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Composition, Economic Use, and Nutrient Contents of Alpine Vegetation in the Khangchendzonga Biosphere Reserve, Sikkim Himalaya, India

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Abstract

The Khangchendzonga Biosphere Reserve in the Sikkim State, India, with an area of 2620 km^2, forms an important reserve to protect biodiversity, habitats, and landscapes of the eastern Himalayan region. More than 18% of the area supports alpine vegetation, which is extensively used as summer grazing grounds by transhumance and nomadic graziers. Despite the global recognition of the region, unfortunately no report has so far been made available on the vegetation composition of the reserve. The present paper reports on floral diversity, economic use, and nutrient contents of selected alpine pastures at elevations between 3800 and 4800 m above sea level in the Khangchendzonga Biosphere Reserve. The growing season lasts from April to October, and during the rest of the months, the area remains under snow. The pastureland showed high species richness: as many as 202 plant species were present. These belong to 38 families, of which 90% of the species are dicotyledons and 9% are monocotyledons. Plant diversity and density increased from April until August and decreased thereafter. Monocotyledon species, such as *Poa angustifolia*, show high dominance during the early and late parts of the growing season, whereas dicot species proliferate mainly during the middle part of the growing season. Asteraceae, Ranunculaceae, Ericaceae, Primulaceae, and Rosaceae are dominant plant families in the area. Life-form distribution patterns showed that >50% of the species were chamaephytes, showing high adaptation by the plants. Besides using the area for grazing, the local people also collect various species for medicine, incense, tea-substitute, and aesthetic purposes. The belowground plant parts contributed nearly 90% of total plant biomass, whereas the aboveground biomass contributed just 10%. Such partitioning of biomass is considered beneficial in pastureland, as the belowground biomass helps the immediate recovery of vegetation after grazing as well as at the start of the growing season. Most of the species are highly nutritive and have high mineral contents, and animals showed a preference for species with low lignin content. In order for the area to continue to provide an important pasturage for animals in the future, the grazing pressure must not exceed an optimum level so that the high species diversity can be conserved.

Introduction

The Himalaya is recognized as a major biodiversity center in the world (Khoshoo, 1992). The eastern Himalaya is very rich in biodiversity and harbors the greatest number of endemic species in India (MacKinnon and MacKinnon, 1986; Myers, 1988). It is located at the juncture of the Indo-Malayan and Indo-Chinese biogeographical realms and includes both Himalayan and Peninsular Indian elements (Khoshoo, 1991). It is considered that this region, along with contiguous regions in China and Southeast Asia, constituted the evolutionary cradle for flowering plants (Takhtajan, 1969). The Khangchendzonga Biosphere Reserve in Sikkim Himalaya falls among the most important protected areas in the eastern Himalaya (Singh et al., 2002). It has extensive alpine areas that provide important pasturage for local and transhumance herders who graze their livestock, such as yaks, dzos, cattle, horses, and sheep on common pastures along with the pack animals for trekking groups and expeditions (Rai and Sundriyal, 1997). The influx of tourists and trekkers to the alpine pastures has begun to have a negative environmental impact because of excessive grazing near the camping grounds at select places, removal of rhododendron bushes for fuelwood, collection of medicinal plants and nontimber forest products, and uncontrolled disposal of trash (Singh et al., 2002).

Alpine vegetation in the western Himalaya have been the subject of previous ecological investigations (Mani, 1978; Ram et al., 1988; Rawat and Pangtey, 1987; Sundriyal, 1992). There are a few studies related to floral diversity of the alpine vegetation of selected areas (Semwal and Gaur, 1981; Dhar and Kachroo, 1993). Reports on the floral diversity of a few sites in the Sikkim Himalaya started in the nineteenth century (Hooker, 1875) and have continued ever since (Smith and Cave, 1911; Smith, 1913; Hara, 1963; Pradhan and Lachungpa, 1990). These studies, however, lack information on structure, economic use, and nutrient contents of the plant species. The baseline data on floristic and structural patterns and economic utility of plant resources are critical for ensuring the sustainable management of any area. The areas that the transhumance and nomadic graziers visit must be able to support their animals in large herds and also provide plants for other diverse purposes. Therefore the present study was undertaken in selected parts of the Khangchendzonga Biosphere Reserve in the Sikkim Himalaya to acquire data on the floristic composition, structure, flowering pattern, nutrient contents, and

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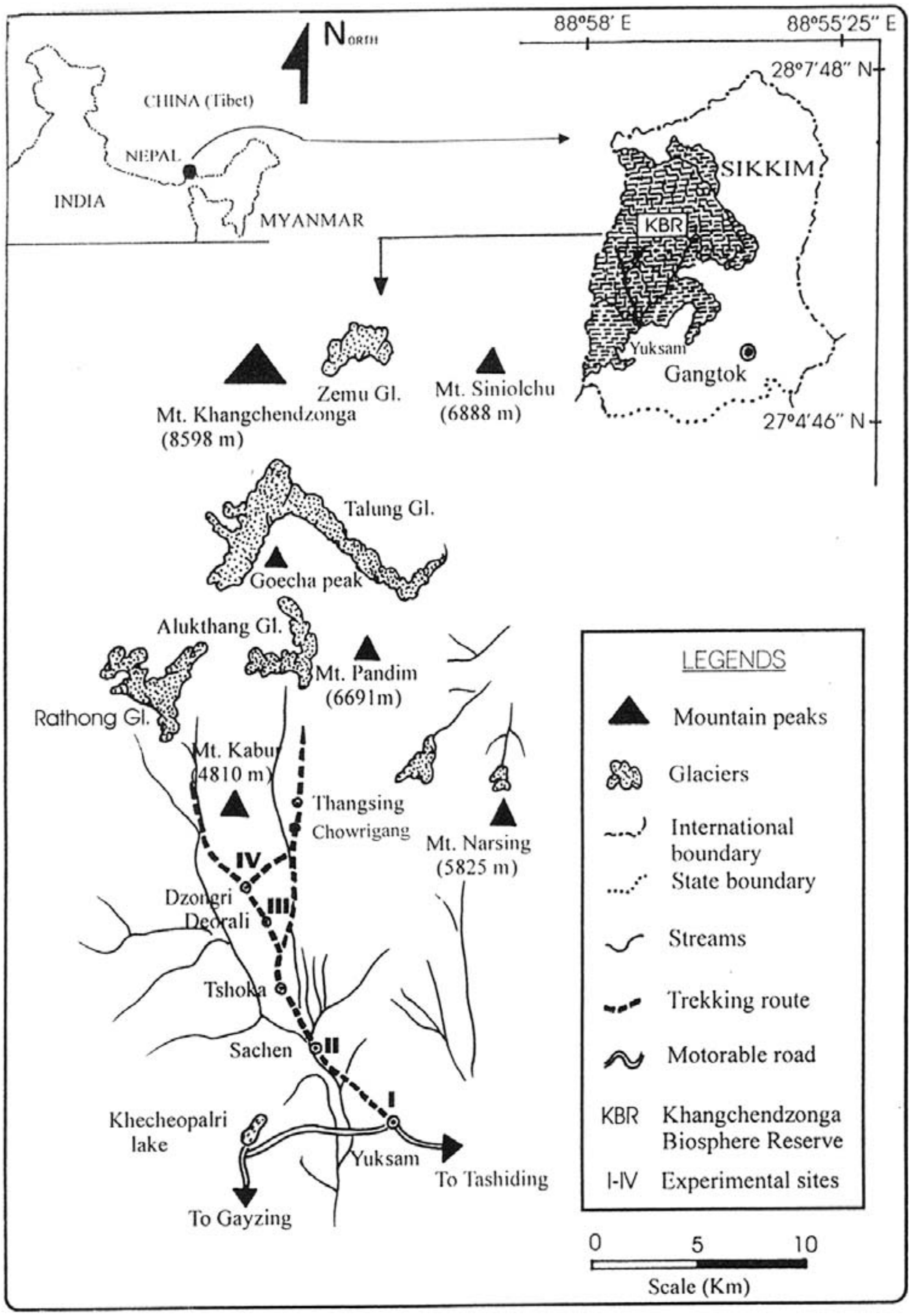

FIGURE 1. Location map of Sikkim Himalaya showing the Khangchendzonga Biosphere Reserve (KBR) (dashed shading).

economic uses of the alpine vegetation. The goal was to provide some valuable information that may further strengthen the management of such an important reserve in near future.

Study Area

Sikkim is a tiny state of India (area 7096 km^2) that falls in the eastern Himalaya. The Khangchendzonga Biosphere Reserve (27°25′N to 27°55′N and 88°30′E to 88°38′E) is located in the North and West Districts of Sikkim (Fig. 1). The biosphere reserve provides a picturesque view of snow-clad mountains, lakes, alpine vegetation, thick forests and ground vegetation in temperate and subalpine zones, and rich wildlife. Thus the reserve has high implications for conservation that relate to the entire eastern Himalayan region. The total area of the biosphere reserve is 2620 km^2; the alpine region (scrubs + pastures + barrens) accounts for 18.4% of the area. The present study area covers three major alpine pastures, namely, Dzongri, Goechala-Thangsing, and Base Camp; these cover an area of ~225 km^2 and have an altitudinal range of 3800–4800 m a.s.l. The alpine region is the popular trekking corridor for more than 2000 national and international tourists every year. A large number of dzos and horses are used as pack animals during tourist season (March to May and September to November). The local communities practice the agro-pastoral system of livelihood, and livestock animals form the backbone of this system (Singh et al., 2003).

The plant-growing season at alpine sites starts in April with the snow melt, and during June–September the area shows a lush green appearance. The vegetation starts drying from late September through the end of October, and thereafter the area is covered with snow until March of the next year. Seasonal animal relocation from lower hills to

TABLE 1

Physical and chemical properties of soils of the alpine zone in the Khangchendzonga Biosphere Reserve of the Sikkim Himalaya (±1 SE).

Properties	Parameters	Soil depth	
		0–15 cm	15–30 cm
Physical	Moisture content (%)	29.0 ± 1.3	24.9 ± 0.9
	Bulk density (g/cm^3)	1.08 ± 0.11	1.18 ± 0.11
	Soil porosity (%)	53.2 ± 2.2	60.0 ± 3.4
	Soil composition (%)		
	Clay	10.9 ± 0.8	14.0 ± 1.3
	Silt	11.5 ± 1.1	8.4 ± 0.8
	Sand	52.0 ± 1.6	62.0 ± 2.2
	Gravel	25.6 ± 0.8	15.6 ± 0.3
Chemical	Soil pH	5.41 ± 0.11	4.93 ± 0.11
	Total nitrogen (%)	0.406 ± 0.011	0.310 ± 0.008
	Total phosphorus (%)	0.019 ± 0.002	0.024 ± 0.001
	Organic carbon (%)	4.46 ± 0.06	4.66 ± 0.07

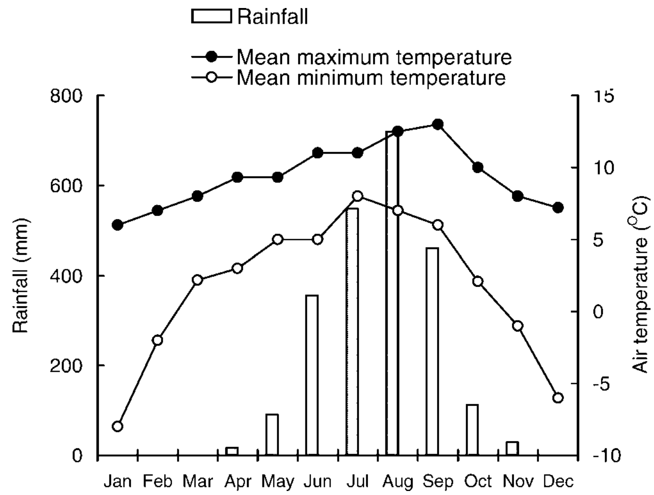

FIGURE 2. Annual rainfall and temperature of Dzongri alpine meadow in the Khangchendzonga Biosphere Reserve, Sikkim Himalaya.

alpine meadows during the plant-growth season is a common strategy for securing sufficient forage for grazing animals. A large number of livestock—namely, yaks, dzos, horses, cattle, and sheep—graze in the alpine pastures during the snow-free period (May to October) and are brought down to the lower-altitude forested areas during colder months (November to April). Besides, the reserve is also visited by local communities for collection of fuel, fodder, and medicinal plants.

Geologically the Khangchendzonga Biosphere Reserve is composed of rocks of the Darjeeling Group; these are mainly high-grade gneisses, consisting of quartz and feldspar with streaks of biotite (GSI, 1984). The soils are loose with 50–60% sand and acidic in nature (pH varies from 4.93 to 5.41) (Table 1). The organic carbon, nitrogen, and phosphorus contents of soils are fairly good. The area has a monsoon-controlled climate; more than 80% of the average annual precipitation of 2300 mm comes in June through September (Fig. 2). The scant precipitation during November to March is mainly in the form of snow. The mean monthly maximum temperature is 13°C (September), and the mean minimum is –8°C (January).

Methods

The field survey was carried out during 1996–1999 on monthly basis from April to November (during the rest of the months, the ground is covered with snow). Random quadrats of 5 × 5 m size were laid at six different locations, namely, Dzongri, Base Camp, Goechala, Thangsing, Chowrigang, and Deorali ($n = 25$ at each location). All the plant species encountered were collected and identified with the help of experts. A checklist of all plant species encountered in the sampling along with their respective life-forms and flowering period are arranged according to Bentham and Hooker's sequence (Appendix 1). Biological spectra were prepared that separated different plant growth and life-forms, following Raunkiaer (1934) and Rawat and Pangtey (1987). The detailed structural analysis of vegetation was conducted in 1998 and 1999, and subsequently the data were combined, because climate, seasonality, and periodicity of growth and phytomass did not vary significantly during the two-year period. The plant density, frequency (F), and abundance (A) (Misra, 1968) and the A/F ratio (Whitford, 1949) were analyzed for all the species from the randomly sampled 1 × 1 m plots ($n = 25$) at three main alpine pastures (namely, Dzongri, Base Camp, and Thangsing-Goechala) during April, June, August, and October. The density of any given species at a site was calculated by dividing the total number of individuals of that species in all quadrats with the total number of quadrats studied at that site. The relative dominance was computed by summing the total basal cover of a species in all quadrats at a given site times 100 and then dividing that value by the total basal area of all species in all quadrats at that site (Misra, 1968). The importance value index (IVI) was determined as the sum of relative dominance, relative frequency, and relative density (Phillips, 1959). Species richness (Margalef, 1957), diversity (Shannon, 1948), equitability (Buzas and Gibson, 1969), and dominance (Simpson, 1949) were also estimated for each site. To assess the plant biomass at each of the three major alpine pastures, 15 random quadrats of 1 × 1 m size were harvested during April, June, August, and October. The aboveground plant material was clipped close to the ground and separated according to species. Belowground phytomass was separated from the monoliths. Litter material was hand-picked after harvesting of aboveground material. The belowground plant material was collected from 15 randomly collected soil monoliths of 25 × 25 cm down to a depth of 30 cm. Further details of the methodology are presented in Singh (2000).

Nutrient contents were analyzed for the plant samples collected during August, which is peak growth period, following standard methods (Allen, 1989; Anderson and Ingram, 1993). Crude fiber was determined by the acid and alkali digestion method using Tecator AB Fibretec apparatus System M_2 (1017 hot extract unit and 1018 cold extract unit, Hoganas, Sweden). Acid detergent–soluble lignin was determined by defatting a known mass of plant sample initially with acetone (cold extraction) and thereafter with acid detergent solution (hot extraction). Cellulose was determined by difference of acid detergent–soluble fiber minus acid detergent–soluble lignin. Hemicellulose was determined as the difference between detergent nutrient fiber and acid detergent–soluble fiber by using a Fibretec apparatus. Nitrogen was estimated following a modified Kjeldahl method (Allen, 1989). Crude protein was obtained by multiplying the nitrogen percent by a factor of 6.25, which is based on the assumption that plant protein consists of 16% nitrogen. Phosphorus was estimated by colorimetric determination using molybdate reagent and ascorbic acid, and absorbance was measured at 880 nm in a UV Spectrascan unit (Anderson and Ingram, 1993). Organic carbon in the soil samples was estimated after partial oxidation with an acidified dichromate solution by using a modified Walkey-Black method (Anderson and Ingram, 1993).

Results

The Khangchendzonga Biosphere Reserve covers nearly 36% of the total land area of the Sikkim State (Fig. 1). The environment of the

TABLE 2

Statistical analysis of the alpine plants of the Khangchendzonga Biosphere Reserve.

Group	Families		Genera		Species	
	Number	(%)	Number	(%)	Number	(%)
Dicotyledons	29	76.3	86	84.3	181	89.6
Monocotyledons	8	21.1	15	14.7	19	9.4
Gymnosperms	1	2.6	1	1.0	2	1.0
Total	38	100.0	102	100.0	202	100.0

area shows great seasonality; major rainfall and moderate temperatures from May to October make that period the best growing season (Fig. 2). For rest of the year, the snow cover does not allow any plant to grow. The soils of the area under investigation have a sandy-loam structure with more nitrogen content in the upper part of the soil cross section and high phosphorus and organic carbon at lower soil depths (Table 1).

FLORAL COMPOSITION, STRUCTURE, LIFE-FORMS, AND BIOMASS

Plants germinated soon after the end-of-April snow melt that commenced the growing season. Maximum species growth was registered during June–August, which was the period of higher rainfall and warmer temperature that provided the best growing conditions. A total of 202 plants species including 102 genera and 38 families (29 dicots, 8 monocots, and 1 gymnosperm) were collected from the study area. These species varied in their life-forms, vegetative growth habits, and flowering period (Appendix 1). Nearly 90% are dicots and 9% are monocots (Table 2). The most dominant families in the study area are Asteraceae (22 species), Ranunculaceae (19 species), Ericaceae (16 species), and Primulaceae (14 species) (Fig. 3). Among different life-forms, chamaephytes showed a clear dominance as more than 50%

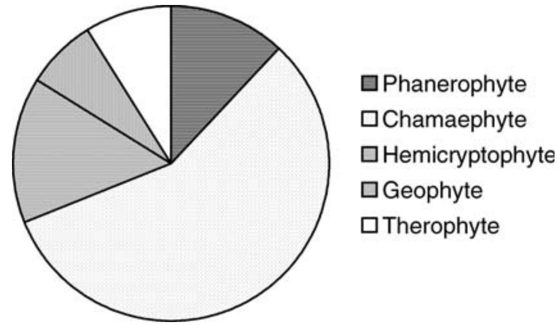

FIGURE 4. Life-form spectra of various alpine plants in the Khangchendzonga Biosphere Reserve, Sikkim Himalaya.

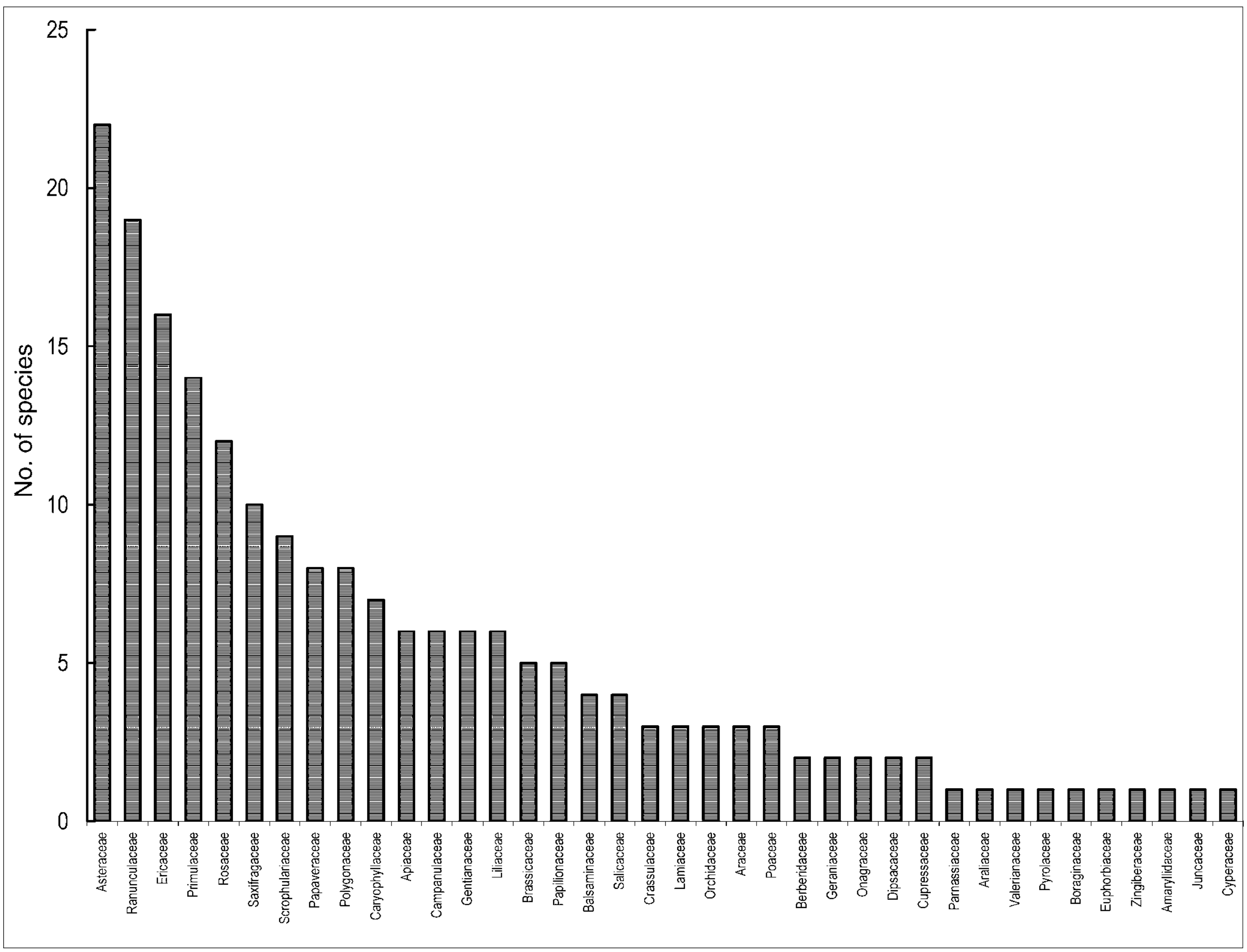

FIGURE 3. Major families and number of plant species encountered in the alpine pasture study area in the Khangchendzonga Biosphere Reserve, Sikkim Himalaya.

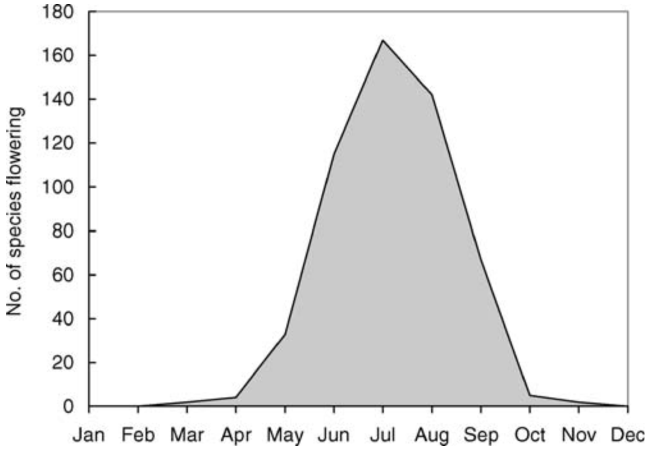

FIGURE 5. Temporal distribution of flowering in alpine plants at Khangchendzonga Biosphere Reserve, Sikkim Himalaya.

of the species were in this category, followed by therophytes (15.3%), hemicryptophytes (14.9%), phanerophytes (12.4%), and geophytes (7.4%) (Fig. 4).

Selected species flowered just after the start of the growing season, e.g., *Bergenia ciliata* started flowering by end of April. *Hemiphragma heterophyllum* also started early flowering that lasted until August (Appendix 1). June to August formed the peak flowering period, and as many as 115, 167, and 142 species recorded blooming in these months, respectively (Fig. 5). The plant-species density increased from April onward; it peaked in August and decreased thereafter. The plant density ranged between 920 and 2075 plants per square meter in different months. *Poa angustifolia* was the species growing at the highest density during April (447 plants per square meter), August (604 plant/m^2), and October (534 plants per square meter), and *Bistorta affinis* showed the highest density for June (387 plants per square meter). The highest *A/F* ratios were also shown by these species in the same respective months. The species having the highest importance value index was *Poa angustifolia* during April and October, *Potentilla coriandrifolia* during June, and *Potentilla peduncularis* during August (Table 3).

TABLE 4

Species richness, diversity, equitability, and concentration of dominance of alpine vegetation (± 1 SE).

Indices	Growing months			
	April	June	August	October
Species richness	0.71	0.93	1.30	1.02
Diversity	1.48	1.81	1.99	1.28
Equitability	0.63	0.61	0.56	0.57
Dominance	0.30	0.30	0.17	0.22
Biomass (g m^{-2})				
Aboveground	134 ± 8.8	208 ± 16.7	310 ± 6.3	181 ± 11.0
Belowground	1104 ± 32.7	1011 ± 24.4	927 ± 16.6	1123 ± 32.4
Litter mass	40 ± 2.1	32 ± 6.1	9 ± 0.9	28 ± 1.7
Root:shoot ratio	6.34	4.86	2.99	6.20

Plant-species richness and diversity indices were also highest in August. On the contrary, the equitability and dominance indices were higher during the initial growth period, showing that only a few species dominated at that period (Table 4). The aboveground biomass registered a continuous increase from April onward and peaked during August, and it ranged between 134 and 310 g m^{-2} for different months (Table 4). On the contrary, the proportion of belowground biomass reached a minimum in August. The belowground biomass was fairly high at the start of growing season, decreased in subsequent months, and again peaked in October before close of the growing season. It ranged from 927 to 1104 g m^{-2} for different months. The contribution of belowground biomass to total plant biomass was always higher

TABLE 3

Structure of alpine vegetation in the Khangchendzonga Biosphere Reserve (±1 SE). Where the species was either absent or not encountered in the sampling quadrats, the cell is marked with a dash (—); A/F is abundance/frequency ratio.

Species	April			June			August			October		
	Density	*A/F*	IVI	Density	*A/F*	IVI	Density	*A/F*	IVI	Density	*A/F*	IVI
Poa angustifolia	447 ± 12	1.24	113.4	278 ± 8.4	0.695	38.24	604 ± 27	1.863	50.7	534 ± 11	1.649	97.42
Poa pseudamoena	123 ± 3.9	0.38	36.05	123 ± 6.9	0.626	15.55	276 ± 3.8	0.853	26.9	222 ± 7.6	0.556	36.85
Poa pratensis	62 ± 4.3	0.19	25.17	—	—	—	58.6 ± 2	0.407	10.8	126 ± 9.1	0.316	26.78
Potentilla peduncularis	178 ± 6.8	0.55	66.61	129 ± 4.2	0.323	39.82	450 ± 11	1.125	86	84.6 ± 7	0.261	46.92
Potentilla coriandrifolia	8 ± 0.5	0.05	13.1	343 ± 12	0.857	81.48	151 ± 10	0.591	33.1	40.4 ± 3	0.239	23.84
Potentilla microphylla	—	—	—	125 ± 7	0.31	20.85	—	—	—	107 ± 6.3	0.269	34.05
Gentiana phyllocalyx	51 ± 2.1	0.16	24.4	42 ± 6.1	0.131	11.97	92 ± 4.4	0.36	16.5	26.9 ± 2	0.081	15.42
Bistorta affinis	51 ± 1.9	0.3	21.24	386 ± 8	0.967	44.34	130.4 ± 4	0.402	25.9	36 ± 2.9	0.184	18.72
Aletris pauciflora	—	—	—	108 ± 1.6	0.271	19.61	226.4 ± 9	0.627	29.7	—	—	—
Phlomis rotata	—	—	—	4.8 ± 0.1	0.078	4.83	—	—	—	—	—	—
Orchis latifolia	—	—	—	4.6 ± 0.2	4.6	0.8	—	—	—	—	—	—
Phaeonychium parryoides	—	—	—	26.6 ± 2	0.092	9.31	—	—	—	—	—	—
Cyananthus lobatus	—	—	—	2.8 ± 0.1	0.311	1.70	—	—	—	—	—	—
Pedicularis hoffmeisteri	—	—	—	5.2 ± 0.1	0.106	4.4	4.8 ± 0.5	0.192	3.78	—	—	—
Corydalis juncea	—	—	—	0.2	0.05	1.02	—	—	—	—	—	—
Arisaema griffithii	—	—	—	12 ± 0.6	0.128	5.91	—	—	—	—	—	—
Euphorbia stracheyi	—	—	—	—	—	—	5.6 ± 0.7	0.184	3.64	—	—	—
Potentilla plurijuga	—	—	—	—	—	—	27 ± 1.3	0.756	6.33	—	—	—
Hemiphragma heterophyllum	—	—	—	—	—	—	42.8 ± 5	0.428	8.6	—	—	—
Primula calderana	—	—	—	—	—	—	6.4 ± 4.8	0.4	4.32	—	—	—
Total	920	—	300	1592	—	300	2075	—	300	1177	—	300

TABLE 5

Economic plant wealth of alpine region in the Khangchendzonga Biosphere Reserve.

Uses and species	Local name	Parts, uses, and mode of uses
Medicinal		
Aconitum ferox	''Bikhma''	Fresh root juice is taken for fever. Higher concentration can be given for food poisoning. Dried roots are used for jaundice and diabetes.
Aconitum hookeri	''Bikhma''	Fresh root juice is taken for fever. Higher concentration can be given for food poisoning. Dried roots are used for jaundice and diabetes.
Bergenia ciliata	''Pakhanbed''	Soup of fried root in boiling water is taken for fever and diarrhea. Higher concentration can be recommended for fever.
Heracleum wallichii	''Chim-phing''	Tender shoots cooked and eaten for gastric problems. Dry fruit powder is used for influenza.
Nardostachys jatamansi	''Jatamansi''	Root soup prepared in boiling water is taken for malaria fever. Dried root powder can be applied for hair loss and also used for epilepsy.
Orchis latifolia	''Panch-aungley''	Fresh root paste with root of *Rheum nobile*, *Rheum australe*, and *Swertia multicaulis* is used for bone fractures, wounds, bruises, and body aches.
Picrorhiza kurroa	''Kutki''	Fresh or dry root boiled in water is taken for cold, cough, and (at a higher dose) fever.
Ponerorchis chusua	''Syanu panch-aungley''	Fresh root paste is applied to cuts, wounds, bruises, and injuries.
Rheum australe	''Khokim''	Root paste is used as a bandage for minor bone fractures and also administered externally for chest pain. Soup prepared from the root is taken for body ache.
R. nobile	''Kenjoh''	Fresh root paste is administered externally for chest pain. Root soup prepared in boiling water can also be taken for the same.
Swertia multicaulis	''Sarma-guru''	Fresh root paste is used for cuts, wounds, other injuries, and bone fractures.
Incense		
Cremanthodium reniforme	''Dhup''	Branchlet along with leaves
Juniperus indica	''Dhupee''	Branchlet along with leaves, used extensively in Buddhist monasteries
J. recurva	''Dhupee''	Branchlet along with leaves, used extensively in Buddhist monasteries
Rhododendron anthopogon	''Sunpate''	Branchlet along with leaves
R. lepidotum	''Sunpate''	Branchlet along with leaves
R. setosum	''Sunpate''	Branchlet along with leaves
Tea substitute		
Rheum australe	''Khokim''	Root used both fresh and dried. One 1 × 1 × 1 cm cube is sufficient for a cup of tea.
Fuelwood		
Rhododendron anthopogon	''Sunpate''	Whole plant
R. fulgens	''Chimal''	Whole plant
R. setosum	''Sunpate''	Whole plant
R. thomsonii	''Chimal''	Whole plant
Juniperus indica	''Dhupee''	Whole plant
J. recurva	''Dhupee''	Whole plant
Edible		
Rheum nobile	''Khokim''	Tender shoots are prepared as pickles.
Miscellaneous uses		
Bergenia ciliata	''Pakhanbet''	Growing in home garden
Primula spp.	''Primula''	Growing in home garden
Rhododendron fulgens	''Chimal''	Made field implement handle from wood

than the aboveground biomass, which shows the importance of the underground parts of plants in such a harsh environment. High litter mass was registered at the start of growing season, which was from the previous year's phytomass. It ranged between 9 and 40 g m^{-2} during different sampling intervals (Table 4). The root:shoot ratio was higher at the start and end of growing season owing to lower aboveground biomass at that period (Table 4).

ECONOMIC UTILITIES OF PLANTS

The alpine plant species are used for diverse purposes by the local peoples. Uses of plant species include medicinal (11 species), incense

TABLE 6

Nutrient concentration of dominant alpine plant species in the Khangchendzonga Biosphere Reserve (±1 SE).

Species	Crude fiber	Cellulose	Hemicellulose	Lignin	Total nitrogen	Total phosphorus	Crude protein
Poa angustifolia	23.71 ± 0.91	21.53 ± 0.87	35.54 ± 0.13	16.81 ± 0.23	1.12 ± 0.03	0.209 ± 0.012	7.00
Poa pseudamoena	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 pratensis	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	14.72 ± 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

(6 species), tea-substitute and edible (a single species each), fuelwood (6 species), garden pot plants, and field implements purposes (Table 5). The plants are collected to cure fever, jaundice, diabetes, diarrhea, gastric problems, influenza, hair loss, epilepsy, cuts and wounds, bruise and injuries, bone fractures, body aches, and chest pain. The root of *Rheum australe* is used in both fresh and dry forms as a tea-leaf substitute by the nomads and also cures body aches. Branches of selected species such as *Rhododendron*, *Juniperus*, and *Cremanthodium* were collected in large quantities and used as incense; the branches are commonly sold in the local markets. The branches are also used for incense in the Buddhist monasteries.

NUTRIENTS

Nutrient concentrations of the 10 most dominant alpine plants were analyzed (Table 6). Crude fiber content of the plant species ranged between 11.41 and 28.45%, the highest being in *Potentilla peduncularis* and the least in *Poa pratensis* (Table 6). Cellulose content ranged between 4.59 and 33.19%; the highest values were recorded for *Aletris pauciflora*, and the least were for *Bistorta affinis*. Hemicellulose content ranged between 19.71 and 35.84%; the highest were for *Hemiphragma heterophyllum*, and the lowest were for *Potentilla coriandrifolia*. Lignin content ranged between 9.32 and 23.11% among various species. Total nitrogen content was estimated at 1.06–1.87%, whereas the phosphorus content varied between 0.185 and 0.377% among the studied species. The crude protein ranged between 6.63 and 11.69%; the highest content was recorded for *Poa pseudamoena*, and the lowest was for *Aletris pauciflora*.

Discussion

The present investigation was limited to a few select pastures that showed high species diversity. By extrapolation, the results indicate that the region has a very rich vegetation composition. Dicots were the most dominant plant types, a result that is well comparable with the data from the central Himalaya where 92% of the species were dicots and 8.3% were monocots (Rawat and Pangtey, 1987). The percentage of chamaephytes (50%) was higher at the present study site than has been reported for the alpine vegetation of the central Himalaya (46.7%) and western Himalaya (46.4%) (Dhar and Kachroo, 1993). The chamaephyte percentage was much higher than was recorded for the Rudranath flora (31%) (Ram et al., 1988). The present study site had more woody plants than alpine sites of the central and western Himalaya. The geophytes (7.4%) are comparatively rarer at the present site than at the Rudranath flora site (28.9%), indicating that rhizomatous plants are rarer in the present study area. Asteraceae, Ranunculaceae, Ericaceae, Rosaceae, and Saxifragaceae were the most dominant families (i.e., they had higher numbers of plant species), thus showing a wider adaptability to cold alpine environment. Such species composition may be attributed to relatively better environmental conditions in the eastern Himalayan region than the central and western ones. Most of the plants bloomed during June to August when the temperature and rainfall were relatively higher than in other months. This finding was in accordance with the reports presented on the phenology of alpine species from central Himalaya (Sundriyal et al., 1987; Ram et al., 1988, Rikhari et al., 1992). The aboveground plant biomass showed an increasing trend from start of the growing season, peaked during August, and decreased thereafter again. On the contrary, the belowground biomass was high at the start and end of the growing season. Similar reports are available from the western and central Himalaya (Kaul and Sapru, 1973; Ram et al., 1988; Rikhari et al., 1992; Sundriyal and Joshi, 1990).

The rainy season (June–August) provided better growth conditions; therefore plants achieved higher aboveground biomass in this period, which helped to store and accumulate higher belowground biomass before closure of the season. The greater volume of belowground biomass is considered beneficial for growing new tissue at the start of next growing season (Sundriyal, 1992). It is an important adaptation in plants for survival under snow because after the snow melts, underground plant parts regenerate the new aboveground parts. The nutrient levels, particularly nitrogen and phosphorus contents, of various species are in accordance with those reported for the species from central Himalayan alpine vegetation (Sundriyal and Joshi, 1992). The cellulose and lignin contents are related to palatability of the species. *Poa pseudamoena* and *Juncus thomsonii* were highly palatable, and the protein content of these species was also estimated high. On the contrary, *Potentilla peduncularis* and *Bistorta affinis* were least palatable, probably because of their high lignin content. A higher concentration of unpalatable species at a particular pasture location was perhaps an indication that that area suffers high grazing pressure, as most of the palatable species have been removed by grazing (Sundriyal and Joshi, 1992; Sundriyal, 1995).

The influx of trekkers and mountaineers to the alpine areas has an obvious environmental impact in the form of excessive grazing near the camping grounds. It also led to the removal of rhododendrons for fuelwood and the disposal of trash at many sites (Singh et al., 2002). Furthermore, trampling of vegetation by trekkers and pack animals has resulted in an increase of patches of bare ground and conspicuous erosion near the trails. Heavy grazing occurred during the growing season.

Two years' protection of vegetation from livestock grazing (1997–1998) increased the pastures' aboveground biomass by 50% and plant density by 40% (Singh et al., 2003). This result indicates that there is a need to adopt a grazing regime to avoid the adverse impact of overgrazing.

Because a large number of species are also collected for diverse needs, the populations of some of these species have been reduced. *Aconitum hookeri*, *Picrorhiza kurooa*, *Orchis latifolia*, *Rheum australe*, and *Nardostachys jatamansi* have been particularly affected, as all these species are collected for medicinal purposes (Rai et al., 2000). Furthermore, the trekkers and local porters commonly collect attractive plant species without knowing their importance. Therefore, awareness is needed to educate these trekkers and local porters.

In the economy of high-altitude dwellers in Sikkim, animals play an important role (Singh, 2000). They provide valuable animal proteins in the form of milk, meat, and other by-products. Large numbers of them are also used as pack animals for tourists and trekkers, which allows their owners to earn direct money. Grazing is adopted as the easiest mean to support animals. Therefore, banning of livestock grazing in the alpine zone is not advisable; instead, a management option such as rotational grazing can be suggested based on the grazing carrying capacity of different pastures. This approach will ensure better pasture status as well as animal health, and the pastureland vegetation could be conserved for years to come.

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APPENDIX 1

List of plant species encountered from the study area. Life-form abbreviations are as follows: Ph = Phanerophytes; Ch = Chamaephytes; He = Hemicryptophytes; Ge = Geophytes, Th = Therophytes.

Families/species	Flowering-period	Life-forms
RANUNCULACEAE (Buttercup family)		
1. *Aconitum ferox* Wallich ex Seringe	Aug–Sep	Ch
2. *A. hookeri* Stapf	Aug–Sep	Ch
3. *A. violaceum* Jacquem. ex Stapf	Jul–Sep	Ch
4. *Anemone obtusiloba* D. Don	May–Jul	Ch
5. *A. polyanthes* D. Don	Jun–Jul	Ch
6. *A. revularis* Buch.-Ham. ex DC.	Jun–Jul	Ch
7. *A. tetrasepala* Royle	Jun–Aug	He
8. *Callianthemum pimpinelloides* (D. Don) Hook. f. Thoms.	Jun–Jul	Ch
9. *Caltha palustris* Linn.	May–Jun	Ch
10. *Delphinium brunonianum* Royle	Jul–Sep	He
11. *D. drepanocentrum* (Bruhl) Munz	Jul–Sep	He
12. *D. graciale* Hook. f. & Thoms.	Jul–Sep	He
13. *D. viscosum* Hook. f. & Thoms.	Aug–Sep	He
14. *Oxygraphis polypetala* (Royle) Hook. f. & Thoms.	Apr–Jun	Ch
15. *Ranunculus adoxifolius* Hand.-Mazz.	May–Jul	Ch
16. *R. diffusus* DC.	May–Jul	Ch
17. *R. hirtellus* Royle ex D. Don	May–Aug	Ch
18. *R. pulchellus* C. Meyer	Jun–Aug	Ch
19. *Thalictrum alpinum* Linn.	May–Aug	Ch
BERBERIDACEAE (Barberry family)		
20. *Berberis angulosa* Wallich ex Hook. f. & Thoms.	Jun–Aug	Ph
21. *B. concinna* Hook. f.	Jun–Jul	Ph
PAPAVERACEAE (Poppy family)		
22. *Corydalis cashmeriana* Royle	May–Aug	Th
23. *C. chaerophylla* DC.	Jun–Sep	Ch
24. *C. juncea* Wallich	Jun–Jul	Ch
25. *C. meifolia* Wallich	Jun–Aug	Ch
26. *Meconopsis dhwojii* G. Taylor	Jun–Jul	Ch
27. *M. grandis* Prain	Jul–Aug	Ch
28. *M. horridula* Hook. f. & Thoms.	Jul–Aug	Ch
29. *M. paniculata* Prain	Jun–Aug	Ch
BRASSICACEAE (Mustard family)		
30. *Braya oxycarpa* Hook. f. & Thoms.	Jun–Jul	He
31. *Ermania himalayensis* (Cambess) O.E. Schulz	Jun–Aug	Th
32. *Lignariella hobsonii* (Pearson) Baehni	Jun–Jul	Th
33. *Pegaeophyton scapiflorum* (Hook. f. & Thoms.) Marquand	Jul–Aug	Ge
34. *Phaeonychium parryoides* (Kurz ex Hook. f. & T. Anderson) O.E. Schulz	Jun–Aug	Ge
CARYOPHYLLACEAE (Pink or Carnation family)		
35. *Arenaria bryophylla* Fern.	Jul–Aug	Ch
36. *A. densissima* Wallich ex Edgew. & Hook. f.	Jun–Aug	Ch
37. *A. glanduligera* Edgew. ex Edgew. & Hook. f.	Jul–Sep	Ch
38. *Gypsophila cerastioides* D. Don	Jun–Jul	He
39. *Silene nigrescens* (Edgew.) Majumdar	Jul–Sep	Ch
40. *S. setisperma* Majumdar	Jul–Sep	Ch
41. *Thylacospermum caespitosum* (Cambess.) Schischkim	Jul–Aug	Ch
GERANIACEAE (Geranium family)		
42. *Geranium nakaoanum* Hara	Jun–Aug	Ch
43. *G. wallichianum* D. Don ex Sweet	Jun–Aug	Th

APPENDIX 1

(Cont.).

Families/species	Flowering-period	Life-forms
BALSAMINACEAE (Balsam family)		
44. *Impatiens bicornuta* Wallich	Jul–Sep	Ch
45. *I. glandulifera* Royle	Jul–Sep	Ch
46. *I. stenantha* Hook. f.	Jul–Aug	Ch
47. *I. urticifolia* Wallich	Jun–Aug	Ch
PAPILIONACEAE (Pea family)		
48. *Astragalus floridus* Benth. ex Bunge	Jun–Aug	Th
49. *Chesneya nubigena* (D. Don) Ali	Jun–Aug	Ch
50. *Gueldenstaedtia himalaica* Baker	Jul–Aug	Ch
51. *Hedysarum sikkimensis* Benth. ex Baker	Jul–Aug	Ch
52. *Parochetus communis* Buch.-Ham. ex D. Don	May–Nov	Th
ROSACEAE (Rose family)		
53. *Cotoneaster microphyllus* Wallich ex Lindley	Jun–Jul	He
54. *Fragaria nubicola* Lindley ex Lacaita	May–Aug	He
55. *Geum sikkimensis* Prain.	Jun–Aug	He
56. *Potentilla astrosanguinea* Lodd.	Jun–Aug	He
57. *P. coriandrifolia* D. Don	Jun–Aug	He
58. *P. fruticosa* Linn.	Jul–Sep	Ph
59. *P. microphylla* D. Don	Jun–Jul	He
60. *P. peduncularis* D. Don	Jun–Aug	He
61. *P. plurijuga* Hand.-Mazz.	Jun–Jul	He
62. *Rosa sericea* Lindley	May–Aug	Ph
63. *Sorbus microphylla* Wenzig	Jun–Jul	Ph
64. *Spiraea arcuata* Hook. f.	Jun–Jul	Ph
SAXIFRAGACEAE (Saxifrage family)		
65. *Bergenia ciliata* (Haw.) Sternb.	Mar–Jul	Ch
66. *Saxifraga asarifolia* Sternb.	Jul–Aug	Ch
67. *S. brachypoda* D. Don	Jul–Aug	Ch
68. *S. brunonis* Wallich ex Seringe	Jun–Sep	Ch
69. *S. engleriana* Harry Smith	Jun–Jul	Ch
70. *S. jacquemontiana* Decne	Jul–Sep	Ch
71. *S. lychnitis* Hook. f. & Thoms.	Jul–Aug	Ch
72. *S. parnassifolia* D. Don	Aug–Oct	Ch
73. *S. pulvinaria* Harry Smith	Jun–Aug	Ch
74. *S. stenophylla* Royle	Jun–Aug	Ch
PARNASSIACEAE (Parnassus family)		
75. *Parnassia nubicola* Wallich ex Royle	Jul–Aug	Th
CRASSULACEAE (Stonecrop family)		
76. *Rhodiola bupleuroides* (Wallich ex Hook. f. & Thoms.) S.H. Fu	Jul–Aug	Ch
77. *R. himalensis* (D. Don) S.H. Fu	Jun–Aug	Ch
78. *R. quadrifida* (Pallas) Fischer & C. Meyer	Jun–Aug	Ch
ONAGRACEAE (Willow-Herb family)		
79. *Epilobium latifolium* Linn.	Jul–Aug	Th
80. *E. wallichianum* Hausskn.	Jul–Sep	Th
APIACEAE (Umbelliferi family)		
81. *Cortia depressa* (D. Don) Norman	Jun–Aug	Ch
82. *Cortiella hookeri* (C.B. Clarke) Norman	Jul–Sep	Ch
83. *Heracleum wallichii* DC.	Jul–Sep	He
84. *H. nepalense* D. Don	Jun–Aug	He
85. *Pleurospermum benthamii* (DC) C.B. Clarke	Jun–Jul	He
86. *Selinum tenuifolium* Wallich ex C.B. Clarke	Jul–Aug	Ch

APPENDIX 1

(Cont.).

Families/species	Flowering-period	Life-forms
ARALIACEAE (Ivy family)		
87. *Panax pseudo-ginseng* Wallich	Jul–Sep	Ge
VALERIANACEAE (Valerian family)		
88. *Nardostachys grandiflora* DC.	Jun–Aug	Ge
DIPSACACEAE (Scabious family)		
89. *Morina nepalensis* D. Don	Jun–Aug	Ch
90. *M. polyphylla* Wallich ex DC.	Jun–Aug	Ch
ASTERACEAE (Daisy family)		
91. *Anaphalis triplinervis* (Sims) C.B. Clarke	Jul–Sep	Th
92. *Aster himalaicus* C.B. Clarke	Aug–Sep	Th
93. *A. stracheyi* Hook. f.	Jul–Aug	Th
94. *Cicerbita macrorhiza* (Royle) Beauv.	Aug–Sep	Th
95. *Cirsium falconeri* (Hook. f.) Petrak	Aug–Sep	Th
96. *Cremanthodium nepalense* Kitam	Jul–Aug	Th
97. *C. oblongatum* C.B. Clarke	Jun–Aug	Th
98. *C. reniforme* (DC) Benth	Jun–Aug	Th
99. *C. retusum* (Wallich ex Hook. f.) R. Good	Aug–Sep	Th
100. *Jurinea dolomiaea* Boiss.	Jul–Sep	Ch
101. *Leontopodium himalayanum* DC.	Jul–Sep	Ch
102. *L. jacotianum* Beauverd	Jul–Sep	Ch
103. *Saussurea costus* (Falc.) Lipsch	Jul–Sep	Ch
104. *S. gossypiphora* D. Don	Jul–Sep	Ch
105. *S. graminifolia* Wallich ex DC.	Aug–Sep	Ch
106. *S. nepalensis* Sprengel	Jul–Sep	Ch
107. *S. obvallata* (DC.) Edgew.	Jul–Sep	Ch
108. *Senecio chrysanthemoides* DC.	Aug–Sep	Th
109. *S. diversifolius* Wallich ex DC.	Aug–Sep	Th
110. *Soroseris hookerana* (C.B. Clarke) Stebbins	Jul–Aug	Ch
111. *Tanacetum gossypinum* Hook. f. & Thoms. ex C.B. Clarke	Aug–Sep	Ch
112. *Waldheimia glabra* (Decne.) *Regel*	Aug–Sep	Ch
CAMPANULACEAE (Bellflower family)		
113. *Campanula modesta* Hook. f. & Thoms.	Jun–Aug	Th
114. *Codonopsis dicentrifolia* (C.B. Clarke) W.W. Smith	Aug–Sep	Th
115. *C. thalictrifolia* Wallich	Jul–Aug	Th
116. *Cyananthus incanus* Hook. f. & Thoms.	Jul–Sep	Ch
117. *C. microphyllus* Edgew	Aug–Sep	Ch
118. *C. lobatus* Wallich ex Benth.	Jul–Sep	Ch
ERICACEAE (Heath family)		
119. *Cassiope fastigiata* (Wallich) D. Don	Jun–Aug	Ch
120. *Gaultheria pyroloides* Hook. f. & Thoms. ex Miq.	Jun–Jul	Ch
121. *G. trichophylla* Royle	May–Jul	Ch
122. *Rhododendron aeruginosum* Hook. f.	Jun–Jul	Ph
123. *R. anthopogon* D. Don	Jun–Jul	Ph
124. *R. campanulatum* D. Don	May–Jun	Ph
125. *R. ciliatum* Hook. f.	May–Jun	Ph
126. *R. fulgens* Hook. f.	Jun–Jul	Ph
127. *R. glaucophyllum* Rehder	May–Jul	Ph
128. *R. lepidotum* Wallich ex G. Don	Jun–Aug	Ph
129. *R. lowndesii* Davidian	Jun–Aug	Ph
130. *R. nivale* Hook. f.	Jun–Jul	Ph
131. *R. setosum* D. Don	Jun–Jul	Ph
132. *R. sikkimensis* Pradhan & Lachungpa	May–Jun	Ph
133. *R. thomsonii* Hook. f.	May–Jul	Ph
134. *Vaccinium nummularia* Hook. f. & Thoms. ex C.B. Clarke	May–Jun	Ph

APPENDIX 1

(Cont.).

Families/species	Flowering-period	Life-forms
PYROLACEAE (Wintergreen family)		
135. *Pyrola sikkimensis* ?	Jul–Aug	Ge
PRIMULACEAE (Primula family)		
136. *Androsace lehmannii* Wallich ex Duby	Jul–Aug	Ch
137. *Primula atrodentata* W.W. Smith	May–Jul	Ch
138. *P. calderana* Balf. f. & Cooper	Jun–Jul	Ch
139. *P. capitata* Hook.	Jul–Aug	Ch
140. *P. denticulata* Smith	May–Jun	Ch
141. *P. deuteronana* Craib	Jul–Sep	Ch
142. *P. glabra* Klatt.	Jun–Sep	Ch
143. *P. glomerata* Pax	Aug–Nov	Ch
144. *P. irregularis* Craib	Apr–May	Ch
145. *P. macrophylla* D. Don	Jun–Aug	Ch
146. *P. petiolaris* Wallich	May–Jun	Ch
147. *P. primulina* (Sprengel) Hara	Jun–Aug	Ch
148. *P. reticularis* Wallich	Jul–Aug	Ch
149. *P. sikkimensis* Hook. f.	May–Jul	Ch
GENTIANACEAE (Gentian family)		
150. *Gentiana algida* Pallas	Sep–Oct	Ch
151. *G. ornata* (G. Don) Griseb.	Sep–Oct	Ch
152. *G. phyllocalyx* C.B. Clarke	Jun–Aug	Ch
153. *G. tubiflora* (G. Don) Griseb.	Jul–Sep	Ch
154. *Megacodon stylophorus* (C.B. Clarke) Harry Smith	Jun–Jul	Ch
155. *Swertia multicaulis* D. Don	Jun–Sep	Ch
BORAGINACEAE (Borage family)		
156. *Trigonotis rotundifolia* (Wall. ex Benth.) Benth. ex C.B. Clarke	Jun–Aug	Th
SCROPHULARIACEAE (Figwort family)		
157. *Hemiphragma heterophyllum* Wallich	Mar–May	Ch
158. *Lagotis kunawurensis* (Royle ex Benth.) Rupr.	Jun–Aug	Ch
159. *Pedicularis hoffmeisteri* Klotzsch	Jul–Aug	Ch
160. *P. longiflora* var. *tubiformis* (Klotzsch) Tsoong	Jul–Aug	Ch
161. *P. megalantha* D. Don	Jun–Sep	Ch
162. *P. rhinanthoides* Schrenk	Jul–Sep	Ch
163. *P. roylei* Maxim.	Jun–Aug	Ch
164. *P. scullyana* Prain ex Maxim.	Jul–Aug	Ch
165. *Picrorhiza kurrooa* Royle ex Benth.	Jun–Aug	Ch
LAMIACEAE (Mint family)		
166. *Dracocephalum wallichii* Sealy	Jun–Aug	Th
167. *Eriophyton wallichii* Benth.	Jul–Sep	Th
168. *Phlomis rotata* Benth. ex Hook. f.	Jun–Aug	Ch
POLYGONACEAE (Dock family)		
169. *Bistorta affinis* (D. Don) Greene	Jun–Sep	He
170. *B. emodi* (Meissner) Hara	Jul–Sep	He
171. *B. macrophylla* (D. Don) Sojak	Jun–Aug	He
172. *B. vaccinifolia* (Wallich ex Meissner) Greene	Aug–Sep	He
173. *Oxyria digyna* (L.) Hill	May–Jul	Ch
174. *Persicaria polystachya* (Wallich ex Meissner) Gross	Jul–Sep	Ph
175. *Rheum australe* D. Don	Jun–Jul	Ge
176. *R. nobile* Hook. f. & Thoms.	Jun–Jul	Ge
EUPHORBIACEAE (Euphorbia family)		
177. *Euphorbia stracheyi* Boiss.	May–Aug	Th
SALICACEAE (Willow family)		
178. *Salix calyculata* Hook. f. ex Andersson	Jun–Aug	Th
179. *S. daltoniana* Andersson	May–Jun	Ph

APPENDIX 1

(Cont.).

Families/species	Flowering-period	Life-forms
180. *S. hylematica* Schneider	May–Jul	Ph
181. *S. sikkimensis* Andersson	May–Jul	Ph
CUPRESSACEAE (Cypress family)		
182. *Juniperus indica* Bertol.	Jun–Jul	Ph
183. *J. recurva* Buch.-Ham. ex D. Don	Jun–Jul	Ph
ORCHIDACEAE (Orchid family)		
184. *Galearis spathulata* (Lindley) P.F. Hunt	Jul–Sep	Ge
185. *Orchis latifolia* Linn.	Jun–Jul	Ge
186. *Ponerorchis chusua* (D. Don) Soo	Aug–Oct	Ge
ZINGIBERACEAE (Ginger family)		
187. *Roscoea alpina* Royle	Jun–Aug	Ge
AMARYLLIDACEAE (Daffodil family)		
188. *Allium wallichii* Kunth	Aug–Sep	He
LILIACEAE (Lily family)		
189. *Aletris pauciflora* (Klotzsch) Hand.-Mazz.	Jun–Aug	He
190. *Fritillaria cirrhosa* D. Don	Jun–Jul	He

APPENDIX 1

(Cont.).

Families/species	Flowering-period	Life-forms
191. *Lloydia flavonutans* Hara	Jul–Aug	Th
192. *Smilacina purpurea* Wallich	May–Jun	Ge
193. *Streptopus simplex* D. Don	Jul–Aug	Th
194. *Trillidium govanianum* (D. Don) Kunth	Jun–Jul	Th
JUNCACEAE (Rus family)		
195. *Juncus thomsonii* Buchenau	Jun–Sep	He
ARACEAE (Arum family)		
196. *Arisaema costatum* (Wallich) Martius ex Schott	May–Jun	Ge
197. *A. griffithii* Schott	May–Jun	Ge
198. *A. jacquemontii* Blume	Jun–Aug	Ge
CYPERACEAE (Cyprus family)		
199. *Carex* sp.	Aug–Sep	He
POACEAE (Grass family)		
200. *Poa angustifolia* Linn.	Jul–Sep	He
201. *P. pseudamoena* Bor	Jul–Sep	He
202. *P. pratensis* Linn.	Jul–Sep	He