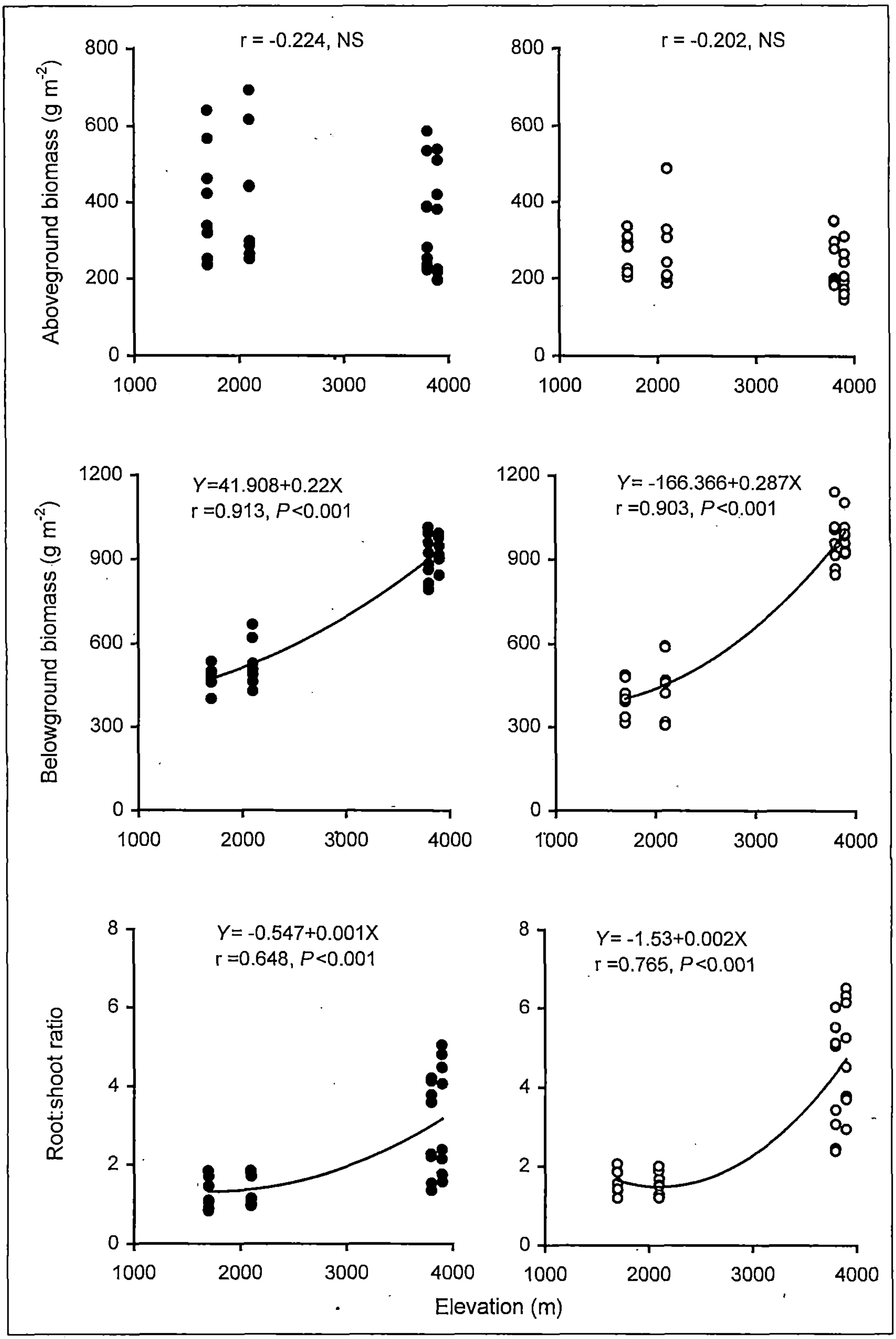

Fig. 6.5 Relationship between aboveground biomass, belowground biomass and root:shoot ratio with elevations in exclosure (dark circle) and grazed (empty circle) plots along the Yuksam-Dzongri trail of Khangchendzonga Biosphere Reserve

CHAPTER VII

NUTRIENT CYCLING AND INFLUENCE BY GRAZING

7.1 INTRODUCTION

Life on the earth is dependent upon the cycle of elements in the biosphere (Bormann & Likens 1967). All the tissues of the plants are made up of complex organic compounds, which are synthesized by the uptake of minerals from soil. These organic compounds return to soil after the death of the plant and form the humus; further breakdown of humus mineralises them into ionic and molecular forms. It becomes available for next plants coming up (Rodin & Bezilevich 1967).

Nutrient requirement is generally viewed as the nutrient quantity annually incorporated into biomass production (Switzer & Nelson 1972; Grier & Ballard 1981; Cole & Rapp 1982). These nutrients recycle again and again endlessly shuttling from organic to inorganic compounds from trophic level to trophic level and plant to animal to soil to water. The pattern of biological circulation of nutrient differs from biome to biome through polar to tropical latitudes (Rodin & Bezilevich 1967). Life requires a constant cycling of nitrogen, oxygen and water. These cycles include a gaseous phase and have self regulating feedback mechanism that make them relatively perfect (Odum 1971), whereas the elements with sedimentary cycles (i.e. phosphorus, potassium, calcium, magnesium) show a continuous loss from biological system in response to erosion with ultimate deposition in sea. Therefore, these sedimentary cycles are less perfect and more easily disrupted by man than carbon and nitrogen cycle (Odum 1971). However, these elements are not less important to life (Bormann & Liken 1967).

Odum (1971) considered the circulation of mineral material and unidirectional flow of energy as two great and equally important laws of ecology. In an ecosystem the mineral cycling through various components can be considered as good indicator of continuity and stability of the living system and thus is believed to be a useful strategy for ecosystem analysis (Pomeroy 1970). Uptake of nutrients might be one way of calculating the photosynthetic rate and hence primary productivity. Nutrient uptake is a quantity of a given nutrient obtained from soil during the year (Ovington 1962; Cole *et al.* 1970; Duviyneard & Denaeyer–De Smet 1970).

Research on grazing lands has historically focused on the effects of various management practices on forage production and animal response; little attention has been given to the impact of grazing on the nutrient dynamics of soil (Manley *et al.* 1995). Soil health has become a major research target for rangeland management strategies in the recent years. Milchunas and Lauenroth (1993) considered the impact of grazing on rangeland as; species composition a fast, annual net primary productivity an intermediate, and soil nutrient pool a slow response variable. Soil nutrient dynamics will largely depend on the intensity, grazing history and types of grazing livestock, temporal cycle and edaphic factors. Ruess and McNaughton (1987) suggested that grazing accelerates the rate of nutrient cycling by stimulating primary production and net nutrient flux, thereby increasing the percentage of system's nutrients that are available and which are rapidly near the soil surface. Nutrient present in the soil will be available for the plants to utilise in response to its requirement and influence by surrounding biotic and abiotic factors that forms an interdependent linkage called as nutrient cycling. The nutrient pool in the soil and vice versa will influence the plant health. Livestock can be a major vector of nutrient removal from rangelands through volatilisation of nitrogen, export of milk and urine to other land types (Powel *et al.* 1995). Thus, cycling of biomass through livestock and the use of manure and urine to fertilise the soil will be important linkage between livestock and soil productivity. As grasslands form an important source of forage for animals, it is very essential to study soil and plant nutrient status as influenced by grazing. This chapter reports on nutrient cycling through plant-herbivore-soil interactions.

7.2 METHODS

Biomass samples of plant species were collected from the field and milled into powder for analysis. The details of procedure have been given in chapter VI.

Procedure of element estimation

The detail procedure for the estimation of nitrogen and phosphorus for plant samples has been given in chapter IV.

Standing state of nutrient in plant and soil

The standing state for vegetation refers to the quantity of individual nutrient (i.e. Nitrogen and Phosphorus) in annual biomass of plant compartments (shoot, root and litter). The value is achieved by multiplying standing state of biomass with corresponding nutrient value.

Nutrient budget

The standing state of nutrient is not as informative as the annual transfer rates between compartments because they are only approximate measure of the storage capacity of the compartments. The method used by Billore and Mall (1976) was followed to estimate net input and output for nutrients. Net uptake for each element was calculated by summing the positive increase in aboveground biomass of positive increment in belowground biomass during temporal cycle. Output of net uptake to standing dead was calculated by summing positive increment in aboveground biomass. The input in litter compartment from standing dead was computed by summing initial standing dead crop biomass + (increment in standing dead – final standing dead).

Output of net uptake to standing belowground was calculated by difference i.e. net uptake – (net uptake to standing dead + net uptake to litter). The decomposition of litter was computed by summing of initial standing crop of litter + (increment in litter compartment – final standing crop of litter), whereas the loss from underground compartment was calculated by multiplying the particular nutrient equivalent with dry matter loss from the underground. The total loss was computed by adding loss from litter + loss from underground. It was considered as release. The difference between uptake and release was taken as retention.

Chemical analysis of soil samples and livestock faecal matters

The soil samples were collected from the study sites for two different depths (0-15 cm and 15-30 cm) and packed inside polythene bags and brought to laboratory. These samples were air-dried and sieved to pass through 2-mm sieve before digestion for nitrogen, phosphorus and organic carbon estimation.

Analysis of total nitrogen in soil was done through modified Kjeldahl method as given by Anderson & Ingram (1993). It was obtained by digesting the samples in the presence of sulphuric acid and catalyst (copper sulfate, mercuric oxide, selenium powder and potassium sulfate). The nitrogen is converted into ammonium sulfate and can be determined after distillation in alkaline condition. The amount of total nitrogen was calculated by the following formula:

$$N\ (\%) = \frac{A \times \text{solution volume (ml)}}{10 \times \text{aliquot volume (ml)} \times w}$$

Where, A = ml of HCl used for titration, w = sample weight (g)

Total phosphorus of soil samples was extracted using acidified ammonium fluoride after oxidation employing 30% H_2O_2 and then estimated by chlorostannous reduced molybdophosphoric blue colour method in the HCl system (Jackson 1967). Per cent phosphorus was calculated using the following formula:

$$P\ (\%) = \frac{C \times \text{solution volume (ml)}}{10 \times \text{aliquot volume (ml)} \times w}$$

Where, C = concentration (mg), w = sample weight (g)

Organic carbon of the soil sample was estimated after partial oxidation with an acidified dichromate solution, which is modified

Walkey-Black Method (Anderson & Ingram 1993). The amount of organic carbon was computed in per cent by the formula;

$$C\ (\%) = \frac{(k \times 0.1)}{w \times 74}$$

Where, k = concentration (mg), w = sample weight (g)

7.3 RESULTS

7.3.1 Plant Nutrient Concentration

Aboveground plant parts

The nutrient concentration for some important species in temperate and alpine/subalpine grasslands are presented in Table 7.1. Generally, aboveground biomass of temperate plants recorded higher concentration of nitrogen than the alpine and subalpine species. Plants in exclosure plots have higher concentration of nitrogen than grazed plots in all the study sites. Nitrogen concentration ranged from 1.48 to 3.41% among temperate species whereas it ranged from 1.01 to 1.87% among alpine and subalpine species. Analysis of variance showed significant ($P<0.0001$) difference of nitrogen concentration among the different species. Grazing significantly ($P<0.01$) reduced nitrogen concentration of plants (Table 7.1). Composite plant sample analysis showed that nitrogen concentration of aboveground biomass increased with the advancement of growing season and peaked during August and then declined towards the end of season in all the study sites except at Deorali where it peaked during June ($P<0.01$). Grazing significantly reduced nitrogen concentration of plants ($P<0.05$). Nitrogen concentration ranged from

1.71 to 2.71% at Yuksam, 1.62 to 2.95% at Sachen, 0.91 to 1.22% at Deorali and from 0.92 to 1.42% at Dzongri. Analysis of variance showed significant ($P<0.0001$) difference in nitrogen concentration across the study sites (Table 7.2).

Similarly, phosphorus concentration was also higher in plants from exclosure plots as compared to grazed plots. Phosphorus concentration of plants ranged from 0.171 to 0.339% among temperate species while it ranged from 0.163 to 0.377% among alpine and subalpine species. Analysis of variance showed that phosphorus concentration among the species differed significantly ($P<0.0001$). Grazing showed no significant difference in phosphorus concentration of plants and their interaction was also not significant (Table 7.1).

Composite sample analysis showed that phosphorus content of shoot biomass was not significant across the study sites. It increased with the advancement of growing season and peaked during June-August and then declined by the end of growing season ($P<0.01$). Grazing showed no significant difference in phosphorus concentration of plants. Phosphorus concentration ranged from 0.163 to 0.247% at Yuksam, 0.168 to 0.233% at Sachen, 0.117 to 0.216% at Deorali and from 0.113 to 0.222% at Dzongri (Table 7.2).

Belowground plant parts

Nitrogen concentration of belowground parts of plants differed significantly ($P<0.01$) across the study sites. Nitrogen concentration increased with the advancement of growing season and peaked during July-August and then declined towards the end of growing season

(P<0.0001). Grazing has increased nitrogen concentration of belowground plant parts significantly (P<0.01). Analysis of variance showed that site and grazing treatment interactions were significant (P<0.05) with least standard deviation value of 0.138. The value of nitrogen concentration ranged from 0.71 to 0.87% at Yuksam, 0.63 to 1.16% at Sachen, 0.74 to 1.38% at Deorali and from 0.63 to 1.50% at alpine Dzongri (Table 7.3).

Phosphorus concentration of belowground plant parts differed significantly across the study sites (P<0.0001). It increased with the advancement of growing season and peaked during July-August and then declined towards the end of the season (P<0.01). Grazing showed no significant change in phosphorus concentration in belowground parts of plants. Phosphorus concentration ranged from 0.122 to 0.152% at Yuksam, 0.103 to 0.168% at Sachen, 0.108 to 0.160% at Deorali and from 0.117 to 0.238% at Dzongri (Table 7.3).

Litter mass

Nitrogen concentration of litter mass differed significantly across the study sites (P<0.01). It increased with the advancement of growing season and peaked during August and then declined towards the end of the growing season (P<0.0001). Grazing showed no significant difference in nitrogen concentration in litter mass. Nitrogen concentration ranged from 0.78 to 1.32% at Yuksam, 0.88 to 1.24% at Sachen, 0.97 to 1.42% at Deorali and 0.94 to 1.68% at Dzongri (Table 7.4).

Phosphorus concentration of litter mass did not differ significantly among study sites. It increased with the advancement of growing season and peaked during June-August and then declined towards the end of the growing season ($P<0.05$). Grazing showed no significant effect on phosphorus concentration in litter mass. Phosphorus concentration of litter mass samples ranged from 0.216 to 0.338% at Yuksam, 0.213 to 0.317% at Sachen, 0.231 to 0.331% at Deorali and from 0.214 to 0.314% at Dzongri (Table 7.4).

7.3.2 Standing State of Nutrient of Plants

Nitrogen

Standing state of nitrogen of aboveground plant parts increased with growing season and peaked during August and then declined towards the end of season in both grazed and exclosure plots in all the study sites. At Yuksam grazing reduced nitrogen content of pasture (per unit area basis) by around 40%. It's content ranged from 3.69 to 6.81 g m^{-2} in grazed plots and 5.05 to 17.37 g m^{-2} in exclosure plots (Table 7.5). At Sachen, standing nitrogen content in exclosure plots was more than by 30%. Nitrogen content ranged from 3.29 to 11.22 g m^{-2} in grazed and 5.1 to 20.44 g m^{-2} in exclosure plots. At Deorali, nitrogen content was more in exclosure plots than grazed plots by more than 35%. Nitrogen content ranged from 1.44 to 3.73 g m^{-2} in grazed plots and 2.03 to 6.81 g m^{-2} in exclosure plots. At Dzongri, it was more by 30% in exclosure plots than grazed plots. It ranged from 1.48 to 3.72 g m^{-2} in grazed plots and 2.43 to 7.65 g m^{-2} in exclosure plots (Table 7.5).

Standing state of nitrogen of belowground parts increased with growing season, peaked during August and then declined towards the end of the growing season in both grazed and exclosure plots at all the study sites (Table 7.5). At Yuksam, grazing reduced nitrogen content of belowground plant parts by more than 30%. It ranged from 2.55 to 4.18 g m^{-2} in grazed plots and 3.38 to 4.29 g m^{-2} in exclosure plots. At Sachen, grazing reduced nitrogen content of belowground plant parts by more than 10%. Nitrogen content ranged from 1.96 to 5.40 g m^{-2} in grazed plots and 3.38 to 5.48 g m^{-2} in exclosure plots. At Deorali, grazing increased nitrogen content of belowground parts by more than 25% except during October. Nitrogen content ranged from 10.32 to 12.07 g m^{-2} in grazed plots and 8.49 to 10.48 g m^{-2} in exclosure plots. At Dzongri, grazing increased nitrogen content of belowground parts by more than 30%. Nitrogen content ranged from 10.16 to 13.91 g m^{-2} in grazed plots and 5.25 to 7.35 g m^{-2} in exclosure plots (Table 7.5).

Standing state of nitrogen in litter increased with growing season and peaked during August and then declined towards the end of the growing season in Yuksam but reverse trend was observed at Sachen, Deorali and Dzongri. Grazing reduced nitrogen content of litter by more than 40% at Yuksam and the value ranged from 0.38 to 0.52 g m^{-2} in grazed plots and 0.79 to 1.03 g m^{-2} in excosure plots. At Sachen, grazing reduced nitrogen content by more than 25%. It ranged from 0.52 to 1.00 g m^{-2} in grazed plots and 0.87 to 1.44 g m^{-2} in exclosure plots. At Dzongri, grazing reduced its content by more than 50%. It ranged from 0.12 to 0.33 g m^{-2} in grazed plots and 0.34 to 1.04 g m^{-2} in exclosure plots (Table 7.5).

Phosphorus

Standing state of phosphorus of aboveground parts increased with growing season peaked during August and declined towards the end of season at all the study sites (Table 7.6). At Yuksam grazing reduced phosphorus content (per unit area basis) by around 40%. Phosphorus content of shoot ranged from 0.352 to 0.778 g m^{-2} in grazed plots and 0.512 to 1.012 g m^{-2} in exclosure plots. At Sachen, standing phosphorus content of shoot in exclosure plots was more by 30%. Phosphorus content ranged from 0.341 to 1.039 g m^{-2} in grazed and 0.51 to 1.60 g m^{-2} in exclosure plots. At Deorali, grazing reduced phosphorus content by 25%. Phosphorus content ranged from 0.215 to 0.743 g m^{-2} in grazed plots and 0.350 to 1.197 g m^{-2} in exclosure plots. At Dzongri, grazing reduced phosphorus content by 30%. Phosphorus content ranged from 0.182 to 0.598 g m^{-2} in grazed plots and 0.320 to 1.197 g m^{-2} in exclosure plots.

Standing state of phosphorus in belowground parts increased with growing season, peaked during August and then declined towards the end of the growing season in both grazed and exclosure plots at Yuksam, Sachen and Deorali but at Dzongri it declined starting from April until the end of growing season. At Yuksam, grazing reduced phosphorus content of belowground plant parts by 30%. Phosphorus content of root ranged from 0.419 to 0.702 g m^{-2} in grazed plots and 0.565 to 0.815 g m^{-2} in exclosure plots. At Sachen, grazing reduced phosphorus content of root by 10%. Phosphorus content ranged from 0.393 to 0.878 g m^{-2} in the grazed plots and 0.542 to 0.982 g m^{-2} in the exclosure plots. At Deorali, grazing increased phosphorus content of belowground parts by 25% except during October. It ranged from 1.198 to 1.357 g m^{-2} in grazed plots and 1.089 to 1.225 g m^{-2} in exclosure plots. At Dzongri, grazing increased phosphorus content of belowground parts by 30%. Phosphorus content ranged from 1.162 to 2.762 g m^{-2} in grazed plots and 1.218 to 2.218 g m^{-2} in exclosure plots (Table 7.6).

At Yuksam, grazing reduced standing state of phosphorus in litter by 40% and the values ranged from 0.085 to 0.110 g m^{-2} in grazed plots and 0.207 to 0.300 g m^{-2} in exclosure plots (Table 7.6). At Sachen, grazing reduced phosphorus content of litter by 25%. It ranged from 0.19 to 0.27 g m^{-2} in grazed plots and 0.23 to 0.31 g m^{-2} in exclosure plots. At Deorali, grazing reduced phosphorus content in litter by 75%. It ranged from 0.02 to 0.09 g m^{-2} in grazed plots and 0.05 to 0.22 g m^{-2} in exclosure plots. At Dzongri, grazing reduced phosphorus content by 50%. It ranged from 0.017 to 0.029 g m^{-2} in grazed plots and 0.059 to 0.200 g m^{-2} in exclosure plots (Table 7.6).

7.3.3 Nutrient Status of Soil

Total nitrogen

Grazing significantly increased nitrogen concentration of soil ($P<0.0001$). Nitrogen concentration differed significantly among the different study sites ($P<0.0001$). Upper (0-15 cm) soil depths showed higher nitrogen concentration compared to lower (15-30 cm) depth, and differed significantly between depths ($P<0.0001$). Nitrogen concentration did not differ significantly between 1998 and 1999. It ranged from 0.33 to

0.88% at Yuksam, 0.407-0.547% at Sachen, 0.490-0.551% at Deorali and 0.310-0.477% at Dzongri. It's content ranged from 292 to 432 g m^{-2} at Yuksam, 428-586 g m^{-2} at Sachen, 519-561 g m^{-2} at Deorali and 463-575 g m^{-2} at Dzongri (Table 7.7).

Total phosphorus

Grazing has no significant effect on phosphorus concentration of soil. Phosphorus concentration significantly differed with soil depth but did not vary among the study sites. Analysis of variance showed no significant interaction on phosphorus concentration between site, treatment, soil depth and year. Phosphorus concentration of soil ranged from 0.019-0.031% at Yuksam, 0.013-0.028% at Sachen, 0.018-0.036% at Deorali and 0.007-0.029% at Dzongri. It's contents ranged from 16.46-26.90 g m^{-2} at Yuksam, 13.67-29.95 g m^{-2} at Sachen, 19.10-38.14 g m^{-2} at Deorali and from 10.47-35.87 g m^{-2} at Dzongri (Table 7.9).

Organic carbon

Grazing significantly reduced organic carbon concentration of soil ($P<0.0001$). It significantly got lowered with soil depth ($P<0.0001$) and also varied with sites ($P<0.0001$). There was no significant difference between 1998 and 1999. Analysis of variance showed that interactions between sites, treatment, depth and year were significant ($P<0.0001$) with least standard deviation value of 0.117. Organic carbon concentration of soil ranged from 3.46-5.61% at Yuksam, 3.73-5.23% at Sachen, 4.24-5.86% at Deorali and from 3.66 to 4.66% at Dzongri. It's content ranged from 3058-4866 g m^{-2} at Yuksam, 3921-5599 g m^{-2} at Sachen, 4494-5990 g m^{-2} at Deorali and 4965-6961 g m^{-2} at Dzongri (Table 7.10).

Carbon:Nitrogen ratio

Carbon:Nitrogen ratio ranged from 11.50-12.69 (grazed) and 9.79-11.48 (exclosure) at Yuksam, 8.98-0.23 (grazed) and 8.29-11.56 (exclosure) at Sachen, and 8.64-10.64 (grazed) and 10.68-10.93 (exclosure) at Deorali, and 9.69 to 15.03 (grazed) and 9.08 to 10.63 (exclosure) at Dzongri.

Nitrogen:Phosphorus ratio

Nitrogen:Phosphorus ratio ranged from 14.86-21.74 (grazed) and 12.69-21.05 (exclosure) at Yuksam, 18.22-29.44 (grazed) and 18.5-35.69 (exclosure) at Sachen, 13.64 to 18.37 (grazed) and 23.43-28.39 (exclosure) and from at Deorali, and 12.92-21.37 (grazed) and 33.17-51.57 (exclosure) at Dzongri (Table 7.10).

7.3.4 Chemical Composition of Faecal Matters

Nitrogen, phosphorus and organic carbon concentration of faecal materials of yak, dzo, cow, horse and sheep has been estimated (Table 7.11).

Nitrogen

Nitrogen concentration was highest in dzo followed by yak, cow, sheep and least in horse. It differed significantly among them ($P<0.0001$) with least standard deviation value of 0.14. Nitrogen concentration among the different livestock faecal matter ranged from 1.41 to 1.89%.

Phosphorus

Phosphorus concentration was highest in cow followed by dzo, yak, sheep and least in horse. It differed significantly ($P<0.0001$) between animal type faecal matter with least standard deviation value of 0.078. The value ranged from 0.20 to 0.50%.

Organic carbon

Organic carbon concentration was highest in horse followed by cow, sheep, yak and least in dzo. It differed significantly ($P<0.05$) between animal type faecal matters with least standard deviation value of 0.668. Organic carbon concentration among livestock ranged from 6.72 to 8.35%.

7.3.5 Nutrient Cycling

Total nitrogen uptake by plants was 4.60 g m^{-2} yr^{-1} in the grazed and 13.47 g m^{-2} yr^{-1} in the exclosure plots at Yuksam, 11.68 g m^{-2} yr^{-1} (grazed) and 17.55 g m^{-2} yr^{-1} (exclosure) at Sachen, 3.73 g m^{-2} yr^{-1} (grazed) and 7.26 g m^{-2} yr^{-1} (exclosure) at Deorali, and 6.20 g m^{-2} yr^{-1} (grazed) and 7.53 g m^{-2} yr^{-1} (exclosure) at Dzongri (Table 7.12). Total nitrogen released from litter and root were 1.22 g m^{-2} yr^{-1} (grazed) and 1.00 g m^{-2} yr^{-1} (grazed) at Yuksam, 2.79 g m^{-2} yr^{-1} (grazed) and 1.96 g m^{-2} yr^{-1} (exclosure) at Sachen, 1.50 g m^{-2} yr^{-1} (grazed) & 1.88 g m^{-2} yr^{-1} (exclosure) at Deorali, and 3.49 g m^{-2} yr^{-1} (grazed) and 2.28 g m^{-2} yr^{-1} (exclosure) at Dzongri. Nitrogen removed by grazing was recorded as

9.42 g m^{-2} yr^{-1} at Yuksam, 7.41 g m^{-2} yr^{-1} at Sachen, 2.81 g m^{-2} yr^{-1} at Deorali and 3.16 g m^{-2} yr^{-1} at Dzongri (Table 7.12).

Phosphorus uptake by plants was 0.684 g m^{-2} yr^{-1} in grazed and 1.405 g m^{-2} yr^{-1} in exclosure plots at Yuksam, 1.243 g m^{-2} yr^{-1} (grazed) and 1.530 g m^{-2} yr^{-1} (exclosure) at Sachen, 0.547 g m^{-2} yr^{-1} (grazed) and 1.103 g m^{-2} yr^{-1} (exclosure) at Deorali, and 0.990 g m^{-2} yr^{-1} (grazed) and 1.255 g m^{-2} yr^{-1} (exclosure) at Dzongri (Table 7.13). Total phosphorus released from litter and root were 0.191 g m^{-2} yr^{-1} (grazed) and 0.240 g m^{-2} yr^{-1} (grazed) at Yuksam, 0.536 g m^{-2} yr^{-1} (grazed) and 0.517 g m^{-2} yr^{-1} (exclosure) at Sachen, 0.089 g m^{-2} yr^{-1} (grazed) and 0.257 g m^{-2} yr^{-1} (exclosure) at Deorali, and 0.552 g m^{-2} yr^{-1} (grazed) and 0.444 g m^{-2} yr^{-1} (exclosure) at Dzongri. Phosphorus removed by grazing was recorded as 0.695 g m^{-2} yr^{-1} at Yuksam, 0.392 g m^{-2} yr^{-1} at Sachen, 0.397 g m^{-2} yr^{-1} at Deorali and 0.454 g m^{-2} yr^{-1} at Dzongri (Table 7.13).

Out of the total uptake of nitrogen, 73.07% was retained while 26.93% released in the grazed condition and 92.44% retained while 7.56% released in the exclosure plot at Yuksam; 75.46% retained while 24.54% released in the grazed and 88.76% retained while 11.24% released in the exclosure plot at Sachen; 59.67% retained while 40.33% released in the grazed and 72.23% retained while 27.77% released in the exclosure plot at Deorali, and 41.74% retained while 58.26% released in the grazed and 67.93% retained while 32.07% released in the exclosure plot at Dzongri (Table 7.14).

Out of the total uptake of phosphorus, 71.17% was retained while 28.83% released in the grazed condition and 81.71% retained while 18.29% released in the exclosure plot at Yuksam; 54.69% retained while 45.31% released in the grazed and 65.30% retained while 34.70% released in the exclosure plot at Sachen; 84.58% retained while 15.42% released in the grazed and 73.86% retained while 26.14% in the exclosure plot at Deorali, and 43.56% retained while 56.44% released in the grazed and 61.09% retained while 38.91% released in the exclosure plot at Dzongri (Table 7.14).

7.4 DISCUSSION

In the present investigation two important elements (nitrogen and phosphorus) for plants and three elements (nitrogen, phosphorus and organic carbon) for soil and livestock faecal matters were analysed under exclosure and grazed treatment plots. Plants uptake these nutrients from soil and are allocated into three main compartments (i.e. aboveground, belowground and litter) for the production of organic compounds with their incorporation into biomass (Kramer & Kozlowaski 1960). These elements were more in aboveground and belowground biomass and decreased as the plant material moved to litter stage; might be due to weathering or leaching of the respective elements by rain interception or by back translocation before moving into dead stage (Billore & Mall 1976). These differences can be contributed to relative requirements of individual elements in the metabolic process and to availability of the nutrients in the ecosystem (Billore & Mall 1976). Maximum percentage values of nitrogen and phosphorus was recorded during peak growing season and then declined towards the end of the growing season; this might be due to the arrest of elements by unfavourable surrounding climate as temperature declined and rainfall reduced in the subsequent months. The annual leaf fall and subsequent conversion to litter mass followed by decomposition brings back the nutrients to the soil. Some amount of nutrients also returned back to soil through urine and faecal matters as showed by the chemical analysis of the present study where nitrogen concentration ranged from 1.41 to 1.89%, phosphorous concentration 0.20 to 0.50% and organic carbon ranged from 6.72 to 8.35% among the livestock.

Grazing modifies nitrogen budgets in grassland (Hobbs *et al.* 1991). Higher concentration of nitrogen and phosphorus in the aboveground biomass in the exclosure plots might be due to healthy growth of plants and active metabolism which accumulates higher nutrients as compared to the plants which are injured due to grazing removal and less photosynthetic areas. The results of the present study are in accordance to Gupta (1985, 1986), Sundriyal (1986) but contrary to Pandey and Simba (1986) who found that nitrogen and phosphorus increased on grazed grassland than protected grasslands.

In the present study, standing states (aboveground + belowground) of nitrogen was more in forested pastures as compared to alpine and subalpine pastures in exclosure plots whereas a reverse trend was observed in grazed plots. Grazing reduced total standing state of nitrogen in forested pastures and subalpine but contrary to it, higher value was recorded in alpine pasture. This can be explained by higher contribution from the belowground parts in alpine pastures. Higher accumulation of nitrogen in the belowground biomass in alpine pasture in mainly attributed to short growing season and storage in belowground part during winter. In the present study, standing nitrogen ranged between 147-259 kg ha^{-1} in exclosure and 110-176 kg ha^{-1} in grazed pastures at different sites which is comparatively higher than the Central Himalayan report of 117 kg ha^{-1} (Billore & Mall 1976) and 116 kg ha^{-1} (Sundriyal 1986). Contrary to nitrogen, phosphorus was more in alpine pastures. Exclosure plots always had higher standing phosphorus compared to grazed plots. Standing state of phosphorus ranged from 24.0-30.4 kg ha^{-1} in exclosure and 14.8-26.9 kg ha^{-1} in grazed pastures. These values are well comparable with the standing state of phosphorus as reported to be 22 kg ha^{-1} in the Central Himalaya (Sundriyal 1986) and 32 kg ha^{-1} in the Central Indian grasslands (Billore & Mall 1976).

Bauer *et al.* (1987) found that grazing reduced soil organic carbon and increased soil nitrogen. Some researchers reported increases in both soil organic carbon and nitrogen (Dormaar *et al.* 1990; Dormar & William 1990; Ruess & McNaughton 1987) while other studies have found no response in soil organic carbon and nitrogen to grazing (Milchunas & Lauenroth 1993; Kieft 1994; Mathews *et al.* 1994). Soil had higher amount of carbon and nitrogen in the surface 30 cm of the grazed pastures as compared to native rangeland where livestock were excluded, however, soil carbon and nitrogen below 30 cm was similar among all the grazing treatments (Manley *et al.* 1995). This might be due to the faecal matters of grazing animals in the open-grazed pastures.

Contrary to it soil organic carbon and nitrogen losses with grazing (Holland *et al.* 1992) because of increase in allocation of carbon and nitrogen to regrowing leaves and a decrease in allocation of carbon to root (Detling *et al.* 1979) resulting in root biomass (Dormaar *et al.* 1990; Johnston 1961) and reduced root exudate contributes to soil organic matter (Manley *et al.* 1995). In the present study open pastures have higher percentage of nitrogen and carbon than the exclosure plots. This might be due to the faecal matters of livestock (faecal matters have 1.4 to 1.88% nitrogen and 7.0-8.3% carbon). In the open-grazed pastures, due to trampling by grazing animals the litter might have mixed to the soil resulting into quicker decomposition, which enriched soil organic carbon. Responsible grazing enhances the overall soil quality (Manley *et al.* 1995).

Nutrient uptake, retention and release in the present study are comparable with the reports from other parts of the Himalaya and tropical grasslands (Table 7.15). In the present study, nitrogen and phosphorus uptake was more efficient at Sachen as compared to other sites where as at Yuksam and Deorali (high grazing intensity) uptake was least. This clearly indicates that grazing intensity influence nutrient uptake. Nutrient retention was higher at Sachen, where most of the plants are ferns having greater root proportions. Nutrient release was highest at Dzongri alpine pasture mainly attributed to short growing period, short life cycle of annuals and death of aboveground parts within six months.

Livestock graze a considerable volume of biomass and in the process nutrients are also removed. However, these nutrients are again returned back to pastures through faecal matters. Nitrogen and phosphorus return to soil through faecal matters by cow, yak and dzo were considerably higher than those of horse and sheep. In most of the rangeland management consideration of nutrient return through livestock faecal matters has been neglected. There is a major impact and contribution to soil fertility from cycling back of nutrients through consumption of biomass and release through faecal matter. More emphasis should be given in considering this aspect in pasture management. The plant community types, species composition and structure, and their response to various climatic conditions are important features that regulate nutrient cycling. Therefore, more comprehensive studies that lead to understanding of nutrient cycling for livestock and pasture management in a gradient of ecological conditions as observed in Khangchendzonga Biosphere Reserve would be helpful and essential ■

Table 7.1 Nutrient concentration of aboveground biomass of some dominant plant species of grazed and exclosure plots at four elevation study sites along the Yuksam-Dzongri trail in Khangchendzonga Biosphere Reserve.

Ecological sites/species	Treatment	Nutrient concentration (%)	
		Nitrogen	Phosphorus
Temperate			
Elatostema sessile	Grazed	2.74	0.193
	Exclosure	2.76	0.221
Viola sp.	Grazed	2.98	0.298
	Exclosure	3.34	0.309
Eupatorium cannabinum	Grazed	2.51	0.227
	Exclosure	2.45	0.211
Impatiens sp.	Grazed	2.74	0.200
	Exclosure	2.93	0.201
Hydrocotyle javanica	Grazed	3.21	0.243
	Exclosure	3.41	0.292
Pilea scripta	Grazed	1.48	0.171
	Exclosure	2.09	0.200
Diplazium umbrosum	Grazed	3.11	0.303
	Exclosure	3.25	0.339
Brachiaria sp.	Grazed	2.91	0.191
	Exclosure	3.01	0.203
Silaginella sp.	Grazed	2.61	0.197
	Exclosure	2.63	0.224
Hedychium ellipticum	Grazed	2.16	0.217
	Exclosure	2.92	0.229
Composite sample	Grazed	2.61	0.222
	Exclosure	2.83	0.239
Alpine/subalpine			
Poa sp. I	Grazed	1.02	0.165

	Exclosure	1.12	0.209
Poa sp. II	Grazed	1.63	0.227
	Exclosure	1.87	0.234
Poa sp. III	Grazed	1.29	0.316
	Exclosure	1.32	0.377
Potentilla peduncularis	Grazed	1.03	0.210
	Exclosure	1.32	0.209
Aletris pauciflora	Grazed	1.03	0.163
	Exclosure	1.06	0.185
Bistorta affinis	Grazed	1.04	0.200
	Exclosure	1.12	0.201
Hemiphragma heterophyllum	Grazed	1.34	0.173
	Exclosure	1.35	0.190
Potentilla microphylla	Grazed	1.01	0.173
	Exclosure	1.21	0.212
Potentilla coriandrifolia	Grazed	1.21	0.187
	Exclosure	1.35	0.213
Juncus thomsonii	Grazed	1.23	0.202
	Exclosure	1.63	0.226
Composite sample	Grazed	1.13	0.202
	Exclosure	1.29	0.213

***ANOVA*: Nitrogen-** Species $F_{19,80}$=26.82, P<0.0001; Treatment $F_{1,80}$=7.40, P<0.01; Species × Treatment $F_{19,80}$=0.406, NS. **Phosphorus-** Species $F_{19,80}$=3.50, P<0.0001; Treatment $F_{1,80}$=3.31, NS; Species × Treatment $F_{19,80}$=0.15, NS.

Table 7.2 Nitrogen and phosphorus concentration in aboveground biomass of herbaceous plants from grazed and exclosure plots at four different elevation study sites (Yuksam = warm temperate, Sachen = cool temperate, Deorali = subalpine, and Dzongri = alpine) along the Yuksam-Dzongri trail.

Nutrient/study sites	Treatment	Nutrient concentration (%)			
		April	June	August	October
Nitrogen					
Yuksam	Grazed	1.73	2.14	2.02	1.71
	Exclosure	2.14	2.38	2.71	2.08
Sachen	Grazed	1.62	2.42	2.30	1.84
	Exclosure	1.93	2.37	2.95	2.11
Deorali	Grazed	0.93	1.12	1.06	0.78
	Exclosure	0.91	1.22	1.16	0.93
Dzongri	Grazed	0.93	1.13	1.20	0.92
	Exclosure	1.12	1.27	1.42	1.08
Phosphorus					
Yuksam	Grazed	0.178	0.216	0.231	0.163
	Exclosure	0.203	0.219	0.247	0.211
Sachen	Grazed	0.168	0.211	0.213	0.186
	Exclosure	0.193	0.233	0.231	0.184
Deorali	Grazed	0.155	0.202	0.211	0.117
	Exclosure	0.157	0.216	0.204	0.141
Dzongri	Grazed	0.143	0.173	0.193	0.113
	Exclosure	0.183	0.204	0.222	0.142

ANOVA: **Nitrogen-** Site $F_{3,64}$=47.02, P<0.0001; Month $F_{3,63}$=4.81, P<0.01; Treatment $F_{1,64}$=5.65, P<0.05; Site × Month $F_{9,64}$=0.39, NS; Site × Treatment $F_{3,64}$=1.05, NS; Month × Treatment $F_{3,64}$=0.21, NS; Site × Month × Treatment $F_{9,64}$=0.26, NS. **Phosphorus-** Site $F_{3,64}$=1.94, NS; Month $F_{3,63}$=4.82, P<0.01; Treatment $F_{1,64}$=2.23, NS; Site × Month $F_{9,64}$=0.19, NS; Site × Treatment $F_{3,64}$=0.15, NS; Month × Treatment $F_{3,64}$=0.037, NS; Site × Month × Treatment $F_{9,64}$=0.071, NS.

Table 7.3 Nitrogen and phosphorus concentration of belowground biomass of herbaceous plants in grazed and exclosure plots at four different elevation study sites (Yuksam = warm temperate, Sachen = cool temperate, Deorali = subalpine, and Dzongri = alpine) along the Yuksam-Dzongri trail.

Nutrient/study sites	Treatment	Nutrient concentration (%)			
		April	June	August	October
Nitrogen					
Yuksam	Grazed	0.81	0.85	0.87	0.77
	Exclosure	0.73	0.83	0.80	0.71
Sachen	Grazed	0.64	1.16	0.91	0.73
	Exclosure	0.73	0.88	0.82	0.63
Deorali	Grazed	0.99	1.26	1.38	0.74
	Exclosure	0.92	1.13	1.32	0.81
Dzongri	Grazed	0.92	1.32	1.50	1.07
	Exclosure	0.73	0.81	0.83	0.63
Phosphorus					
Yuksam	Grazed	0.133	0.138	0.146	0.127
	Exclosure	0.122	0.127	0.152	0.131
Sachen	Grazed	0.128	0.168	0.149	0.114
	Exclosure	0.117	0.152	0.147	0.103
Deorali	Grazed	0.112	0.138	0.160	0.108
	Exclosure	0.118	0.142	0.153	0.141
Dzongri	Grazed	0.235	0.238	0.226	0.117
	Exclosure	0.216	0.231	0.218	0.133

ANOVA**: Nitrogen**- Site $F_{3,64}$=4.46, P<0.01; Month $F_{3,63}$=8.59, P<0.0001; Treatment $F_{1,64}$=11.38, P<0.001; Site × Month $F_{9,64}$=1.41, NS; Site × Treatment $F_{3,64}$=2.78, P<0.05; Month × Treatment $F_{3,64}$=1.18, NS; Site × Month × Treatment $F_{9,64}$=0.75, NS; $LSD_{(0.05)}$=0.138. **Phosphorus**- Site $F_{3,64}$=10.86, P<0.0001; Month $F_{3,64}$=4.58, P<0.01; Treatment $F_{1,64}$=0.04, NS; Site × Month $F_{9,64}$=1.37, NS; Site × Treatment $F_{3,64}$=0.15, NS; Month × Treatment $F_{3,64}$=0.19, NS; Site × Month × Treatment $F_{9,64}$=0.06, NS.

Table 7.4 Nitrogen and phosphorus concentration of litter mass in grazed and exclosure plots at four different elevation study sites (Yuksam = warm temperate, Sachen = cool temperate, Deorali = subalpine, and Dzongri = alpine) along the Yuksam-Dzongri trail.

Nutrient/study sites	Treatment	Nutrient concentration (%)			
		April	June	August	October
Nitrogen					
Yuksam	Grazed	0.84	1.26	1.32	0.82
	Exclosure	0.87	1.13	1.26	0.78
Sachen	Grazed	0.96	1.21	1.24	0.94
	Exclosure	1.07	1.16	1.23	0.88
Deorali	Grazed	1.13	1.36	1.42	1.08
	Exclosure	1.08	1.11	1.38	0.97
Dzongri	Grazed	1.18	1.47	1.71	1.12
	Exclosure	1.21	1.22	1.68	0.94
Phosphorus					
Yuksam	Grazed	0.216	0.278	0.309	0.238
	Exclosure	0.228	0.338	0.323	0.216
Sachen	Grazed	0.261	0.286	0.300	0.213
	Exclosure	0.229	0.268	0.317	0.247
Deorali	Grazed	0.281	0.331	0.301	0.256
	Exclosure	0.284	0.316	0.309	0.231
Dzongri	Grazed	0.261	0.304	0.249	0.222
	Exclosure	0.238	0.317	0.297	0.214

ANOVA: **Nitrogen-** Site $F_{3,64}$=5.04, P<0.01; Month $F_{3,64}$=13.4, P<0.0001; Treatment $F_{1,64}$=1.02, NS; Site × Month $F_{9,64}$=0.60, NS; Site × Treatment $F_{3,64}$=0.16, NS; Month × Treatment $F_{3,64}$=0.62, NS; Site × Month × Treatment $F_{9,64}$=0.09, NS. **Phosphorus-** Site $F_{3,64}$=0.85, NS; Month $F_{3,64}$=2.84, P<0.05; Treatment $F_{1,64}$=0.012, NS; Site × Month $F_{9,64}$=0.27, NS; Site × Treatment $F_{3,64}$=0.29, NS; Month × Treatment $F_{3,64}$=0.34, NS; Site × Month × Treatment $F_{9,64}$=0.26, NS.

Table 7.5 Standing state of nitrogen in various plant components of grazed and exclosure plots at four different elevation study sites (Yuksam = warm temperate, Sachen = cool temperate, Deorali = subalpine, and Dzongri = alpine) along the Yuksam-Dzongri trail.

Study sites	Plant components	Treatment	Standing state of nitrogen (g m^{-2})			
			April	June	August	October
Yuksam	Aboveground	Grazed	3.91	6.03	6.81	3.69
		Exclosure	5.05	10.99	17.37	7.03
	Belowground	Grazed	2.55	2.86	4.18	3.10
		Exclosure	3.38	4.01	4.29	3.49
	Litter mass	Grazed	0.45	0.52	0.49	0.38
		Exclosure	0.79	0.99	1.03	0.83
Sachen	Aboveground	Grazed	3.29	7.94	11.22	3.85
		Exclosure	5.10	10.50	20.44	6.03
	Belowground	Grazed	1.96	4.91	5.40	3.09
		Exclosure	3.38	4.46	5.48	3.83
	Litter mass	Grazed	1.00	0.94	0.52	0.83
		Exclosure	1.44	1.18	0.87	0.98
Deorali	Aboveground	Grazed	1.76	3.11	3.73	1.44
		Exclosure	2.03	4.75	6.81	2.61
	Belowground	Grazed	10.32	12.07	11.70	10.83
		Exclosure	8.49	9.75	10.48	9.21
	Litter mass	Grazed	0.36	0.27	0.10	0.11
		Exclosure	0.83	0.62	0.22	0.71
Dzongri	Aboveground	Grazed	1.87	3.18	3.72	1.48
		Exclosure	2.64	5.33	7.65	2.43
	Belowground	Grazed	10.16	13.02	13.91	10.63
		Exclosure	5.25	7.35	7.01	5.77
	Litter mass	Grazed	0.33	0.25	0.12	0.15
		Exclosure	1.04	0.74	0.34	0.76

Table 7.6 Standing state of phosphorus in various plant components in grazed and exclosure plots at four different elevation study sites (Yuksam = warm temperate, Sachen = cool temperate, Deorali = subalpine, and Dzongri = alpine) along the Yuksam-Dzongri trail.

Study sites	Plant components	Treatment	Standing state of phosphorus (g m^{-2})			
			April	June	August	October
Yuksam	Aboveground	Grazed	0.402	0.609	0.778	0.352
		Exclosure	0.512	1.012	1.583	0.713
	Belowground	Grazed	0.419	0.465	0.702	0.511
		Exclosure	0.565	0.613	0.815	0.645
	Litter mass	Grazed	0.085	0.110	0.110	0.110
		Exclosure	0.207	0.300	0.260	0.230
Sachen	Aboveground	Grazed	0.341	0.692	1.039	0.389
		Exclosure	0.510	1.032	1.600	0.526
	Belowground	Grazed	0.393	0.711	0.878	0.482
		Exclosure	0.542	0.771	0.982	0.545
	Litter mass	Grazed	0.270	0.220	0.130	0.190
		Exclosure	0.310	0.270	0.230	0.270
Deorali	Aboveground	Grazed	0.293	0.562	0.743	0.215
		Exclosure	0.350	0.840	1.197	0.396
	Belowground	Grazed	1.230	1.322	1.357	1.198
		Exclosure	1.089	1.225	1.215	1.128
	Litter mass	Grazed	0.090	0.070	0.020	0.040
		Exclosure	0.220	0.180	0.050	0.170
Dzongri	Aboveground	Grazed	0.287	0.451	0.598	0.182
		Exclosure	0.432	0.857	1.197	0.320
	Belowground	Grazed	2.594	2.367	2.095	2.762
		Exclosure	2.145	2.095	1.842	2.218
	Litter mass	Grazed	0.070	0.052	0.017	0.029
		Exclosure	0.200	0.193	0.059	0.173

Table 7.7 Nitrogen concentration and content of soil in grazed and exclosure plots at four different elevation study sites (Yuksam = warm temperate, Sachen = cool temperate, Deorali = subalpine, and Dzongri = alpine) along the Yuksam-Dzongri trail.

Nutrient/study sites	Soil depth (cm)	1998		1999	
		Gr	Ex	Gr	Ex
Concentration (%)					
Yuksam	0-15	0.481	0.400	0.488	0.461
	15-30	0.413	0.330	0.431	0.386
Sachen	0-15	0.530	0.464	0.547	0.417
	15-30	0.443	0.461	0.492	0.407
Deorali	0-15	0.551	0.523	0.511	0.539
	15-30	0.511	0.490	0.491	0.498
Dzongri	0-15	0.406	0.399	0.477	0.398
	15-30	0.310	0.361	0.330	0.403
Content (g m^{-2})					
Yuksam	0-15	417.0	346.9	423.4	399.8
	15-30	396.0	291.7	380.8	341.0
Sachen	0-15	567.3	496.5	585.6	446.5
	15-30	465.4	484.7	482.0	428.1
Deorali	0-15	561.0	531.6	519.6	548.4
	15-30	541.4	519.2	520.3	527.9
Dzongri	0-15	489.6	480.6	575.1	479.1
	15-30	463.4	539.3	492.9	601.8

Gr = grazed, Ex = exclosure. ***ANOVA*:** Site $F_{3,62}$=31, P<0.0001; Soil depth $F_{1,62}$=69, P<0.0001; Treatment $F_{1,62}$=70, P<0.0001; Year $F_{1,62}$=0.021, NS; Site × Soil depth $F_{3,62}$=5.15, P<0.001; Site × Treatment $F_{3,62}$=7.6, P<0.0001; Site × Year $F_{3,62}$=6.19, P<0.0001; Soil depth × Treatment $F_{1,62}$=10.5, P<0.05; Soil depth × Year $F_{1,62}$=5.32, P<0.05; Treatment × Year $F_{1,62}$=1.14, NS; Site × Soil depth × Treatment $F_{3,62}$=2.12, NS; Site × Soil depth × Year $F_{3,62}$=9.8, P<0.0001; Site × Treatment × Year $F_{3,62}$=9.33, P<0.0001; Soil depth × Treatment × Year $F_{1,62}$=0.057, NS; Site × Soil depth × Treatment × Year $F_{3,62}$=6.2, P<0.0001; $LSD_{(0.05)}$=0.152.

Table 7.8 Total phosphorus concentration and content of soil in grazed and exclosure plots at four different elevation study sites (Yuksam = warm temperate, Sachen = cool temperate, Deorali = subalpine, and Dzongri = alpine) along the Yuksam-Dzongri trail.

Nutrient/study sites	Soil depth (cm)	1998		1999	
		Gr	Ex	Gr	Ex
Concentration (%)					
Yuksam	0-15	0.029	0.019	0.031	0.028
	15-30	0.019	0.026	0.029	0.030
Sachen	0-15	0.018	0.013	0.028	0.020
	15-30	0.016	0.013	0.027	0.022
Deorali	0-15	0.030	0.020	0.036	0.023
	15-30	0.028	0.018	0.036	0.021
Dzongri	0-15	0.019	0.009	0.026	0.012
	15-30	0.007	0.024	0.018	0.011
Content ($g\ m^{-2}$)					
Yuksam	0-15	25.14	16.46	26.90	24.30
	15-30	16.81	22.99	25.63	26.54
Sachen	0-15	19.28	13.91	29.95	21.41
	15-30	16.82	13.67	28.38	23.13
Deorali	0-15	30.54	20.34	36.60	23.40
	15-30	29.67	19.10	38.14	22.25
Dzongri	0-15	22.92	10.86	31.32	14.43
	15-30	35.87	10.47	26.92	16.65

Gr = grazed, Ex = exclosure. ***ANOVA*:** Site $F_{3,62}$=2.29, NS; Soil depth $F_{1,62}$=4.26, P<0.05; Treatment $F_{1,62}$=2.61, NS; Year $F_{1,62}$=2.79, NS; Site × Soil depth $F_{3,62}$=0.69, NS; Site × Treatment $F_{3,62}$=0.201, NS; Site × Year $F_{3,62}$=1.67, NS; Soil depth × Treatment $F_{1,62}$=1.48, NS; Soil depth × Year $F_{1,62}$=0.097, NS; Treatment × Year $F_{1,62}$=0.312, NS; Site × Soil depth × Treatment $F_{3,62}$=0.821, NS; Site × Soil depth × Year $F_{3,62}$=0.72, NS; Site × Treatment × Year $F_{3,62}$=1.42, NS; Soil depth × Treatment × Year $F_{1,62}$=0.05, NS; Site × Soil depth × Treatment × Year $F_{3,62}$=2.17, NS.

Table 7.9 Organic carbon concentration and content of soil in grazed and exclosure plots at four different elevation study sites (Yuksam = warm temperate, Sachen = cool temperate, Deorali = subalpine, and Dzongri = alpine) along the Yuksam-Dzongri trail.

Nutrient/study sites	Soil depth (cm)	1998		1999	
		Grazed	Exclosure	Grazed	Exclosure
Concentration (%)					
Yuksam	0-15	4.59	5.56	5.61	5.02
	15-30	3.46	5.24	5.01	3.78
Sachen	0-15	5.03	4.82	4.99	5.23
	15-30	3.82	4.53	4.42	3.73
Deorali	0-15	5.71	5.86	5.63	5.89
	15-30	5.27	4.81	4.24	5.32
Dzongri	0-15	4.12	4.46	4.62	4.23
	15-30	3.81	4.66	4.13	3.66
Content (g m^{-2})					
Yuksam	0-15	4822	3981	4866	4354
	15-30	4631	3058	4427	3341
Sachen	0-15	5160	5385	5342	5599
	15-30	4762	4016	4226	3921
Deorali	0-15	5960	5807	5726	5990
	15-30	5130	5586	4494	5639
Dzongri	0-15	5375	4965	5568	5099
	15-30	6961	5689	6319	5467

***ANOVA*:** Site $F_{3,62}$=87, P<0.0001; Soil depth $F_{1,62}$=231, P<0.0001; Treatment $F_{1,62}$=22.8, P<0.0001; Year $F_{1,62}$=0.183, NS; Site × Soil depth $F_{3,62}$=31, P<0.0001; Site × Treatment $F_{3,62}$=42, P<0.0001; Site × Year $F_{3,62}$=2.09, NS; Soil depth × Treatment $F_{1,62}$=14.6, P<0.0001; Soil depth × Year $F_{1,62}$=25.7, P<0.0001; Treatment × Year $F_{1,62}$=1.71, NS; Site × Soil depth × Treatment $F_{3,62}$=43, P<0.0001; Site × Soil depth × Year $F_{3,62}$=4.87, P<0.001; Site × Treatment × Year $F_{3,62}$=3.9, P<0.05; Soil depth × Treatment × Year $F_{1,62}$=26, P<0.0001; Site × Soil depth × Treatment × Year $F_{3,62}$=7.99, P<0.0001; $LSD_{(0.05)}$=0.152.

Table 7.10 Ratio between organic carbon and nitrogen (C/N) and between nitrogen and phosphorus (N/P) of soils in grazed and exclosure plots at four different elevation study sites (Yuksam = warm temperate, Sachen = cool temperate, Deorali = subalpine, and Dzongri = alpine) along the Yuksam-Dzongri trail.

Ratio/study sites	Soil depth (cm)	1998		1999	
		Grazed	Exclosure	Grazed	Exclosure
C/N					
Yuksam	0-15	11.56	11.48	11.50	10.89
	15-30	12.69	10.48	11.62	9.79
Sachen	0-15	9.09	10.84	9.12	11.56
	15-30	10.23	8.29	8.98	9.16
Deorali	0-15	10.64	10.92	11.02	10.93
	15-30	9.41	10.76	8.64	10.68
Dzongri	0-15	10.99	10.33	9.69	10.63
	15-30	15.03	10.55	12.52	9.08
N/P					
Yuksam	0-15	16.59	21.05	15.74	16.46
	15-30	21.74	12.69	14.86	12.87
Sachen	0-15	29.44	35.69	19.54	20.85
	15-30	27.69	35.46	18.22	18.50
Deorali	0-15	18.37	26.15	14.19	23.43
	15-30	18.25	28.39	13.64	23.71
Dzongri	0-15	21.37	44.33	18.35	33.17
	15-30	12.92	51.57	18.33	36.64

Table 7.11 Chemical concentration of faecal materials for different livestock grazing animals. Analysis has been done on dry weight samples.

Animal types	Concentration (%)		
	Nitrogen	Phosphorus	Organic carbon
Yak	1.87	0.42	7.00
Dzo	1.89	0.49	6.72
Cow	1.63	0.50	7.78
Horse	1.40	0.20	8.35
Sheep	1.41	0.37	7.23

***ANOVA*: Nitrogen-** Animal type $F_{4,10}$=17.01, P<0.0001, $LDS_{(0.05)}$=0.140; **Phosphorus-** Animal type $F_{4,10}$=16.74, P<0.0001, $LDS_{(0.05)}$=0.078; **Organic carbon-** Animal type $F_{4,10}$=5.62, P<0.05, $LDS_{(0.05)}$=0.668.

Table 7.12 Annual uptake and loss of nitrogen (g m^{-2} yr^{-1}) at four different elevation study sites (Yuksam = warm temperate, Sachen = cool temperate, Deorali = subalpine, and Dzongri = alpine) along the Yuksam-Dzongri trail.

Study sites	Treatment	Soil (g m^{-2} upto 30 cm)	Net uptake				Shoot to litter	Loss from litter	Loss from root	Total loss	Removed by grazing
			Shoot	Root	Litter	Total					
Yuksam	Grazed	1318	2.90	1.63	0.07	4.60	3.12	0.14	1.08	1.22	9.42
	Exclosure	937	12.32	0.91	0.24	13.47	10.34	0.20	0.80	1.00	
Sachen	Grazed	1229	7.93	3.44	0.31	11.68	7.37	0.48	2.31	2.79	7.41
	Exclosure	926	15.34	2.10	0.11	17.55	14.41	0.31	1.65	1.96	
Deorali	Grazed	978	1.97	1.75	0.01	3.73	2.29	0.26	1.24	1.50	2.81
	Exclosure	833	4.78	1.99	0.49	7.26	4.20	0.61	1.27	1.88	
Dzongri	Grazed	1325	2.24	3.75	0.21	6.20	2.24	0.21	3.28	3.49	3.16
	Exclosure	937	5.01	2.10	0.42	7.53	5.22	0.70	1.58	2.28	

Table 7.13 Annual uptake and loss of phosphorus (g m^{-2} yr^{-1}) at four different elevation study sites (Yuksam = warm temperate, Sachen = cool temperate, Deorali = subalpine, and Dzongri = alpine) along the Yuksam-Dzongri trail.

Study sites	Treatment	Soil (g m^{-2} upto 30 cm)	Net uptake				Shoot to litter	Loss from litter	Loss from root	Total loss	Removed by grazing
			Shoot	Root	Litter	Total					
Yuksam	Grazed	1318	0.376	0.283	0.025	0.684	0.426	-	0.191	0.191	0.695
	Exclosure	937	1.062	0.250	0.093	1.405	0.870	0.070	0.170	0.240	
Sachen	Grazed	1229	0.698	0.485	0.060	1.243	0.650	0.140	0.396	0.536	0.392
	Exclosure	926	1.090	0.400	0.040	1.530	1.074	0.080	0.437	0.517	
Deorali	Grazed	978	0.450	0.127	0.020	0.547	0.597	0.070	0.159	0.089	0.397
	Exclosure	833	0.847	0.136	0.120	1.103	0.801	0.170	0.087	0.257	
Dzongri	Grazed	1325	0.311	0.667	0.012	0.990	0.416	0.053	0.499	0.552	0.454
	Exclosure	937	0.765	0.376	0.114	1.255	0.877	0.141	0.303	0.444	

Table 7.14 Annual balance sheet of nitrogen and phosphorus (g m^{-2} yr^{-1}) from four different elevations study sites (Yuksam = warm temperate, Sachen = cool temperate, Deorali = subalpine, and Dzongri = alpine) along the Yuksam-Dzongri trail.

Study sites	Treatment	Nutrient	Soil (g m^{-2}) upto 30 cm	Uptake	Retention		Release	
				(g m^{-2})	(g m^{-2})	(%)	(g m^{-2})	(%)
Yuksam	Grazed	Nitrogen	1318	4.530	3.310	73.07	1.220	26.93
		Phosphorus	30	0.659	0.469	71.17	0.190	28.83
	Exclosure	Nitrogen	937	13.230	12.230	92.44	1.000	7.56
		Phosphorus	56	1.312	1.072	81.71	0.240	18.29
Sachen	Grazed	Nitrogen	1229	11.370	8.580	75.46	2.790	24.54
		Phosphorus	60	1.183	0.647	54.69	0.530	45.31
	Exclosure	Nitrogen	926	17.440	15.480	88.76	1.960	11.24
		Phosphorus	50	1.490	0.973	65.30	0.517	34.70
Deorali	Grazed	Nitrogen	978	3.720	2.220	59.67	1.500	40.33
		Phosphorus	20	0.577	0.488	84.58	0.089	15.42
	Exclosure	Nitrogen	833	6.770	4.890	72.23	1.880	27.77
		Phosphorus	33	0.983	0.726	73.86	0.257	26.14
Dzongri	Grazed	Nitrogen	1325	5.990	2.500	41.74	3.490	58.26
		Phosphorus	30	0.978	0.426	43.56	0.552	56.44
	Exclosure	Nitrogen	937	7.110	4.830	67.93	2.280	32.07
		Phosphorus	19	1.141	0.697	61.09	0.444	38.91

Table 7.15 Comparison of annual uptake, retention and release of nutrients of the present study and its comparison with different ecosystems of India.

Vegetation types	Nutrient parameters	Nutrients (kg ha^{-1})	
		Nitrogen	Phosphorus
Sehima grassland (Ratlam)[1]	Uptake	58	16
	Retained	29	9
	Release	29	7
Tropical grassland (Jhansi)[2]	Uptake	83	10
	Retained	36	2
	Release	47	8
Alpine grassland (Garhwal Himalaya)[3]	Uptake	41-89	18-42
	Retained	28-71	11-29
	Release	13-18	7-13
Present investigation			
(Yuksam-warm temperate forbs dominated)	Uptake	54-132	7-13
	Retained	33-122	5-11
	Release	12-10	1.9-2.4
(Sachen-cool temperate ferns dominated)	Uptake	114-174	12-15
	Retained	86-155	6-10
	Release	20-28	5.2-5.3
(Deorali-subalpine grassland)	Uptake	37-68	6-10
	Retained	22-49	5-7
	Release	15-19	0.9-2.6
(Dzongri-alpine grassland)	Uptake	60-71	10-11
	Retained	25-48	4-7
	Release	23-35	4.5-5.5

Billore and Mall (1976)[1]; Trivedi and Misra (1983)[2]; Sundriyal (1986)[3]

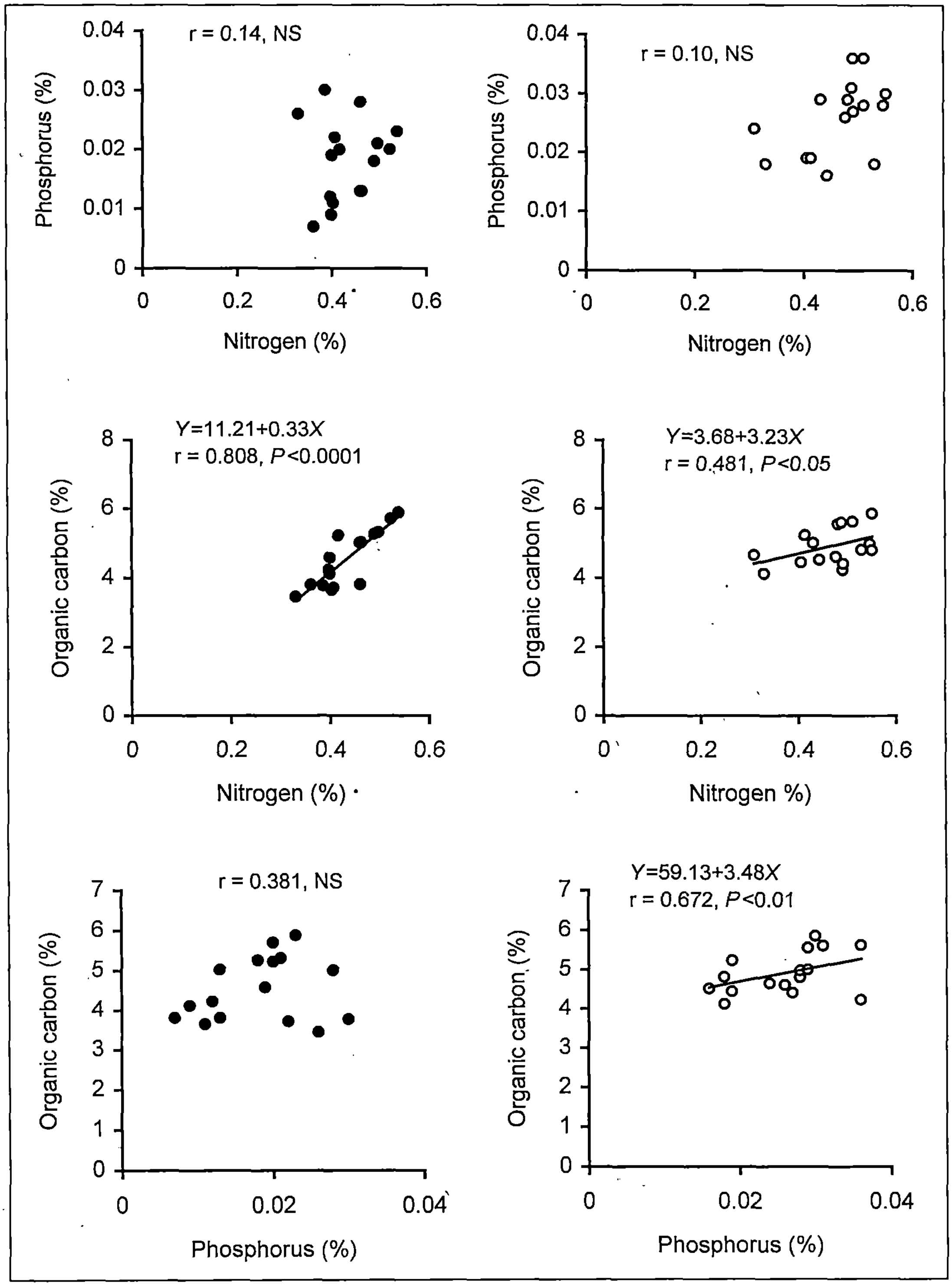

Fig. 7.1 Correlation between nitrogen and phosphorus, nitrogen and organic carbon and between phosphorus and organic carbon concentration of soils in livestock grazing exclosure (dark circle) and grazed (empty circle) plots at pastures of different elevations along the Yuksam-Dzongri trail.

CHAPTER VIII

STOCKING RATE, CARRYING CAPACITY AND LIVESTOCK MANAGEMENT

8.1 INTRODUCTION

Indian Himalayan pastures are beyond the carrying capacity because they are stocked more than double the actual number of animals it can fed (Gupta 1986). This pressure has lead to the deterioration of vegetation in terms of quality and quantity, and accelerated soil erosion that aggravated the degradation of the habitat and loss in soil fertility.

Grazing carrying capacity can be defined as the grazing ability of a pasture land which can support adequately to a constant number of grazing animals for a definite period every year, without deteriorating the same land in respect to grazing value or other proper land uses and expressed in number of livestock per appropriate unit area (Sundriyal 1989a; Gupta 1990). In the Himalaya, cattle are mainly dependent on forests and pastures for their fodder requirement. If the forage removal is more than the net primary production, the vegetation of the area will be lost in one way or the other in course of time. Forage removal beyond the carrying capacity severely effects herbage compensation and non-palatable species proliferates in such areas. Proliferation of non-palatable species will definitely reduce the grazing carrying capacity and pasture quality. The importance of establishing an ecologically sound grazing regime with proper stocking rate is obvious for sustainable and ecologically sound management of pasture (Gupta 1986). Generally, there are more animals grazing on these lands than they can carry. Due to ill effect of overgrazing, these ecosystems display the sign of deterioration and disruption on herbage compensation process. There is a need to manage these grasslands for maintaining balance between sustained animal production and the plant productivity by the application of ecological principles. Attention has now rightly been drawn towards scientific management of grasslands by maintaining the grazing ability.

In the Yuksam-Dzongri trekking corridor, due to increased number of tourist trekkers in the recent years, the livestock enterprise (mainly pack animals) has become a potential and expanding income-generating sector. This has necessitated the study on livestock production, economy and environmental linkages. Estimation of grazing carrying capacity is very essential for sustainable management of the trekking corridor in the Khangchendzonga Biosphere Reserve. Current stocking rate and its comparison with the carrying capacity are needed for development of strategies of sustainable management. The present chapter deals with the estimation of livestock stocking rate and grazing carrying capacity of different pastures at different ecological zones along the Yuksam-Dzongri trail in the Khangchendzonga Biosphere Reserve.

8.2 METHODS

The four ecological pastures (warm temperate, cool temperate, subalpine and alpine) as described earlier were considered for the estimation of livestock stocking rate and grazing carrying capacity. Foraging characteristics of different grazing livestock have been studied and presented in Chapter IV. The conversion of cow equivalent unit (CEU) for different livestock were calculated based on daily forage consumption rate. Stocking rate was calculated as the number of livestock per unit area.

$$\text{Stocking rate} = \frac{\text{Livestock number (CEU)}}{\text{Total area (ha)}}$$

The livestock grazing carrying capacity was estimated by the formula given by Brown (1954).

$$\text{Carrying capacity} = \frac{\text{Total forage production (ha}^{-1}\text{)} \times \text{Forage use factor}}{\text{Forage demand}}$$

Forage demand is the dry forage consumption per animal per year. Forage use factor was calculated as the ratio between aboveground forage removal by grazing to the aboveground net biomass in exclosure plots per unit area basis.

8.3 RESULTS

8.3.1 Current Stocking Rate

All the livestock grazing animals have been converted into cow equivalent units based on the forage consumption by each animal types and differed between temperate and alpine/subalpine sites (Table 8.1). At temperate pasture, one dzo is equivalent to 1.14 cow, one horse to 1.03 cow, one sheep to 0.37 cow and one goat to 0.38 cow, whereas in alpine and subalpine pastures, one dzo is equivalent to 1.14 cow, one yak to 0.92 cow, one horse to 1.01 cow and one sheep to 0.33 cow (Table 8.1).

Different livestocks have separate time period of grazing at various pastures. At Yuksam (warm temperate), 454 cows grazed for the whole year, 22 horse for 140 days, 461 sheep for 255 days, 122 dzos for 180 days and 311 goats grazed for the whole year. At Sachen (cool temperate), 45 cows, 7 horse and 23 dzos grazed for three months only

(Sachen is the winter resident area for Tshoka villagers when Tshoka village gets covered with snow during mid-December to mid-February). At Deorali (subalpine), 38 cows grazed for 20 days, 25 yaks for 80 days, 13 horses for 13 days and 60 dzos for 13 days. At Dzongri (alpine), 38 cows grazed for 90 days, 78 yaks for 285 days, 13 horses for 100 days, 461 sheep for 110 days and 122 dzos for 160 days (Table 8.2).

The animals were converted into cow equivalent units (cow) and estimated as 904 cows at Yuksam, 78 cows at Sachen, 143 cows at Deorali and 334 cows at Dzongri (Table 8.2). Current annual stocking rates were calculated for different pastures and recorded 1.29 cow ha^{-1} for Yuksam, 0.49 cow ha^{-1} for Sachen, 1.02 cow ha^{-1} for Deorali and 0.56 cow ha^{-1} for Dzongri (Table 8.2).

8.3.2 Grazing Carrying Capacity

Based on the aboveground net biomass productivity, animal forage demand and forage use factor, livestock grazing carrying capacity in terms of cow equivalent unit (cow) has been calculated for different pastures along the Yuksam-Dzongri trail and presented in Table 8.2. Forage used factor has been regarded as 50% of the aboveground biomass, this value is based on present study findings given in details in the biomass chapter. Out of the four different pastures studied, Yuksam pasture has the highest carrying capacity of 1.34 cow ha^{-1} $year^{-1}$, followed by Sachen (1.18 cow ha^{-1} $year^{-1}$), Deorali (0.96 cow ha^{-1} $year^{-1}$) and least at the Dzongri alpine pasture with 0.86 cow ha^{-1} $year^{-1}$ (Table 8.2). The potential carrying capacity of pastures based on 60% herbage utilization has been estimated and recorded 1.61 cow ha^{-1} for Yuksam, 1.42 cow ha^{-1} for Sachen, 1.15 cow ha^{-1} for Deorali and 1.03 cow ha^{-1} for Dzongri (Fig. 8.1).

8.4 DISCUSSION

Pasture area conducive for grazing is highest at Yuksam followed by Dzongri, Sachen and Deorali. The pasture at Sachen is mainly used by Tshoka villagers in winter and also by pack animals during brief halting on the trek. Yuksam and Dzongri are more of settled pastures for longer period of grazing. Yuksam being populated settlement area faces highest annual stocking rate, while Dzongri being the remotest place only the summer grazing and pack animal grazing during tourist season reasonably makes the lower stocking rate. At Yuksam, the annual stocking rate is marginally smaller than carrying capacity, which clearly indicates that pastures have reached the limit where more scientific management is required. At Sachen, animal stocking is well below carrying capacity. The Dzongri pasture is also within the limits. The subalpine transition zone at Deorali pasture is more critical and fragile that has crossed the carrying capacity limit. This is a serious concern and a definite grazing regime for grazing livestock and regulation of pack animal halting has to be established for this pasture. Visible symptoms of site deterioration are already conspicuous at Deorali.

The carrying capacity of 1.34 cow ha^{-1} at warm temperate (Yuksam), 1.18 cow ha^{-1} at cool temperate (Sachen), 0.96 cow ha^{-1} at subalpine (Deorali) and 0.86 cow ha^{-1} at alpine (Dzongri) pasture is comparable with the reports from Garhwal Himalaya (Gupta 1986) as they have reported 1.09 cow ha^{-1} for warm temperate, 0.91 to 3.49 cow ha^{-1} for cool temperate, 0.89 to 1.80 cow ha^{-1} for subalpine and 0.65 to 1.81 cow ha^{-1} for alpine. Grazing by different types of animals on the same range to obtain more efficient use is referred to as common use. It is well recognised that forage species selection varies considerably among different animal species on the same range. The species grazed by all types of animals in the same range is termed as dietary overlap. Controversy exists over how grazing capacity should be evaluated when common use is involved. Scarnecchia (1985, 1986) argues that grazing capacity should be based on animal-related factors because dietary overlaps between different animal species vary with terrain, season of use, grazing system, stocking rate, and year-to-year weather fluctuations that affect forage production and species composition. Hobbs and Carpenter (1986) advocate that animal unit equivalents should be weighed relative to degree of dietary overlap. They based their argument on the fact that different herbivores have different impact on the range due to their consumption of different forage. In the shortgrass prairie of eastern Colorado, 335 kg ha^{-1} will give maximum economic returns and maintain forage production (Bement 1969). On the South-Eastern Oregon big sagebrush ranges, grass residues for 180 kg ha^{-1} will maintain or improve range condition on most sites (Hyder 1953). In the California annual grassland type, from 300-1200 kg ha^{-1} of maximum residue is needed depending on the site (Hooper & Heady 1970). In the present study sites, the forage residue needed to be left for good rangeland condition are recorded as 1130-3370 kg ha^{-1} for warm temperate (Yuksam pasture), 1010-4880 kg ha^{-1} for cool temperate (Sachen pasture), 1260-3520 kg ha^{-1} for subalpine (Deorali pasture) and 134-3100 kg ha^{-1} for alpine pasture (Dzongri pasture).

Carrying capacity is one of the indicators of the productivity of pasture and is not the determining factor. The pasture with a high carrying capacity for one species of livestock in one situation can have a very low carrying capacity for another species of livestock in a different situation. For example, a pasture with a high carrying capacity in the tropical and sub-tropical zones will have 'zero value' for yaks, as they cannot graze on it. Similarly, sheep or goats because of their ability to graze on bushes and weeds could very efficiently utilise a pasture of low carrying capacity. Grazing carrying capacity is regarded as 50% aboveground biomass utilisation as upper limit from the findings of the present study. Because of concentrate grazing near campsites, trail and near livestock sheds more prominently at Dzongri and Deorali, there has been an observable sign of vegetation loss, soil erosion and habitat degradation. This has deteriorated the site appearance conducive for tourism. Therefore, grazing in the vicinity of the campsites and sheds has to be minimized. Concentration of large number of pack animals during the same period should be avoided. Pack-animal number and movement should be regulated at the entry point. The major settlement area of Yuksam and its surrounding pasture has reached the carrying capacity limit. Collection of fodder, fuelwood, timber and other non-timber forest products might be another factor for vegetation deterioration. Another site that is the Deorali pasture has crossed the limit. Therefore, a grazing regime has to be established at these two sites. Yuksam being a settlement area should concentrate on raising of more valuable fodder in agroforestry itself rather than free grazing. There is a lot of potential for strengthening the agroforestry and meeting the fodder demands at Yuksam. However, at Deorali the strategy has to be on establishing of grazing regime especially by working with the owners of pack animals and other livestock. If the pack animal related range management is done at Deorali the problem could be considerably solved.

The area has high potential for livestock related livelihood. The livestock types and range of pastures from the warm temperate to cool temperate, subalpine and alpine provide a situation of great potential for development. The livestock products have established market and pack animals already draw large proportion of income for local community. The area receives high rainfall and conducive relative humidity stimulates and promotes growth of vegetation. The concern is mainly on the management of the rangelands, which more or less have not received any scientific input until now. A concerted effort by the biosphere reserve managers involving the livestock graziers and owners has to be made on the scientific management of rangelands in an urgent basis. Linkages between livestock grazing, rangeland and tourism related activities and management options are shown in Fig.8.2. ■

Table 8.1 Conversion of different animal groups in terms of cow equivalent unit (CEU) at different pastures along the Yuksam-Dzongri trail.

Animal Type	Cow equivalent unit	
	Temperate	Alpine/subalpine
Dzo	1.14	1.14
Yak	-	0.92
Horse	1.03	1.01
Sheep	0.37	0.33
Goat	0.38	-

Table 8.2 Pasture area, livestock numbers, grazing days, stocking rate and grazing carrying capacity at different pastures along the Yuksam-Dzongri trail.

Parameters	Name of the pastures			
	Yuksam	Sachen	Deorali	Dzongri
Pasture area (ha)	800	200	200	1360
Area conducive for grazing (ha)	700	160	140	600
Livestock number				
Cow	454	45	38	38
Yak	-	-	25	78
Horse	22	7	13	13
Sheep	461	-	-	461
Dzo	122	23	60	122
Goat	311	-	-	-
Duration of grazing (days $year^{-1}$)				
Cow	365	90	20	90
Yak	-	-	80	285
Horse	140	90	13	100
Sheep	255	-	-	110
Dzo	180	90	13	160
Goat	365	-	-	-
Total cow equivalent unit	904	78	143	334
Annual stocking rate (Cow ha^{-1})	1.29	0.49	1.02	0.56
Carrying capacity (Cow ha^{-1} $year^{-1}$)	1.34	1.18	0.96	0.86

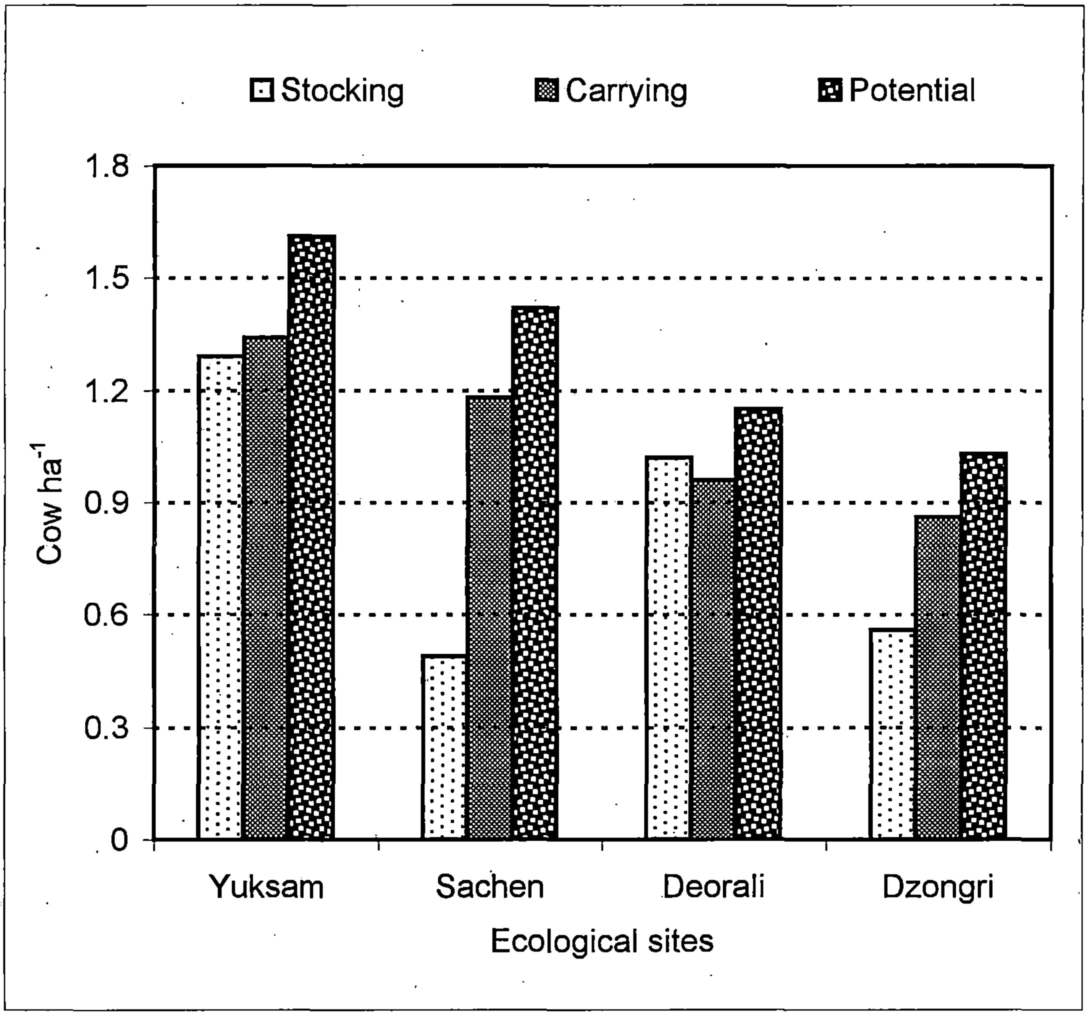

Fig. 8.1 Current stocking rate of livestock, carrying capacity and potential carrying capacity of pastures at different ecological sites (Yuksam at 1700 m-warm temperate, Sachen at 2100 m- cool temperate, Deorali at 3800 m-subalpine/near timberline and Dzongri at 3900 m-alpine zone) along the Yuksam-Dzongri trail in Khangchendzonga Biosphere Reserve of Sikkim Himalaya.

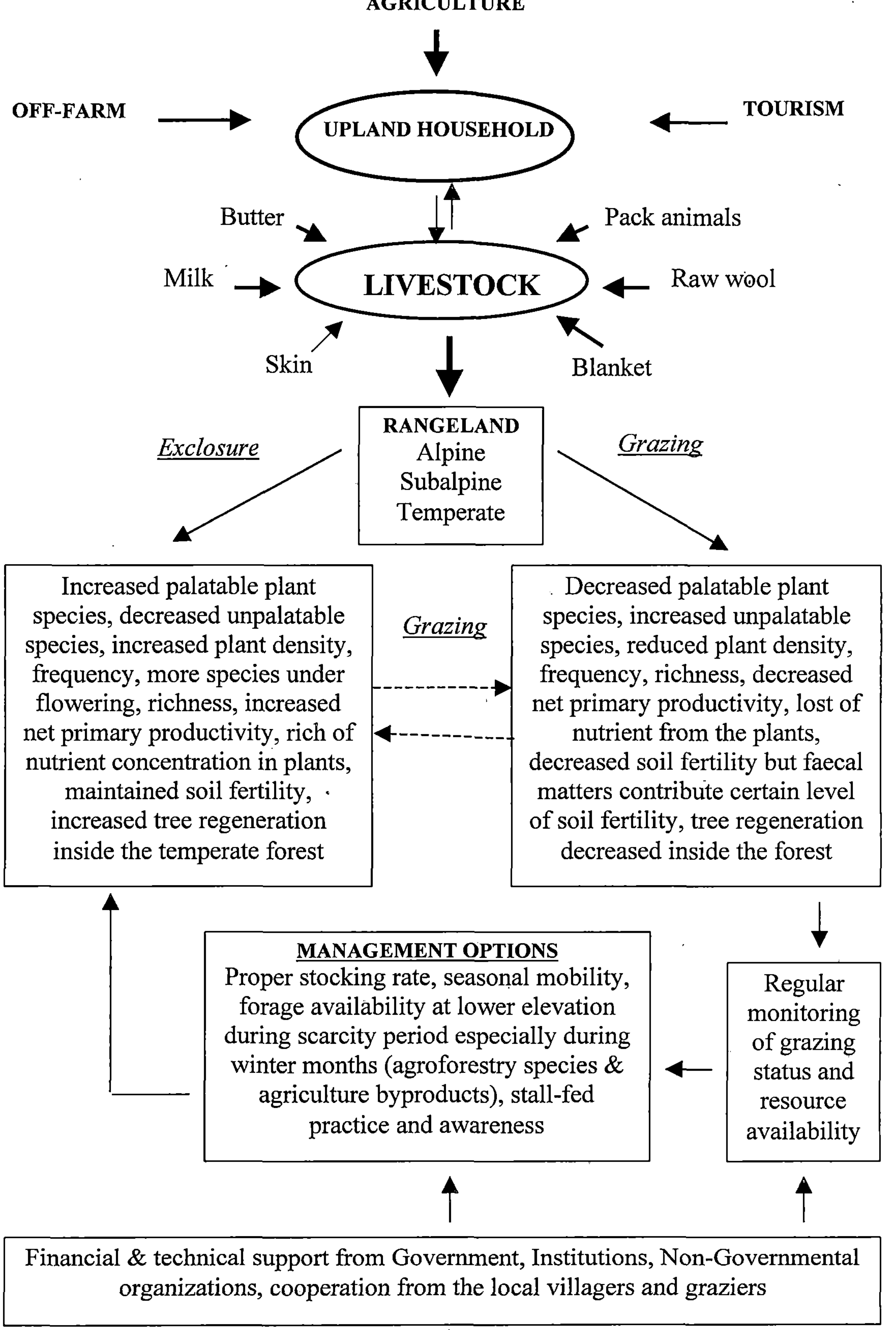

Fig. 8.2 Linkages between livestock grazing and rangeland and its management options in the Khangchendzonga Biosphere Reserve

CHAPTER IX

GENERAL DISCUSSION AND RECOMMENDATIONS

The present study deals with structural and functional aspects of vegetation, soil properties and nutrient dynamics as a response to livestock grazing along the Yuksam-Dzongri trekking corridor in the Khangchendzonga Biosphere Reserve of the Sikkim Himalaya. Assessment of plant resources, exploitation and their linkage with human induced pressure is important for understanding the ecosystem resilience. The study area covers four major ecological zones (warm temperate, cool temperate, subalpine and alpine) that extends between 1600 m to 4200 m altitude in the buffer zone. This trekking corridor is a representative of climatic zones, vegetation types and landscapes in the Khangchendzonga Biosphere Reserve and the region. Around 2000 tourists (national and international) trek in this corridor every year. Besides, Himalayan Mountaineering Institute (Darjeeling, West Bengal) conducts training programs for about one thousand trainees every year. Around 145 dzos and 22 horses are used as pack animals for trekking and mountaineering.

Animal migration to alpine meadows (Dzongri) during the summer months is a common strategy adopted by locals for getting sufficient forage as is also reported from other parts of the Himalaya (Ram 1986; Farooquee 1996). There are five types of animals viz. cattle, dzo, yak, horse and sheep that graze in alpine pastures while goats graze inside the lower forest throughout the year. Yaks never come down to lower elevations for their climatic non-tolerance. During snowfall yaks concentrate near the timberline and browse rhododendrons and other bushes. In Yuksam village, 454 cows, 22 horses, 461 sheep, 122 dzos and 311 goats have been recorded and most use surrounding forests for grazing. Therefore, livestock grazing pattern and seasonal mobility draws special interest for assessing the impacts on the fodder resources for sustainable management. Concept of ecotourism is becoming more popular and more tourists are attracted for nature trail where involvement of livestock is gaining ground consequently providing higher economic returns. Sikkim has become one of the most important ecotourism destinations in the country and also in the Himalayan region, and is visited by about one hundred fifty thousand tourists every year. The State Government has tourism as priority sector and a master plan for 20 years has been already drawn. Newer routes are opened to diffuse the concentration of visitors in a few sites. Yuksam-Dzongri trail is the most popular trekking area opened since early 1960s and is also used for training youths on mountaineering. About 167 pack animals operate in this trail throughout the year for tourism and mountaineering. Other livestock have indirect linkage with tourism.

In the Yuksam-Dzongri trail, Rs 11,14,600/- was generated from grazing livestock in 1997 and Rs 10,07000/- during 1998. The reduction of about 10% income from livestock in 1998 was mainly because of less tourist arrivals resulting from road disruption due to landslides. Around 60% of the income from livestock was contributed by pack animals. In this trekking corridor livestock forms an integral part of sustenance especially linked with tourism. Since substantial amount of economic benefits come from tourism through livestock the communities are encouraged in livestock rearing. However, the rangeland management and fodder development were not considered until the current study was taken up. Services of pack animals can only be provided for tourism in longer term if the trail, camping ground and rangeland management is scientifically done.

Livestock population has increased by 66% in a period of five years (1987 to 1992) in Sikkim State, the reasons being family fragmentation and very nature of each family rearing some livestock. In the case of Yuksam village it increased by 15% from 1996 to 1998. The increase in the livestock population caused more dependence on forest for fodder, however about 20% came from the agroforestry species. The fodder species are preserved as 'forage bank' for utilization during the scarcity period (Photoplate 6). *Ficus* species are most preferable as agroforestry species because they are highly palatable and also gave high production. *Ficus* trees are commonly grown in agroforestry. Large cardamom and ginger are cash crops that generate most of the cash benefits to the local people, however the importance of livestock is not less. The livestock rearing is taken up by locals for easy accessibility to forest/pastures for forage and constriction of agriculture land holding. Livestock in the upland farming apart from direct economic benefits also provides energy force for ploughing and manure for soil fertility.

The rangelands in the trekking corridor of Yuksam-Dzongri have elevation range from 1600-4200 m. Woody structure decrease with increasing elevation while forbs increase. As the elevation further increases, cushion and spreading forbs become dominant. This is a general observation made by many workers all over the world and rightly so in the present studies. Such a change is observed as plant responds by adapting to harsh climatic conditions. A lack of trees, and the low stature of vegetation in the alpine region have been ascribed to winter desiccation and ice abrasion and to a low carbon gain which is inadequate to build and maintain large woody support structures (Billings and Mooney 1968; Tranquillini 1979). The temperate zone is having more arboreal structure compared to Raunkier's normal spectrum and also compared to other western and central Himalayan forests. The plant group (such as dicots, monocots and gymnosperms) representations are closely comparable with other parts of the Himalaya. The growth of herbaceous plants with the commencement of monsoon (April-May) that ensures water availability for sustain growth was also supported by Ralhan *et al.* (1985). In alpine and subalpine, most of the plants bloomed during July-August, which is also the period of peak livestock grazing. It is obvious that livestock grazing have pressure on seed production and propagation as evidenced from the exclosure plots of the present study where most of the species inside the exclosure plots bloomed (Photoplate 7). Erratic collection of economically important plants by the local villagers, porters and trekkers is another threat. Local porters while on the trek collected incense and medicinal plants from the alpine areas (Photoplate 2). Collection of large number of wild edible plants from the lower elevation forested areas is also quite common. The Sikkim Biodiversity and Ecotourism project addressed to these issues where awareness drive and capacity building of different stakeholders in Yuksam and school children were carried out. Now much of the activities of awareness have been taken over by the Khangchendzonga Conservation Committee, a local NGO from Yuksam.

In comparative foraging behaviour study among the animals and at different ecological zones, bite rates were higher in alpine and subalpine pastures than temperate forested grounds. Contrary to it, bite size and foraging hours were more in temperate pastures, this is required to compensate the loss in slow bite rate at the temperate pastures. Forage intake rates were more in temperate pastures that might be due to lesser content of cellulosic materials in the temperate plant species affecting on the digestion.

The decrease of palatable species and increase of unpalatable species due to livestock grazing is matched with the findings of the earlier workers (Ellision 1960; Thurow & Hussein 1989; Curry & Hacher 1990). Livestock grazing have higher dietary selectivity and this has definitely changed the species composition and vegetation pattern (see Photoplate 5) and also net productivity of pastures. Yaks and sheep grazed on slopy sides while horse, cow and dzo grazed on less slopy terrain. It was also visualized that livestock types have preferential grazing species. Yak and goat browse shrubs too while dzo, cow, horse and sheep grazed ground phytomass. Climate of the region is also strongly responsible in the compensation process. Higher rainfall, humidity and moisture content in the eastern Himalaya favour better compensation than the western and central Himalaya. In the present study, species number was inversely related with elevation but contrary to it plant density and basal coverage was much more in alpine and subalpine areas. Within the temperate sites, the plant density in cool temperate was comparatively less than the warm temperate but contrary to it basal coverage was more in cool temperate, this strongly favours the healthy growth of plants in terms of individual species survivorship. Warm temperate rangelands are close to Yuksam settlement and receive intense grazing pressure. High anthropogenic pressure caused dominance by secondary and exotic species, and this has lead to decrease in the carrying capacity of the pastures.

Species richness and diversity of plants decreased with increasing elevation. But livestock grazing did not show any drastic change in species richness ad diversity of plants. Observation on two years of exclosure experiment may not be sufficient enough to conclude on impacts, however a general trend as reported above is evident. Long-term exclosure evaluation will however contribute for proper understanding of system operation. Livestock grazing have definite pressure on regeneration of tree species inside the forest that has been shown clearly in the present study. Seedlings and saplings of secondary species increased while palatable species decreased. Therefore grazing controls the quality and quantity of forest vegetation and in turn forest structure in long period.

The productivity of herbaceous plants is comparable with the other Himalayan reports. Exclosure has resulted in increase of biomass by more than 80% at Yuksam site. This rangeland has been highly stocked. On an average grazing removed around 50% of the aboveground biomass that is almost within the limit of acceptable level. In the open grazed pasture biomass contribution by unpalatable or least palatable species was highest. Grazing exclosure improved in the recovery of palatable species. Belowground biomass was not severely affected by livestock grazing. Litter is an important interface that on decomposition help in returning nutrients to soil contributing to fertility. Grazing removed substantial biomass decreasing the higher contribution and consequently affecting the nutrient cycling. Generally, grazing also reduced nutrient concentration of aboveground parts but increased in the belowground parts. Organic carbon and soil nutrients increased in the soil under grazing. This supports the findings made by Manley *et al.* (1995), Dormaar *et al.* (1990), Ruess & McNaughton (1987). The increase in nutrients of soils under the grazed pasture is contributed by animal wastings.

The carrying capacity of the present study rangelands has been recorded as 1.34 cow ha^{-1} for warm temperate (Yuksam), 1.18 cow ha^{-1} for cool temperate (Sachen), 0.96 cow ha^{-1} for subalpine (Deorali) and 0.86 cow ha^{-1} for alpine (Dzongri) and is comparable to that of the report from the Garhwal Himalaya (Gupta 1986). In the present study, grazing are more intense and critical at Yuksam pasture (stocked 1.29 cow ha^{-1}) and Deorali pasture (1.02 cow ha^{-1}) as compared to Sachen pasture (0.49 cow ha^{-1}) and Dzongri pasture (0.56 cow ha^{-1}). Because of concentrate grazing near campsites, trail and near livestock sheds more prominently at Dzongri and Deorali, there has been an observable sign of vegetation loss, soil erosion and habitat degradation. The subalpine transition zone at Deorali pasture is more critical and fragile that has crossed the carrying capacity limit and visible symptoms of site deterioration are already conspicuous. This is a serious concern and definite grazing regime for grazing livestock and regulation of pack animals halting has to be established for this pasture. Therefore, grazing in the vicinity of the campsites and sheds has to be minimized. Extraction like fodder, fuelwood, timber and non-timber forest products are quite common and that has direct effect on pasture productivity. Management of these resources can increase the productivity of Yuksam pasture.

M

RECOMENDATIONS

The following recommendations are made for management of livestock in Yuksam village and along the Yuksam-Dzongri trekking corridor:

1. Livestock number should not be increased anymore in Yuksam and Deorali pastures which is already at the carrying capacity level. Strong scientific management is most urgently required. Sachen and Dzongri pastures are still well within the carrying capacity. The maintenance of current stocking rate at these two pastures will keep the pasture healthy and productive with not much deterioration.

2. Deferred grazing can recover the decline of grazing palatable species and in turn the proliferation of non-palatable species could be checked. Rotational grazing for three years is expected to keep the pasture in good shape based on the evaluation of exclosure study. Concentrate grazing at the campsite and livestock sheds should be strongly discouraged.

3. Collections of resources such as fuelwood, timber and non-timber forest products are to be regulated under certain management regime for regeneration and establishment of species. These anthropogenic pressures cause imbalance among the species association and survivorship.

4. Strengthening of good quality fodder species especially species of *Ficus* in agroforestry at Yuksam village should be encouraged. This will reduce pressure in adjoining forests and trail in biosphere reserve.

5. Establishment of veterinary service at Yuksam and Tshoka villages are in urgent need because till now there is no such facilities available in these areas. Livestock rearing if unhygienic can cause reduction in production and in turn less economic return.

6. Repairing and proper maintenance of trekking corridor (pack animals trampling has drastic effect on soil erosion) can check trail erosion that has detrimental effects on adjacent vegetation and in turn loss of soil fertility, and landscape change in course of time.

7. Regular scientific monitoring on livestock health and its cause effect on rangeland health are essential. For this, establishment of permanent representative fence exclosure plots at different climatic zones, vegetation types and important livestock sites be started and participatory monitoring should be encouraged ■

SUMMARY

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

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

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

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

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

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

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

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

13. Exclosure of forest ground from livestock grazing increased the density of seedling of tree species by 29% in cool temperate and 46% in warm temperate sites. Regenerating plant density ranged from 7000-10750 seedlings ha^{-1} in cool temperate and 3750-8750 seedlings ha^{-1} in warm temperate forest sites at Yuksam.

14. Exclosure in grazed pasture increased aboveground biomass by 50% at all the elevations (P<0.0001) and 78.06 to 92.66% of biomass was contributed by palatable species. Exclosure increased biomass contribution of palatable species by 25% at Yuksam, 12% at Sachen, 11% at Deorali and 75% at Dzongri. Dicot plants were more in grazed plots while monocot plants more in exclosure plots at all the study sites. Aboveground biomass contribution by different growth forms was dominated by shrub/undershrub (33.2%) at Yuksam, tall forbs (41.2%) at Sachen, and graminoid at both Deorali (41.2%) and Dzongri (37.5%). Aboveground biomass showed strong positive relationship with rainfall in all the study sites (P<0.01-0.001).

15. Protection from livestock grazing for two years has increased accumulation of litter mass significantly (P<0.0001) at all the study sites. Litter accumulation decreased with increase in elevation.

16. No significant change was recorded in belowground root biomass after 2 years of fencing at all the study sites. Root:shoot ratio

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

17. Protection from livestock grazing has enhanced the productivity of pastures by 63.5% at Yuksam, 75.6% at Deorali and 113.7% at Dzongri. Species contribution to the net aboveground biomass productivity was highest by *Pilea scripta* (19.29% in grazed) and *Brachiaria* sp. (23.09% in exclosure) at Yuksam; *Urtica dioica* (15.98% in grazed) and *Diplazium umbrosum* (29.73% in exclosure) at Sachen; *Potentilla peduncularis* (23.01% in grazed) and *Poa* sp. I (24.19% in exclosure) at Deorali, and *Potentilla peduncularis* (39.68% in grazed) and *Poa* sp. I (20.78% in exclosure) at Dzongri. Turnover rate of aboveground biomass was more at exclosure plots in all the study sites except in Sachen and the value ranged from 0.329 to 0.584 in grazed plots while 0.475 to 0.620 in exclosure plots. Turnover rate of belowground biomass decreased with exclosure at Yuksam and Sachen while increased at Deorali and Dzongri. The value ranged from 0.06 to 0.479 in grazed plots while 0.072 to 0.307 in exclosure plots.

18. Nitrogen concentration of aboveground biomass of different species increased at the exclosure plots ($P<0.01$). It ranged from 0.92 to 2.14% in species of grazed plots, while 0.91 to 2.71% in exclosure plot species.

19. Phosphorus concentration of aboveground shoot ranged from 0.113 and 0.231% in the species of grazed plots, and 0.141 to 0.247% in exclosure plots. Nitrogen concentration has decreased in

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

20. Nitrogen concentration of soil increased in grazed plots (P<0.0001) and the values ranged from 0.413 to 0.488% (grazed) and 0.33 to 0.461% (exclosure) at Yuksam; 0.443 to 0.547% (grazed) and 0.407 to 0.464% (exclosure) at Sachen; 0.491 to 0.551% (grazed) and 0.490 to 0.539% (exclosure) at Deorali, and from 0.310 to 0.477% (grazed) and 0.361 to 0.403% (exclosure) at Dzongri. Nitrogen content of soil upto 30 cm depth ranged from 380 to 423 g m^{-2} (grazed) and 292 to 400 g m^{-2} (exclosure) at Yuksam; 465 to 586 g m^{-2} (grazed) and 428 to 497 g m^{-2} (exclosure) at Sachen; 520 to 561 g m^{-2} (grazed) and 519 to 548 g m^{-2} (exclosure) at Deorali and 463 to 575 g m^{-2} (grazed) and 479 to 601 g m^{-2} (exclosure) at Dzongri.

21. There was no significant change in phosphorus concentration of soils as an impact of grazing in all the study sites. It's concentration in soil ranged from 0.016 to 0.036% in grazed plots and 0.007 to 0.030% in exclosure plots. Phosphorus content of soil upto 30 cm depth ranged from 16.81 to 36.60 g m^{-2} in grazed plots and 10.47 to 26.54 g m^{-2} in exclosure plots across the study sites.

22. Grazing exclosure has resulted into significant decrease in organic carbon content of soil (P<0.0001) and the values ranged from 4.13 to

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

23. Total net uptake of nitrogen was 5.37 g m^{-2} $year^{-1}$ in grazed and 14.36 g m^{-2} $year^{-1}$ in exclosure plots at Yuksam; 11.00 g m^{-2} $year^{-1}$ (grazed) and 18.21 g m^{-2} $year^{-1}$ (exclosure) at Sachen; 14.04 (grazed) and 16.96 g m^{-2} $year^{-1}$ (exclosure) at Deorali and 20.69 g m^{-2} $year^{-1}$ (grazed) and 21.66 g m^{-2} $year^{-1}$ (exclosure) at Dzongri. Total net uptake of phosphorus was 1.47 g m^{-2} $year^{-1}$ in grazed and 2.6 g m^{-2} $year^{-1}$ in exclosure plots at Yuksam; 2.09 g m^{-2} $year^{-1}$ (grazed) and 2.87 g m^{-2} $year^{-1}$ (exclosure) at Sachen; 2.09 g m^{-2} $year^{-1}$ (grazed) and 2.51 g m^{-2} $year^{-1}$ (exclosure) at Deorali and 2.64 g m^{-2} $year^{-1}$ (grazed) and 3.05 g m^{-2} $year^{-1}$ (exclosure) at Dzongri.

24. In terms of forage consumption rate, different animals were converted into cow equivalent unit (CEU). In temperate pastures, 1 dzo, 1 horse, 1 sheep and 1 goat is equivalent to 1.14 cow, 1.03 cow, 0.37 cow and 0.38 cow, respectively. In alpine and subalpine pastures 1 dzo, 1 yak, 1 horse, 1 sheep is equivalent to 1.14 cow, 0.92 cow, 1.01 cow and 0.33 cow, respectively.

25. The annual stocking rate was recorded as 1.29 cow ha^{-1} at Yuksam, 0.49 cow ha^{-1} at Sachen, 1.02 cow ha^{-1} at Deorali and 0.56 cow ha^{-1} at Dzongri.

26. The carrying capacity of pastures at different elevation zones was estimated. The carrying capacity of 1.34 cow ha^{-1} $year^{-1}$ was recorded at Yuksam pasture, 1.18 cow ha^{-1} $year^{-1}$ at Sachen pasture, 0.96 cow ha^{-1} $year^{-1}$ at Deorali pasture and 0.86 cow ha^{-1} $year^{-1}$ at Dzongri pasture. The potential carrying capacity of pastures were calculated as 1.61 cow ha^{-1} $year^{-1}$ for Yuksam pasture, 1.42 cow ha^{-1} $year^{-1}$ for Sachen pasture, 1.15 cow ha^{-1} $year^{-1}$ for Deorali pasture and 1.03 cow ha^{-1} $year^{-1}$ for Dzongri pasture.

27. Livestock number shoud not be increased anymore in Yuksam and Deorali pastures that already has reached the carrying capacity level. Strong scientific management is urgently required. The Maintenance of current stocking rate at Dzongri and Sachen pasture is expected to keep these two pastures healthy and productive ■

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APPENDICES

Appendix 1

List of species by flowering period, life-forms and growth-forms in temperate zone along the Yuksam-Dzongri trail in Khangchendzonga Biosphere Reserve

Families/Species	*Flowering period*	*Life-forms**	*Growth-forms***
RANUNCULACEAE (Buttercup family)			
Clematis montana Buch.-Ham. ex DC.	Apr-May	Ph	Cl
MAGNOLIACEAE (Magnolia family)			
Magnolia campbellii Hook. f. Thoms.	Mar-May	Ph	Tr
Michelia cathcartii Hook. f. & Thoms.	Sep-Oct	Ph	Tr
M. champaca Linn.	Jul-Aug	Ph	Tr
M. excelsa Wallich.	Mar-Apr	Ph	Tr
M. lanuginosa Wall.	Aug-Sep	Ph	Tr
MENISPERMACEAE			
Stephania rotunda Lour.	May-Jun	Ph	Cl
BERBERIDACEAE (Barberry family)			
Berberis wallichiana DC.	Apr-Jun	Ph	Us
Mahonia napaulensis DC.	Oct-Apr	Ph	Sh
BRASSICACEAE (Mustard family)			
Nasturtium indicum Linn.	May-Jul	Th	Sf
VIOLACEAE (Violet family)			
Viola canescens Wallich.	Mar-May	Ch	Sf
FLACOURTIACEAE			
Casearia glomerata Roxb.	Apr-May	Ph	Sh
HYPERICACEAE			
Hypericum japonicum Thunb. ex Murray	Apr-Sep	Ph	Sh
CARYOPHYLLACEAE (Carnation family)			
Drymaria cordata Linn.	Jun-Sep	Ch	Sp
Stellaria medica (Linn.) Cyrill.	Jun-Aug	Ch	Sf
THEACEAE (Tea family)			
Eurya acuminata DC.	Sep-Nov	Ph	Tr
SAURAUIACEAE			
Saurauia napaulensis DC.	Mar-May	Ph	Sh
ELAEOCARPACEAE (Olive family)			
Elaeocarpus sikkimensis Mast.	May-Jun	Ph	Tr
BALSAMINACEAE (Balsam family)			
Impatiens sp.	May-Aug	Th	Tf

RUTACEAE (Citrus family)			
Evodia fraxinifolia Benth.	Apr-Jun	Ph	Tr
Zanthoxylum acanthopodium DC.	Jun-Sep	Ph	Sh
Z. alatum Roxb.	Jun-Sep	Ph	Sh
BURSERACEAE			
Garuga pinnata Roxb.	May-Jun	Ph	Tr
MELIACEAE (Mahogany family)			
Amoora wallichii King.	Apr-Aug	Ph	Tr
Cedrela toona Roxb.	Feb-May	Ph	Tr
Heynea trijuga Roxb.	Mar-May	Ph	Tr
VITACEAE (Vine family)			
Cissus repanda Vahl.	May-Jun	Ph	Cl
STAPHYLEACEAE (Bladder Nut family)			
Turpinia nepalensis Wall.	May-Jun	Ph	Tr
ACERACEAE (Mapple family)			
Acer campbellii Hook. f. & Thoms.	Apr-May	Ph	Tr
A. cappadocicum Gled.	May-Aug	Ph	Tr
A. laevigatum Wall.	May-Jun	Ph	Tr
A. oblongum Wallich. ex DC.	May-Jul	Ph	Tr
A. pectinatum Wallich. ex. Pax.	May-Jul	Ph	Tr
A. villosum Wallich.	Feb-Apr	Ph	Tr
ANACARDIACEAE (Mango family)			
Rhus insignis Hook. f.	Jul-Aug	Ph	Tr
R. semialata Murr.	Aug-Sep	Ph	Tr
FABACEAE (Pea family)			
Albizzia procera Benth.	Jun-Aug	Ph	Tr
ROSACEAE (Rose family)			
Eriolobus indica Schn.	Mar-Apr	Ph	Tr
Fragaria nubicola Lindley ex Lacaita	Apr-Jun	Ch	Sf
Neillia rubiflora D. Don	Jul-Aug	Ph	Sh
Prunus cerasoides D. Don	Oct-Nov	Ph	Tr
Rubus ellipticus Smith.	Jun-Feb	Ph	Sh
R. nepalensis (Hook. f.) Kuntze	Jun-Feb	Ph	Sh
R. paniculatus Smith	Jun-Feb	Ph	Sh
SAXIFRAGACEAE (Saxifrage family)			
Astilbe revularis Buch.-Ham. ex D. Don	Jul-Sep	Ph	Sh
Ribes graciale Wall.	Apr-May	Ph	Tr
HAMAMELIDACEAE (Witch Hazel family)			

Bucklandia populnea R. Br.	Jun-Aug	Ph	Tr
MELASTOMATACEAE			
Melastoma normale D. Don	Mar-Jun	Ph	Us
Osbeckia nepalansis Hook.	Jul-Nov	Ph	Sh
O. stellata Buch.-Ham. ex. D. Don	Jul-Oct	Ph	Sh
Oxyspora paniculata (D. Don) DC.	Aug-Oct	Ph	Sh
CUCURBITACEAE (Cucumber family)			
Citrullus colocynthis Schrad.	Jun-Aug	Ph	Cl
BEGONIACEAE (Begonia family)			
Begonia sp.	Jul-Aug	Th	Sf
APIACEAE (Umbellifer familly)			
Heracleum nepalense D. Don	Jul-Aug	Th	Tf
Centella asiatica (Linn.) Urb.	Jun-Aug	He	Sp
Hydrocotyle javanica (Linn.) Urb.	Jun-Aug	He	Sp
ARALIACEAE (Ivy family)			
Acanthopanax cissifolius Harms	Jun-Jul	Ph	Tr
Brassaiopsis mitis C.B. Clarke	Jun-Jul	Ph	Sh
Gamblia ciliata C.B. Clarke	May-Jun	Ph	Tr
Pentapanax leschenaultii Seem.	May-Jul	Ph	Sh
CORNACEAE (Dogwood family)			
Nyssa javanica Wangerin	May-Jun	Ph	Tr
CAPRIFOLIACEAE (Honeysuck family)			
Lonicera glabrata Wall.	Aug-Sep	Ph	Cl
Viburnum colebrookianum Wall.	Apr-Jun	Ph	Sh
V. cordifolium Wallich ex DC.	Apr-May	Ph	Sh
V. erubescens Wallich ex DC.	Apr-Jun	Ph	Sh
RUBIACEAE (Madder family)			
Galium verum Linn.	Jul-Aug	Ch	Sf
Mussaenda roxburghii Linn.	Mar-Apr	Ph	Sh
Rubia manjith Roxb ex. Fleming	Jun-Nov	Ph	Cl
Rubus calycinus Wallich ex D. Don	Mar-May	Ch	Sf
R. ellipticus Smith	May-Feb	Ph	Sh
R. niveus Thunb.	Apr-Jun	Th	Sf
ASTERACEAE (Daisy family)			
Adenostema viscosum Frost.	Jul-Aug	Th	Tf
Ageratum conyzoides Linn.	Aug-Sep	Th	Tf
Anaphalis sp.	Jun-Oct	Th	Tf
Artimissia vulgaris Linn.	Juy-Oct	Ch	Tf

Eupatorium cannabinum Linn.	Oct-Mar	Ch	Tf
E. odoratum Linn.	Oct-Mar	Ch	Tf
Gynura cushimboa (D. Don) S. Moore	Mar-Oct	Ch	Tf
G. nepalensis DC.	Apr-Oct	Ch	Tf
VACCINIACEAE			
Agapetes serpens (Wight) Sleumer	Feb-Jun	Ph	Sh
Vaccinium retusum Hook. f.	May-Jul	Ph	Ep
V. serratum Wight.	Mar-Apr	Ph	Ep
ERICACEAE (Heath family)			
Andromeda elliptica Sieb. & Zucc.	Jun-Sep	Ph	Tr
Rhododendron arboreum Linn.	Feb-May	Ph	Tr
R. vaccinioides Hook. f.	Jun-Jul	Ph	Ep
PLANTAGINACEAE			
Plantago erosa Wall.	Aug-Sep	Th	Cu
MYRSINACEAE			
Maesa chisia Buch.-Ham. ex D. Don	Mar-May	Ph	Sh
SYMPLOCACEAE			
Symplocos theifolia Don.	Aug-Sep	Ph	Tr
ASCLEPIADACEAE (Milkweed family)			
Asclepias curassavica Linn.	Jul-Aug	Ph	Tf
LOGANIACEAE (Buddleia family)			
Buddleja asiatica Lour.	Jul-Aug	Ph	Us
SCROPHULARIACEAE (Figwort family)			
Drymaria cordata Linn.	Jul-Sep	Ch	Sp
Hemiphragma heterophyllum Wallich.	Apr-May	Ch	Sp
Mazus dentatus Wallich ex Benth.	May-Jun	Ch	Sf
Wulfenia amherstiana Benth.	Jul-Aug	Ch	Sp
GESNERIACEAE (Gloxinia family)			
Aeschynanthus sikkimensis Stapf.	May-Jun	Ph	Ep
Chirita bifolia D. Don	Jul-Aug	Th	Sf
AMARANTHACEAE (Cockscomb family)			
Achyranthes aspera Linn.	Jul-Aug	Th	Us
Amaranthus sp.	Jun-Jul	Th	Tf
VERBENACEAE (Verbena family)			
Calicarpa arborea Roxb.	Apr-May	Ph	Tr
C. macrophylla Vahl.	Jul-Oct	Ph	Tr
LAMIACEAE (Mint family)			
Ajuga lobata D. Don.	May-Jun	Ch	Sp

Leucosceptrum canum Smith	Oct-Mar	Ph	Sh
POLYGONACEAE (Dock family)			
Aconogonum molle D. Don	May-Oct	Ph	Sh
Persicaria capitata Gross.	Apr-Nov	Ch	Sp
Polygonum sp.	Jun-Jul	Th	Sf
PIPERACEAE (Piper family)			
Piper boehmeriaefolia (Miq.) DC.	May-Jun	Ph	Cl
P. longum Linn.	May-Jun	Ph	Cl
ARISTOLOCHIACEAE (Birthworth family)			
Aristolochia griffithii Duchartre	Apr-May	Ph	Cr
LAURACEAE (Laurel family)			
Beilschmiedia roxburghiana Nees.	May-Jun	Ph	Tr
B. sikkimensis King.	May-Jun	Ph	Tr
Cinnamomum cecidodaphne Meissn.	Jul-Aug	Ph	Tr
C. impressinervium Meissn.	Jul-Aug	Ph	Tr
C. obtusifolium Nees.	Sep-Nov	Ph	Tr
C. tamala (Buch.-Ham.) Nees and Eberm.	Apr-May	Ph	Tr
Litsaea citrata Blume	Nov-Mar	Ph	Tr
L. polyantha Juss.	Mar-Apr	Ph	Tr
M. edulis King.	Mar-Apr	Ph	Tr
Machilus gammieana King.	Apr-Jun	Ph	Tr
M. odoratissima (Nees) Kosterm	Mar-Apr	Ph	Tr
THYMELIACEAE (Daphne family)			
Daphne involucrata Wall.	Aug-Sep	Ph	Us
Edgeworthia gardneri (Wallich) Meissner	Oct-May	Ph	Sh
LORANTHACEAE (Mistletoe family)			
Viscum articulatum Linn.	Jul-Aug	Ph	Ep
EUPHORBIACEAE (Spurge family)			
Aporosa dioica Muell.	Apr-May	Ph	Tr
Glochidion acuminatum Muell.	Apr-Jun	Ph	Tr
Macaranga pustulata King.	Oct-Nov	Ph	Tr
URTICACEAE (Nettle family)			
Debregeasia salicifolia (D. Don) Rendle	Apr-Jun	Ph	Sh
Elatostema sessile Wedd.	Apr-Jun	Ch	Tf
Girardinia dicursifolia (Link) Friis.	Jun-Aug	Ph	Us
Laportia terminalis Wight.	Jun-Aug	Ph	Us
Lecanthus peduncularis (Royle) Wedd.	May-Aug	Ch	Tf
Pilea scripta (Buch.-Ham. ex D. Don) Wedd.	Aug-Sep	Ch	Tf

Urtica dioica Linn.	Jun-Aug	Ph	Us
MORACEAE (Fig family)			
Ficus cunia Buch.-Ham. ex Roxb.	Jun-Sep	Ph	Sh
F. foveolata Wall.	Jun-Aug	Ph	Ep
F. infectorius Linn.	Jul-Aug	Ph	Tr
F. nemoralis Wall.	Jul-Aug	Ph	Tr
F. roxburghii Wallich ex. Miq.	Apr-Jun	Ph	Tr
Morus laevigata Wall.	Apr-May	Ph	Tr
JUGLANDACEAE (Walnut family)			
Engelhardtia spicata Leschen ex. Blume	Apr-Aug	Ph	Tr
Juglans regia Linn.	Mar-May	Ph	Tr
BETULACEAE (Birch family)			
Alnus nepalensis D. Don	Oct-Dec	Ph	Tr
Betula alnoides Ham.	Mar-Apr	Ph	Tr
FAGACEAE (Oak family)			
Castanopsis hystrix Miq.	Apr-May	Ph	Tr
C. indica (Roxb.) Miq.	Oct-Nov	Ph	Tr
C. tribuloides (Smith) A. DC.	Aug-Sep	Ph	Tr
Lithocarpus pachyphylla (Kurz) Rehder	Jul-Aug	Ph	Sh
Quercus lamellosa Smith	Apr-May	Ph	Tr
Q. lanata Smith	Apr-Jun	Ph	Tr
TAXODIACEAE (Swamp cypress family)			
Cryptomeria japonica D. Don	Aug-Sep	Ph	Tr
CUPRESSACEAE (Cypress family)			
Juniperus sp.	Aug-Sep	Ph	Tr
ORCHIDACEAE (Orchid family)			
Bulbophyllum affine Lindley	Jun-Jul	Ph	Ep
Calanthe brevicornu Lindley	May-Jun	Ch	Tf
Coelogyne cristata Lindley	Mar-Apr	Ph	Tr
C. flaccida Lindley	Apr-May	Ph	Ep
C. ochracea Lindley	Apr-May	Ph	Ep
Habenaria pectinata D. Don	Jun-Aug	Ph	Ep
Dendrobium fimbriatum Hook.	May-Jun	Ph	Ep
Malaxis muscifera (Lindley) Kuntze	Jul-Aug	Th	Tf
Pleione praecox (Smith) D. Don	Oct-Nov	Ph	Tr
ZINGIBERACEAE (Ginger family)			
Hedychium aurantiacum Roscoe	Jul-Aug	Ch	Tf
H. ellipticum Smith	Jun-Aug	Ch	Tf

Roscoea purpurea Smith	Jun-Aug	Ch	Tf
LILIACEAE (Lily family)			
Paris polyphylla Smith	May-Jun	Ge	Tf
Smilax aspera Linn.	Sep-Oct	Ph	Cl
S. ferox Wallich ex Kunth	May-Jun	Ph	Us
Tupistra nutans Hook. f.	Apr-Jun	Th	Gr
COMMELINACEAE (Spiderwort family)			
Commelina benghalensis Linn.	Jul-Aug	Ch	Gr
C. paludosa Blume	Jul-Aug	Ch	Gr
Cyanotis vaga (Lour) Schultes & Schultes f.	Jul-Sep	Ch	Gr
ARACEAE (Arum family)			
Arisaema costatum Martius ex Schott	May-Jun	Ch	Tf
A. erubescens (Wallich) Schott	May-Jun	Ch	Tf
A. griffithii Schott	May-Jun	Ch	Tf
A. intermedium Blume	May-Jun	Ch	Tf
A. jacquemontii Blume	Jul-Aug	Ch	Tf
A. speciosum Martius ex Schott	May-Jun	Ch	Tf
Colocasia esculenta (Linn.) Schott	Aug-Sep	Ge	Tf
Gonatanthus pumilus Engler & Krause	Jun-Aug	Ge	Tf
Pothos scandens Linn.	-	Ph	Cl
Rhaphidophora dicursiva (Roxb.) Schott	Nov-Dec	Ph	Cl
CYPERACEAE (Cyprus family)			
Cyperus sp.	Jul-Sep	Ge	Gr
POACEAE (Grass family)			
Arundinaria maling Gamble	Sporodic	Ph	Tr
Brachiaria sp.	Jul-Aug	Th	Tf

*(Ph = Phanerophyte; Ch = Chaemephyte; He = Hemigeophyte; Ge = Geophyte, Th = Therophyte), **(Tr = Tree; Sf = Short forb; Tf = Tall forb; Cu = Cushion forb; Sp = Spreading forb; Sh = Shrub; Us = Undershrub; Cl = Climber; Gr = Graminoid; Ep = Epiphyte; Cr = Creeper).

Appendix 2

List of species by flowering period, life-forms and growth-forms of subalpine meadows along the Yuksam-Dzongri trail of Khangchendzonga Biosphere Reserve

Families/Species	Flowering period	Life-forms	Growth-forms
RANUNCULACEAE (Buttercup family)			
Anemone tetrasepala Royle	Jun-Aug	He	Tf
Ranunculus diffusa DC.	Jun-Aug	Th	Tf
Thalictrum foliosum DC.	Jul-Aug	Ch	Tf
Th. Virgatum Hook. f. & Thoms.	Jun-Aug	Ch	Tf
PAPAVERACEAE			
Corydalis juncea Wallich.	Jun-Jul	Ch	Tf
Meconopsis paniculata Prain.	Jun-Aug	Ch	Tf
BRASSICACEAE (Mustard family)			
Lignariella hobsonii (Pearson) Baehni	Jun-Jul	Th	Sp
Pegaeophyton scapiflorum Marquand & Shaw	Jun-Jul	Ge	Cu
BERBERIDACEAE (Berberry family)			
Berberis wallichiana DC.	Apr-May	Ph	Us
THEACEAE (Tea family)			
Eurya acuminata DC.	Sep-Nov	Ph	Tr
BALSAMINACEAE (Balsam family)			
Impatiens stenantha Hook. f.	Jul-Sep	Ch	Tf
I. sulcata Wallich.	Jul-Aug	Ch	Tf
I. urticifolia Wallich.	Jun-Aug	Ch	Tf
ACERACEAE (Maple family)			
Acer campbellii Hook. f. & Thoms.	Jun-Aug	Ph	Tr
A. sterculiaceum Wallich.	Mar-Jun	Ph	Tr
GERANIACEAE			
Geranium nakaoanum Hara	Jun-Aug	Ch	Sp
FABACEAE (Pea family)			
Parochetus communis Buch.-Ham. ex. D. Don	May-Oct	Ch	Sf
ROSACEAE (Rose family)			
Fragaria daltoniana Gay.	Apr-Jun	Ch	Sp
F. nubicola Lindley ex Lacaita	Apr-Jun	Ch	Sp
Potentilla coriandrifolia D. Don	Jun-Aug	He	Sf
P. microphylla D. Don	Jun-Jul	He	Sf
P. peduncularis D. Don	Jun-Aug	Ch	Tf
P. plurijuga Hand.-Mazz.	Jun-Aug	Th	Sf
Rosa sericea Lindley	May-Aug	Ph	Sh
Sorbus foliolosa (Wallich) Spach.	Jun-Jul	Ph	Sh

S. microphylla Wenzing	Jun-Jul	Ph	Sh
PARNASSIACEAE			
Parnassia nubicola Wallich ex Royle	Jul-Aug	Th	Sf
ONAGRACEAE (Willow-herb family)			
Epilobium latifolium Linn.	Jul-Aug	Th	Tf
E. wallichianum Hausskn.	Jul-Sep	Th	Tf
APIACEAE (Umbellifer family)			
Heracleum wallichii DC.	Jul-Sep	Th	Tf
Selinum tenuifolium Wallich ex C.B. Clarke	Jul-Sep	Ch	Tf
ARALIACEAE (Ivy family)			
Schefflera impressa (C.B. Clarke) Harms	Aug-Sep	Ph	Sh
CAPRIFOLIACEA (Honeysuckle family)			
Viburnum erubescens Wallich ex DC.	Apr-May	Ph	Sh
V. nervosum D. Don	Apr-May	Ph	Sh
VACCINIACEAE			
Gaultheria pyroloides Miq.	Jun-Jul	Ph	Sp
G. tricophylla Royle	Jun-Aug	Ph	Sp
Vaccinium nummularia C.B. Clarke	Apr-Jun	Ph	Sp
CAMPANULACEAE			
Cyananthus lobatus Wallich ex Benth.	Jul-Sep	Ch	Sf
ERICACEAE (Heath family)			
Rhododendron barbatum Wallich ex. G. Don	Apr-May	Ph	Tr
R. cinnabarinum Hook. f.	May-Jun	Ph	Sh
R. dalhousiae Hook. f.	Apr-May	Ph	Sh
R. falconeri Hook. f.	Apr-May	Ph	Sh
R. fulgens Hook. f.	Jun-Jul	Ph	Sh
R. hodgsonii Hook. f.	Apr-May	Ph	Tr
R. lepidotum Wall. ex G. Don	Jun-Aug	Ph	Tr
R. thomsonii Hook. f.	May-Jun	Ph	Sh
R. wightii Hook. f.	Apr-May	Ph	Sh
PRIMULACEAE (Primula family)			
Primula calderana Balf. f. Cooper	May-Jul	Ch	Tf
P. irregularis Craib.	May-Aug	Ch	Cu
P. sikkimensis Hook. f.	May-Jul	Ch	Tf
GENTIANACEAE (Gentian family)			
Giantiana phyllocalyx C.B. Clarke	Jul-Aug	Ch	Sp
G. algida Pallas.	Jul-Aug	Ch	Sp
SCROPHULARIACEAE			
Pedicularis hoffmeisteri Klotzsch	Jul-Aug	Ch	Sf
LAMIACEAE			
Phlomis rotata Hook. f.	Jun-Aug	Ch	Sf
Prunella vulgaris Linn.	Jun-Sep	Th	Sf

SYMPLOCACEAE			
Symplocos theifolia Don.	Aug-Sep	Ph	Tr
THYMELIACEAE (Daphne family)			
Daphne bholua Buch.-Ham. ex. D. Don	Oct-Mar	Ph	Sh
EUPHORBIACEAE			
Euphorbia stracheyi Boiss.	Jun-Jul	Th	Sf
BETULAEAE (Birch family)			
Betula cylindrostachys Wall.	Dec-Jan	Ph	Tr
SALICACEAE (Willow family)			
Salix sikkimensis Andersson	Apr-May	Ph	Tr
PINACEAE (Pine family)			
Abies densa Griffith ex R. Parker	Apr-May	Ph	Tr
Tsuga dumosa (D. Don) Eichler	Jul-Sep	Ph	Tr
ORCHIDACEAE			
Galearis spathulata (Lindley) P.F. Hunt	Jul-Sep	Ge	Sf
LILIACEAE (Lily family)			
Aletris pauciflora (Klotzsch) Hand-Mazz	Jun-Aug	Th	Gr
Polygonatum multiflorum (Linn.) All.	May-Jun	Th	Tf
Smilacina oleracea (Baker) Hook. f.	May-Jul	Ge	Tf
S. purpurea Wallich.	May-Jul	Ge	Tf
Streptopus simplex D. Don	May-Jul	Ge	Tf
JUNCACEAE			
Juncus thomsonii Buchenau	Jun-Sep	He	Gr
POACEAE (Grass family)			
Arundinaria maling Gamble	Sporodic	Ph	Sh
Poa sp. I	Jun-Jul	He	Gr
Poa sp. II	Jun-Jul	He	Gr
Poa sp. III	Jun-Jul	He	Gr

*(Ph = Phanerophyte; Ch = Chaemaphyte; He = Hemigeophyte; Ge = Geophyte, Th = Therophyte), **(Tr = Tree; Sf = Short forb; Tf = Tall forb; Cu = Cushion forb; Sp = Spreading forb; Sh = Shrub; Us = Undershrub; Cl = Climber; Gr = Graminoid).

Appendix 3

List of species by flowering period, life-forms and growth-forms of Dzongri and/its surrounding alpine meadows in Khangchendzonga Biosphere

Families/species	*Flowering period*	*Life-forms**	*Growth-forms***
RANUNCULACEAE (Buttercup family)			
Aconitum ferox Wallich ex Seringe	Aug-Sep	Ch	Tf
Aconitum hookeri Stapf.	Aug-Sep	Ch	Sf
Anemone tetrasepala Royle	Jun-Aug	He	Tf
Caltha palustris Linn.	Mau-Jun	Ch	Sp
Delphinium drepanocentrum (Breehl) Munz	Jul-Sep	He	Tf
D. graciale Hook. f. & Thoms.	Jul-Sep	He	Sf
D. viscosum Hook. f. & Thoms.	Aug-Sep	He	Tf
Oxygraphis polypetala (Royle) Hook. f. & Thoms.	Apr-Jun	Ch	Sf
Thalictrum alpinum Linn.	May-Aug	Ch	Tf
PAPAVERACEAE (Poppy family)			
Corydalis cashmeriana Royle	May-Aug	Th	Sf
C. juncea Wallich.	Jun-Jul	Ch	Sf
C. meifolia Wallich.	Jun-Aug	Ch	Sf
Meconopsis dhwojii G. Taylor	Jun-Jul	Ch	Sf
M. grandis Prain	Jul-Aug	Ch	Tf
M. horridula Hook. f. & Thoms.	Jul-Aug	Ch	Sf
M. paniculata Prain.	Jun-Aug	Ch	Tf
BRASSICACEAE (Mustard family)			
Lignariella hobsonii (Pearson) Baehni	Jun-Jul	Th	Sp
CARYOPHYLLACEAE (Pink or Carnation family)			
Silene nigrescens (Edgew.) Majumdar	Jul-Sep	Ch	Sf
S. setisperma Majumdar	Jul-Sep	Ch	Sf
GERANIACEAE (Geranium family)			
Geranium nakaoanum Hara	Jun-Aug	Ch	Sp
G. wallichianum D. Don ex Sweet	Jun-Aug	Th	Tf
BALSAMINACEAE (Balsam family)			
Impatiens glandulifera Royle	Jul-Sep	Ch	Sf
I. stenantha Hook. f.	Jul-Aug	Ch	Sf
I. urticifolia Wallich.	Jun-Aug	Ch	Sf
PAPILIONACEAE (Pea family)			
Parochetus communis Buch.-Ham. Ex D. Don	May-Nov	Th	Sp
ROSACEAE (Rosa family)			
Geum sikkimensis Prain.	Jun-Aug	He	Sp

Potentilla coriandrifolia D. Don	Jun-Aug	He	Sp
P. microphylla D. Don	Jun-Jul	He	Sf
P. pedunculáris D. Don	Jun-Aug	He	Tf
P. plurijuga Hand.-Mazz.	Jun-Jul	He	Sf
Rosa sericea Linley	May-Aug	Ph	Us
Spiraea arcuata Hook. f.	Jun-Jul	Ph	Sh
SAXIFRAGACEAE (Saxifraga family)			
Arenaria densissima Wallich ex Edgew & Hook. f.	Apr-Jun	Ch	Cu
Bergenia ciliata (Haw.) Sternb.	Mar-Jul	Ch	Cu
Saxifraga brunonis Wallich ex. Seringe	Jun-Sep	Ch	Sp
S. engleriana Harry-Smith	Jun-Jul	Ch	Cu
S. pulvinaria Harry-Smith	Jun-Aug	Ch	Cu
S. stenophylla Royle	Jun-Aug	Ch	Sf
PARNASSIACEAE (Parnassus family)			
Parnassia nubicola Wallich ex Royle	Jul-Aug	Th	Sf
CRASSULACEAE (Crassula family)			
Rhodiola himalensis (D. Don) S.H. Fu	Jun-Aug	Ch	Sf
ONAGRACEAE			
Epilobium latifolium Linn.	Jul-Aug	Th	Tf
APIACEAE (Umbellifer family)			
Cortia depressa (D. Don) Norman	Jun-Aug	Ch	Sf
Selinum tenuifolium Wallich ex C.B. Clarke	Jul-Aug	Ch	Tf
DIPSACACEAE (Scabious family)			
Morina nepalensis D. Don	Jun-Aug	Ch	Sf
M. polyphylla Wallich ex DC.	Jun-Aug	Ch	Tf
ASTERACEAE (Daisy family)			
Anaphalis triplinervis (Sims) C.B. Clarke	Jul-Sep	Th	Sf
Cremanthodium oblongatum C.B. Clarke	Jun-Aug	Th	Sf
C. reniforme (DC) Benth	Jun-Aug	Th	Tf
Jurinea dolomiaea Boiss.	Jul-Sep	Ch	Sf
Leontopodium jacotianum Beauvered	Jul-Sep	Ch	Sf
Saussurea costus (Falc.) Lipsch	Jul-Sep	Ch	Sf
S. nepalensis Sprengel	Jul-Sep	Ch	Cu
S. obvallata (DC.) Edgew.	Jul-Sep	Ch	Tf
Soroseris hookerana (C.B. Clarke) Stebbins	Jul-Aug	Ch	Sf
CAMPANULACEAE (Bellflower family)			
Codonopsis thalictrifolia Wallich	Jul-Aug	Th	Sf
Cyananthus incanus Hook. f. & Thoms.	Jul-Sep	Ch	Sp
C. lobatus Wallich ex Benth.	Jul-Sep	Ch	Sf
ERICACEAE (Heath family)			
Cassiope fastigiata (Wallich) D. Don	Jun-Aug	Ch	Sf
Gaultheria pyroloides Hook. f. & Thoms. ex Miq.	Jun-Jul	Ch	Sp

G. trichophylla Royle	May-Jul	Ch	Sp
Rhododendron aeruginosum Hook. f.	Jun-Jul	Ph	Us
R. anthopogon D. Don	Jun-Jul	Ph	Us
R. fulgens Hook. f.	Jun-Jul	Ph	Sh
R. lepidotum Wallich ex G. Don	Jun-Aug	Ph	Us
R. lowndesii Davidian	Jun-Aug	Ph	Us
R. nivale Hook. f.	Jun-Jul	Ph	Us
R. setosum D. Don	Jun-Jul	Ph	Us
R. sikkimensis Pradhan & Lachungpa	May-Jun	Ph	Sh
R. thomsonii Hook. f.	May-Jul	Ph	Sh
PYROLACEAE (Wintergreen family)			
Pyrola sikkimensis ?	Jul-Aug	Ge	Cu
PRIMULACEAE (Primula family)			
Androsace lehmannii Wall.	Jul-Aug	Ch	Cu
Primula antrodenta W.W. Smith	May-Jul	Ch	Sf
P. calderana Balf. f. & Cooper	Jun-Jul	Ch	Tf
P. capitata Hook.	Jul-Aug	Ch	Tf
P. glabra Klatt.	Jun-Sep	Ch	Sf
P. glomerata Pax.	Aug-Nov	Ch	Tf
P. irregularis Craib.	Apr-May	Ch	Cu
P. macrophylla D. Don	Jun-Aug	Ch	Tf
P. primulina (Sprengel) Hara	Jun-Aug	Ch	Sf
P. sikkimensis Hook. f.	May-Jul	Ch	Tf
GENTIANACEAE (Gentian family)			
Gentiana algida Pallas	Sep-Oct	Ch	Sf
Gentiana ornata (G. Don) Griseb.	Sep-Oct	Ch	Sp
G. phyllocalyx C.B. Clarke	Jun-Aug	Ch	Sp
G. tubiflora (G. Don) Griseb.	Jul-Sep	Ch	Cu
Megacodon stylophorus (C.B. Clarke) Harry-Smith	Jun-Jul	Ch	Tf
Swertia multicaulis D. Don	Jun-Sep	Ch	Cu
BORAGINACEAE (Borage family)			
Trigonotis rotundifolia Benth. ex C.B. Clarke	Jun-Aug	Th	Cu
SCROPHULARIACEAE (Figwort family)			
Hemiphragma heterophyllum Wallich.	Mar-May	Ch	Sp
Lagotis kunawurensis (Royle ex Benth.) Rupr.	Jun-Aug	Ch	Sf
Pedicularis hoffmeisteri Klotzsch	Jul-Aug	Ch	Sf
P. megalantha D. Don	Jun-Sep	Ch	Tf
P. roylei Maxim.	Jun-Aug	Ch	Sf
P. scullyana Prain ex Maxim.	Jul-Aug	Ch	Sf
Picrorhiza kurrooa Royle ex Benth.	Jun-Aug	Ch	Cu
LAMIACEAE (Mint family)			
Eriophyton wallichii Benth.	Jul-Sep	Th	Cu

Phlomis rotata Benth. ex Hook. f.	Jun-Aug	Ch	Sf
POLYGONACEAE (Dock family)			
Bistorta affinis (D. Don) Greene	Jun-Sep	He	Sp
B. emodi (Meissner) Hara	Jul-Sep	He	Tf
B. macrophylla (D. Don) Sojak.	Jun-Aug	He	Tf
B. vaccinifolia Greene	Aug-Sep	He	Sp
Oxyria digyna (Linn.) Hill.	May-Jul	Ch	Tf
Persicaria polystachya Gross	Jul-Sep	Ph	Tf
Rheum australe D. Don	Jun-Jul	Ge	Tf
R. nobile Hook. f. & Thom.	Jun-Jul	Ge	Tf
EUPHORBIACEAE (Euphorbia family)			
Euphorbia stracheyi Boiss.	May-Aug	Th	Sp
CUPRESSACEAE (Cupress family)			
Juniperus indica Bertol.	Jun-Jul	Ph	Sf
J. recurva Buch.-Ham. ex D. Don	Jun-Jul	Ph	Us
ORCHIDACEAE (Orchid family)			
Galearis spathulata (Lindley) P.F. Hunt	Jul-Sep	Ge	Sf
Orchis latifolia Linn.	Jun-Jul	Ge	Sf
ZINGIBERACEAE (Ginger family)			
Roscoea alpina Royle	Jun-Aug	Ge	Sf
LILIACEAE (Lily family)			
Aletris pauciflora (Klotzsch) Hand.-Mazz.	Jun-Aug	He	Gr
Allium wallichii Kunth.	Aug-Sep	He	Gr
Lloydia flavonutans Hara	Jul-Aug	Th	Sf
JUNCACEAE (Rus family)			
Juncus thomsonii Buchenau	Jun-Sep	He	Gr
ARACEAE (Arum family)			
Arisaema griffithii Schott.	May-Jun	Ge	Tf
A. jacquemontii Blume	Jun-Aug	Ge	Tf
CYPERACEAE (Cyprus family)			
Carex sp.	Aug-Sep	He	Gr
POACEAE (Grass family)			
Poa sp. I	Jul-Sep	He	Gr
Poa sp. II	Jul-Sep	He	Gr
Poa sp. III	Jul-Sep	He	Gr

*(Ph = Phanerophyte; Ch = Chamaephyte; He = Hemigeophyte; Ge = Geophyte, Th = Therophyte), **(Sf = Short forb; Tf = Tall forb; Cu = Cushion forb; Sp = Spreading forb, Sh = Shrub; Us = Undershrub; Gr = Graminoid).

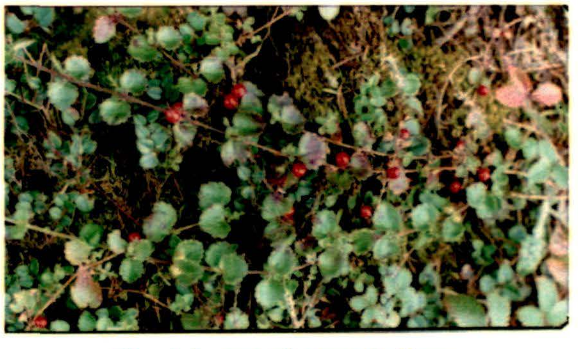
PHOTOPLATES

Pedicularis hoffmeisteri; Family - Scrophulariaceae; Location - Dzongri (3900 m)

Geranium nakaoanum; Family - Geraniaceae; Location - Deorali (3850 m)

Bistorta affinis; Family - Polygonaceae; Location - Dzongri (3900 m)

Rhodiola himalensis; Family - Crassulaceae; Location - Samiti (4100 m)



Hemiphragma heterophyllum; Family - Scrophulariaceae; Location - Dzongri (3850 m)

Galearis spathulata; Family - Orchidaceae; Location - Deorali (3800 m)

Caltha sp.; Family - Ranunculaceae; Location - Dzongri (3850 m)

Primula sikkimensis; Family - Primulaceae; Location - Dzongri (3850 m)

Roots of *Rheum emodi*. It is used as tea-substitute by local people and sometimes also taken as medicine suffering from muscular pains

Rheum emodi; Family - Polygonaceae;
Local name - 'Khokim';
Location - Dzongri (3850 m)

Allium wallichii; Family - Liliaceae; Local name - 'Dung-dungey'; Location Deorali (3850 m). Eaten as vegetables and leaf decoction given to patients suffering from fever

Orchis latifolia; Family - Orchidaceae;
Local name - 'Panch aungley';
Location - Dzongri (3800 m). A medicinal plant widely used by ethnics for curing bone fracture and treatment of wound and bruises.

Panoramic view of pasture land at Dzongri showing herds of livestock

Horse (pack animal used by trekkers) grazing at alpine pasture near *Rhododendron* bushes

A flock of sheep in alpine pasture

Potentilla peduncularis, an unpalatable alpine pasture species proliferated in a large area at Dzongri

Rhododendrons are least palatable, however associated species are being grazed by yaks

Yak grazing in Dzongri alpine pasture. The animal provides revenue from fur, meat and milk products

Pack animals (Dzo) feeding lopped fodder at Tshoka on the way to Dzongri

Pack animals on the corridor

Trail erosion exposing soil profile on the Yuksam-Dzongri corridor. *Rhododendron* roots are exposed

Brassaiopsis mitis, locally called 'Phutta' or 'Chuletro' is one of the preferred fodder tree planted in agriculture land or wasteland

Ficus hookeri, locally called 'Nebhara' is most preferably planted by villagers because of its high production and good quality fodder

Acer campbellii, locally called "Kapasey" is a good fodder tree generally lopped for pack animals along the Yuksam-Dzongri corridor

Livestock exclosure established in May 1997 at Dzongri pasture (3900 m)

Vegetation difference in and outside the grazing exclosure after 1 year

Exclosure of 2 years showed marked growth of vegetation inside and most species are in flowering stage