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

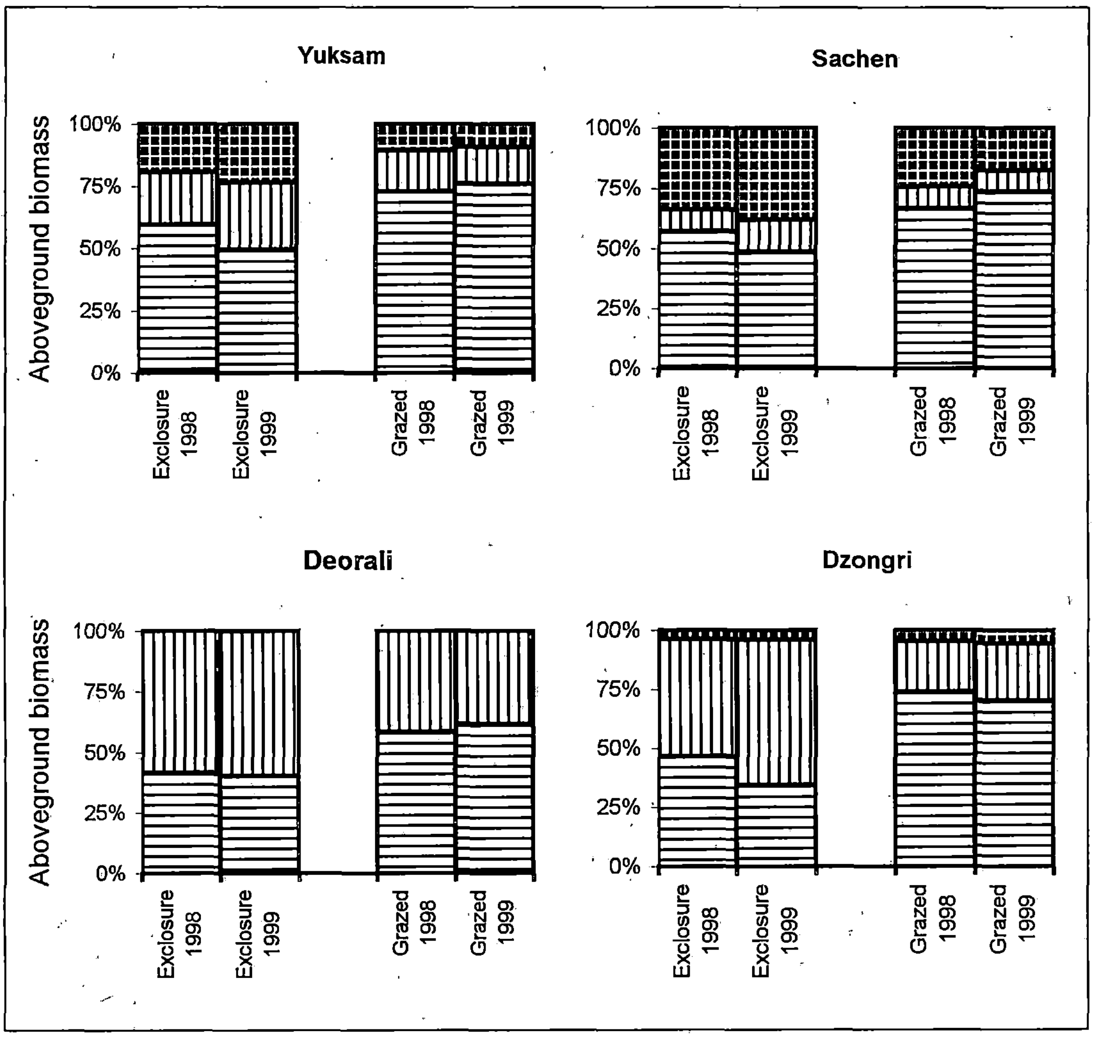

Fig. 6.1 Per cent contribution of aboveground biomass by dicot (horizontal strips), monocot (vertical strips) and others (check) plant in exclosure and grazed pots along the Yuksam-Dzongri trail.

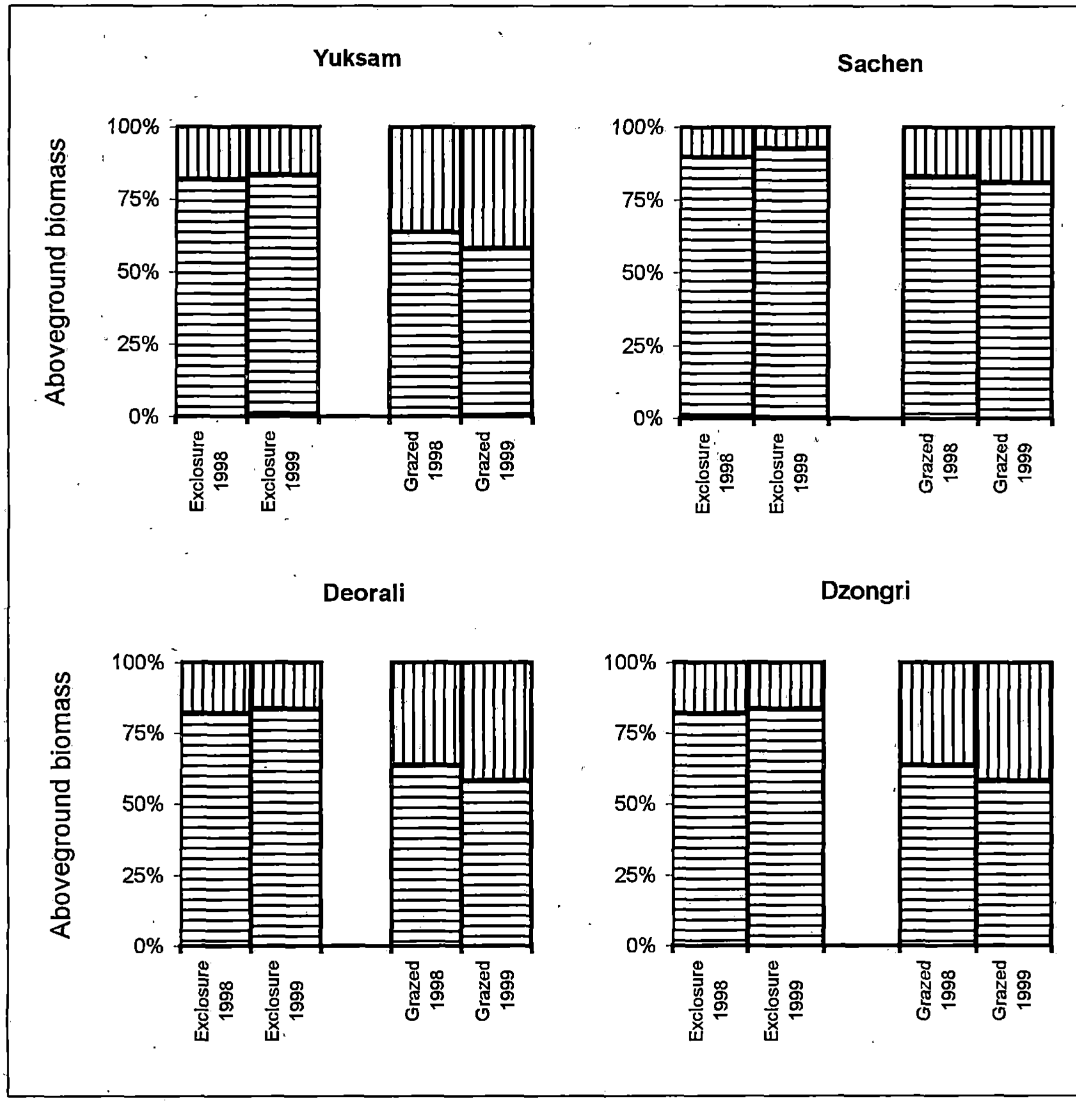

Fig. 6.2 Per cent contribution of aboveground biomass by palatable (horizontal strips) and unpalatable (vertical strips) plant species in exclosure and grazed plots at different study sites along the Yuksam-Dzongri trail.

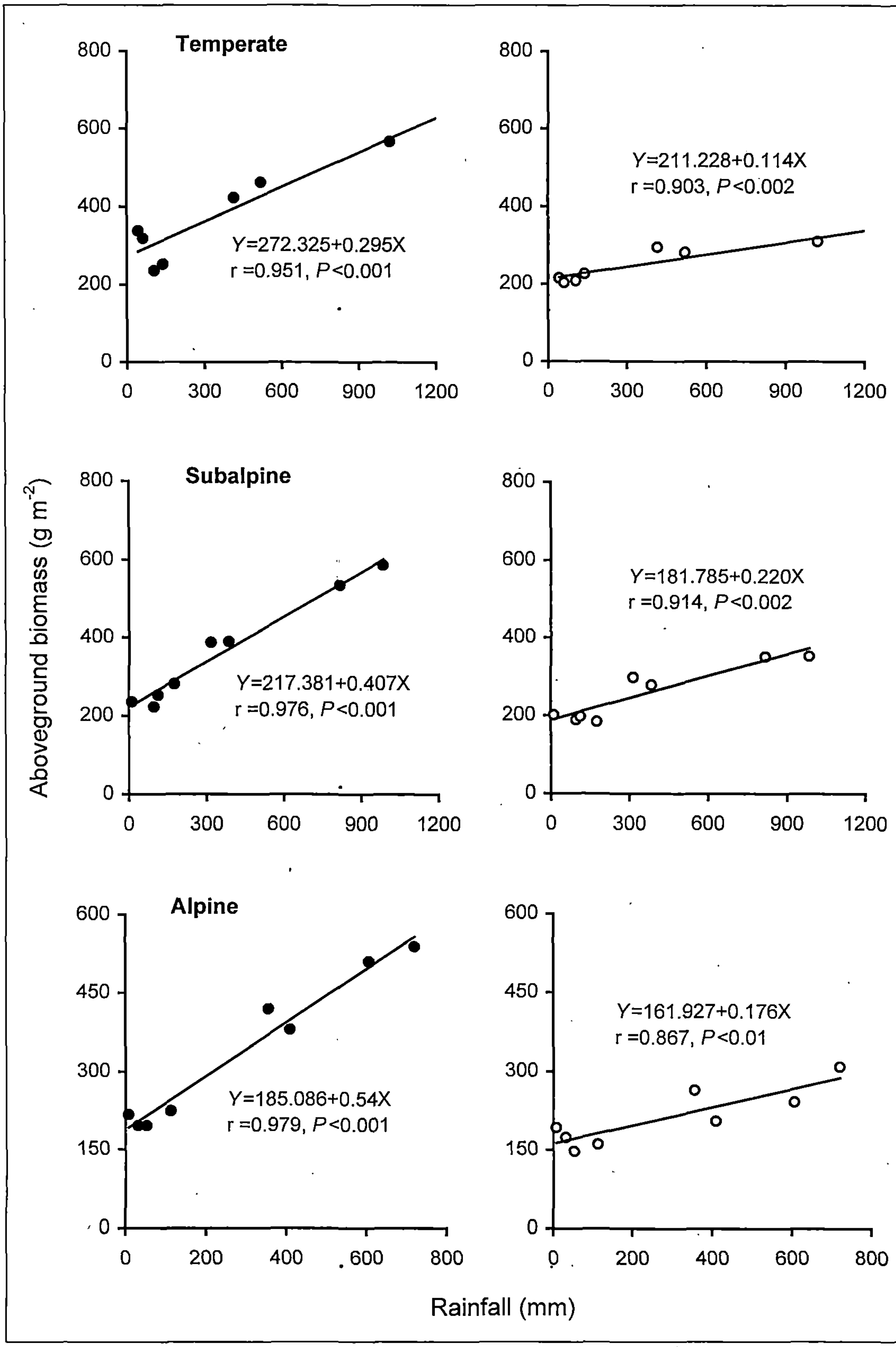

Fig. 6.3 Relationship between monthly rainfall and aboveground biomass in exclosure (dark circle) and grazed (empty circle) plots at different ecological zones along the Yuksam-Dzongri trail of Khangchendzonga Biosphere Reserve

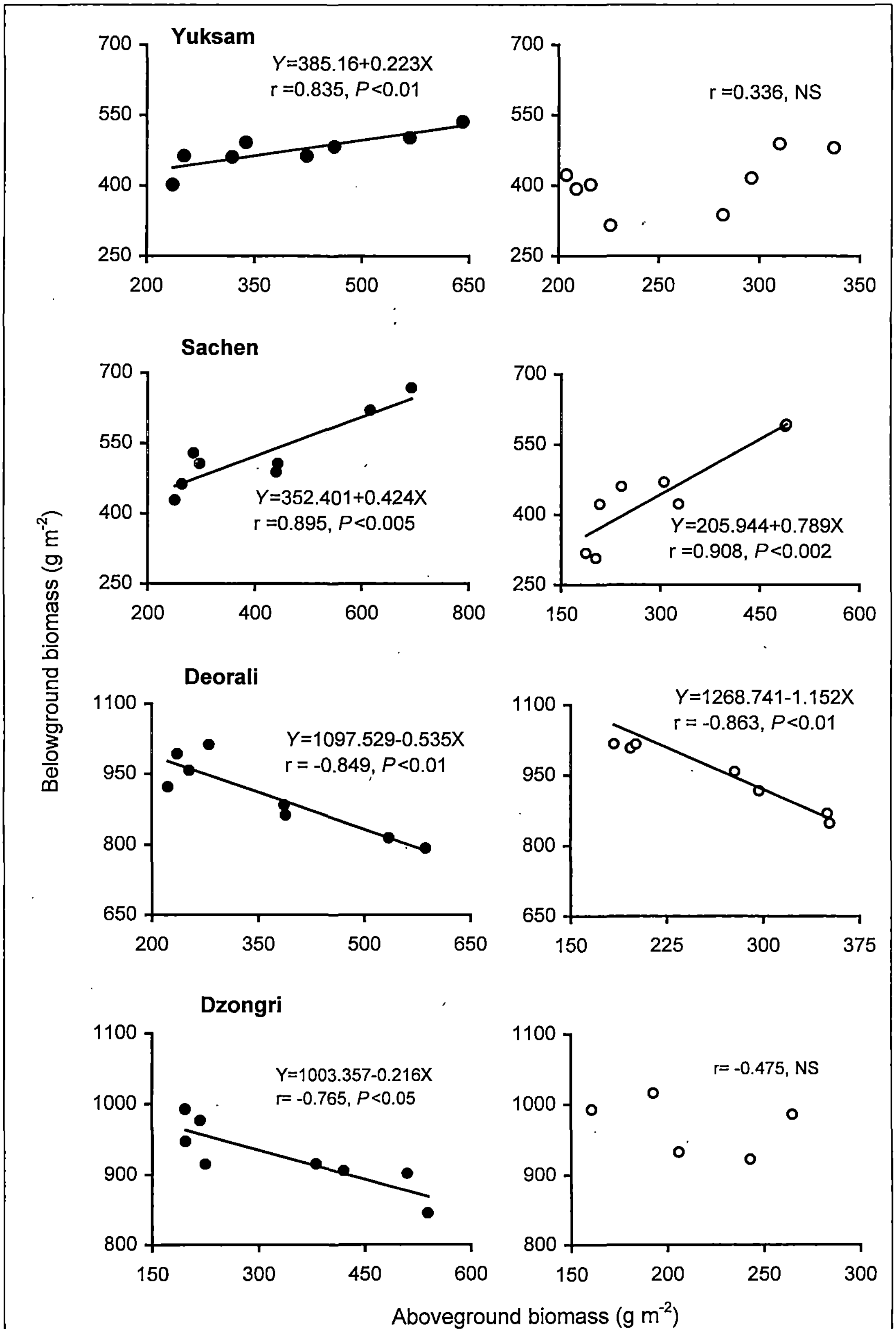

Fig. 6.4 Relationship between aboveground and belowground biomass in exclosure (dark circle) and grazed (empty circle) plots at different ecological sites along the Yuksam-Dzongri trail of Khangchendzonga Biosphere Reserve.

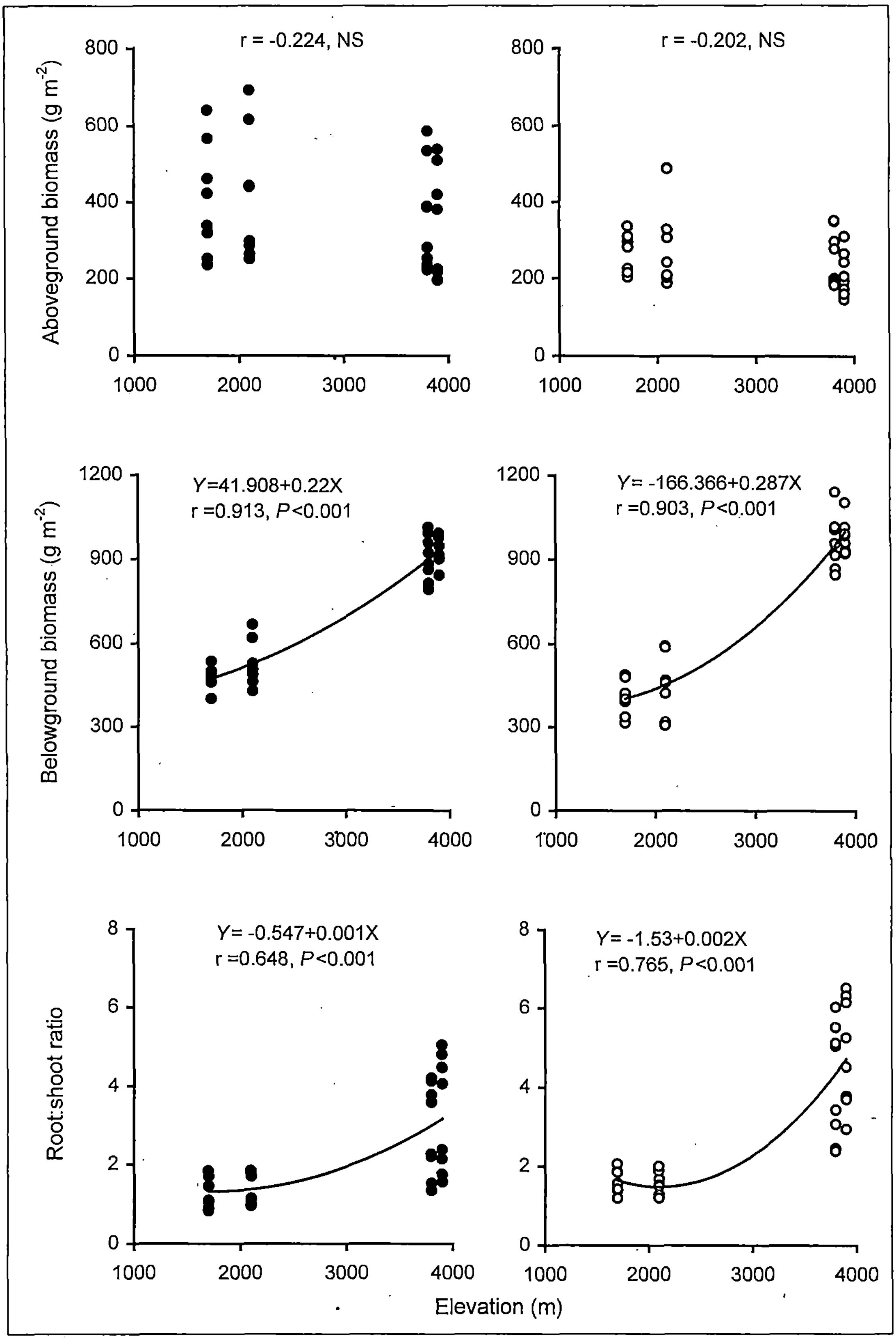

Fig. 6.5 Relationship between aboveground biomass, belowground biomass and root:shoot ratio with elevations in exclosure (dark circle) and grazed (empty circle) plots along the Yuksam-Dzongri trail of Khangchendzonga Biosphere Reserve