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WOODY SPECIES COMPOSITION OF TEMPERATE FORESTS ALONG AN ELEVATIONAL GRADIENT IN INDIAN CENTRAL HIMALAYA

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RIKHARI, H.C., ADHIKARI, B.S. & RAWAT, Y.S. 1997. Woody species composition of temperate forests along an elevational gradient in Indian Central Himalaya. The species composition, community patterns and diversity of temperate forests along an elevational gradient of 2000-3300 m above sea-level in the Pindar catchment of Central Himalaya were studied. On the basis of the importance value index (IVI) of the dominant species, eight forest types were identified. These were alder (*Alnus nepalensis*), mixed deciduous-evergreen, mixed evergreen-deciduous, silver-fir (*Abies pindrow*), maple (*Acer cappadocium*), burans (*Rhododendron arboreum*), kharsu oak (*Quercus semecarpefolia*) and birch (*Betula utilis*) forests. The total basal area and biomass for trees were recorded in the ranges of 10.5 - 81.5 m^2 ha^{-1} and 49.3 - 630.7 t ha^{-1} respectively. *Arundinaria falcata* was the dominant shrub species in most of the forest types. In the three-dimensional ordination based on species composition, stands of different forests showed continuity with elevation except for the birch forest, whereas the ordination based on structural/functional features exhibited less separation of forest types. Tree species diversity and beta diversity across the forest types were higher for the tree layer compared to the shrub layer.

Key words: Central Himalaya - temperate forests - ordination - diversity - regeneration

RIKHARI, H.C., ADHIKARI, B.S. & RAWAT, Y.S. 1997. Komposisi spesies kayu hutan iklim sederhana di sepanjang cerun curam di Himalaya Tengah India. Kajian mengenai komposisi spesies kayu, pola komuniti dan kepelbagaian hutan sederhana dijalankan di sepanjang cerun dengan ketinggian 2000-3300 m di atas aras laut di kawasan tadahan Pindar di Himalaya Tengah. Berdasarkan indeks kepentingan nilai (IVI) spesies dominan, lapan jenis hutan dikenalpasti iaitu hutan Alder (*Alnus nepalensis*), hutan malar hijau daun luruh, hutan daun luruh malar hijau, hutan fir perak (*Abies pindrow*), hutan maple (*Acer cappadocium*), hutan buran (*Rhododendron arboreum*), hutan kharsu oak (*Quercus semecarpefolia*) dan hutan birch (*Betula utilis*). Jumlah luas pangkal dan biojisim pokok tersebut dicatatkan berjulat antara 10.5 - 81.5 m^2 ha^{-1} dan 49.3 - 630.7 t ha^{-1}, masing-masing. *Arundinaria falcata* merupakan spesies pokok renik yang utama terdapat di kebanyakan hutan. Dalam pengordinatan tiga-dimensi berdasarkan komposisi spesies, dirian hutan yang berbeza menunjukkan persambungan dengan ketinggian kecuali hutan birch, manakala pengordinatan berdasarkan ciri-ciri struktur/ fungsi mempamerkan kurangnya pengasingan jenis-jenis hutan. Kepelbagaian spesies pokok dan kepelbagaian beta di sepanjang hutan didapati lebih tinggi pada lapisan pokok berbanding lapisan pokok renik.

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Introduction

Central Himalaya, accounting for 8.68% of the total Indian Himalayan area (594.36 km^2), harbours a great variety of forest, ranging from tropical dry deciduous in the foothills to alpine scrub near the timberline, with one major river system of the gangatic plains of India, the Ganga and a large number of its tributaries. Increasing human activities in the catchments of these tributaries [below 2000 m asl (above sea-level)] in recent years has caused substantial reduction of forest cover resulting in soil erosion and loss of soil fertility in hills, violent floods in plains and silting up of rivers. Further, the catchment efficiency depends upon the type of vegetation.

Reasonably good information for lower altitude (300 - 2500 m asl) Central Himalayan forests is now available (Saxena & Singh 1982, Singh & Singh 1987). However, there is a general paucity of quantitative information on temperate vegetation (2000 - 3300 m asl) due to the remoteness of the area and logistic facilities, except for some qualitative and quantitative information (Champion & Seth 1968, Singh *et al.* 1994).

This study deals with community patterns, species composition, structural/ functional features, biomass and productivity, and the diversity of the temperate region (2000 - 3300 m asl) in the Pindar catchment of Central Himalaya. Major questions asked were: (1) Does elevation determine the community patterns? (2) How is vegetation influenced by natural disturbances? (3) What is the impact of tree basal area, elevation and aspects on species diversity?

Materials and methods

Study sites, climate and soil

Although the present study area altitudinally falls within the temperate region, latitudinally it lies within the subtropical zone. The study sites were located within the Pindar catchment (2000 - 3300 m asl; 30°5' - 30° 10' N, 79° 45' - 80° 15'E) in a part of Central Himalaya (Figure 1). Detailed site characteristics of each forest are given in Table 1. All the forest sites had minimal biotic disturbances in terms of lopping (removal of branches) and logging of trees. Grazing of the ground flora by summer-migrating animals towards alpine grasslands during May and their return to the low altitude areas during October were common. However, in birch (*Betula utilis*) forest, *Rhododendron campanulatum* (scrub) is cut for fuel and hut construction by shepherds around their settlements.

The area has a high mountain climate. The mean monthly temperature ranges from 5.5 °C (January) to 20.1°C (August) at 2250 m asl within the Pindar catchment. The year is divisible into rainy (June to mid-September), prolonged winter (October to April) and short summer (May) seasons. Winters are very severe and snowfall from November to March is a common phenomenon. Seventy-six per cent of the average annual rainfall (2755 mm) occurs in the rainy season, indicating that the effect of the monsoon does not weaken at this temperate site.

The area is covered with drizzling mist and cloud throughout the snow-free period. Although rainfall is sometimes nil during winter, atmospheric humidity is high, especially in the morning and evening (Sakai & Malla 1981).

The soil moisture (weight basis up to 10 cm depth) varies between 21.0 and 37.3% in May and increases with increase in elevation. High soil moisture as a result of snow melt during April-May is a characteristic feature of the present study sites, contrary to the lower elevation (300 - 2500 m asl) where premonsoon summer (April to mid-June) is dry due to high temperature, long days, clear sky and little or no snowfall. The soils are residual and fairly deep on moderate slopes. The soil up to 30 cm depth is clay-loam and acidic in nature (Table 1) with 25 - 51% sand, 2.8-3.4% organic carbon and 0.262 - 0.400% nitrogen (Singh *et al*. 1992).

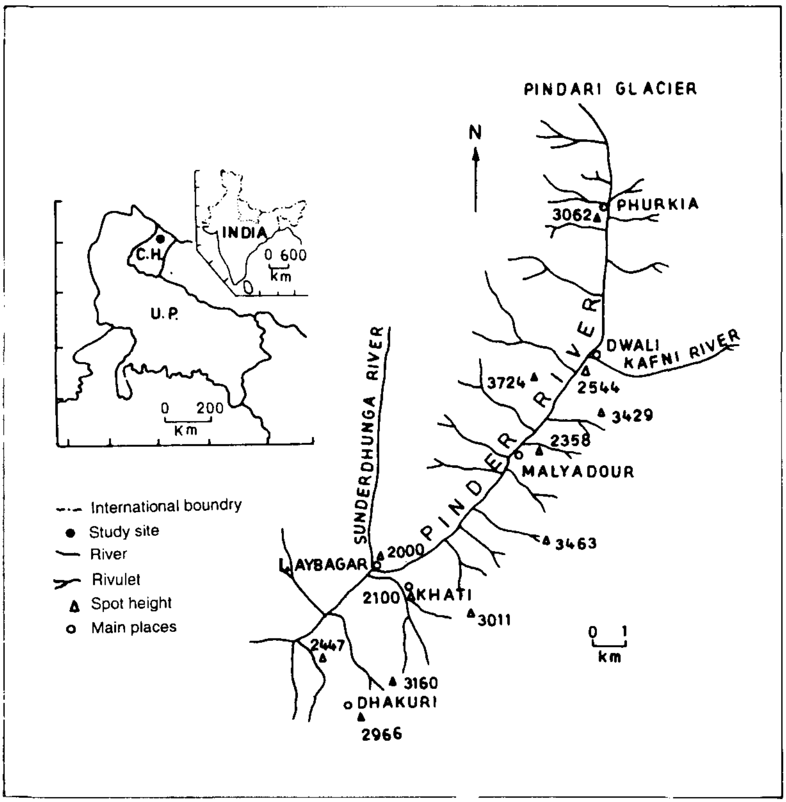

Figure 1. Map of the study area

Data collection

Various phytosociological data used in this study have been collected by Adhikari (1988), Bhatt (1988), Dumka (1988) and Singh *et al*. (1992). Trees (>10.1 cm dbh, diameter at breast height, i.e. 1.37 m above the ground), saplings (≥30 cm high and <10 cm dbh), seedlings (< 30 cm high), and shrubs were sampled using 10 × 10 m randomly placed quadrats (sample plots) in each forest stand following Saxena and Singh (1982). The stands, ranging from 3 to 6 ha in size, were located at random along the elevational gradient to represent the various forest types. The vegetational data were analysed for density, frequency and basal area of trees and for density of shrubs. The importance value index (IVI) for the tree species was the sum of the relative density, relative frequency and relative basal area. Biomass of each of the forest stands was calculated using allometric equations (Sharma & Ambsht 1991, Singh *et al.* 1992, Adhikari *et al.* 1995).

Table 1. Characteristics of the study sites

Forest type no.*	Location	Elevation (m)	Aspect	Slope angle (°)	Soil moisture (%)	Soil pH	Lithology
1.	Khati & Dwali	2000 - 2450	E, SE	34 - 75	21.0 ± 2.2	6.8 ± 0.72	Mica schist, bands of augen gneisses
2.	Khati	2100 - 2190	NE, N, S	26 - 51	23.7 ± 1.8	5.3 ± 0.13	Bands of augen gneisses
3.	Malyadour	2100 - 2350	N, E,W	35 - 71	27.3 ± 1.3	4.9 ± 0.20	Quartzite, shale, slates, mica schist, bands of augen gneisses
4.	Dhakuri	2390 - 2700	N, S, SW	47 - 77	28.7 ± 2.3	5.2 ± 0.18	Gneisses schist, quartzite, inter-bedded biotite schist
5.	Dwali	2350 - 2550	NW, SE	31 - 78	33.2 ± 4.5	5.5 ± 0.51	Quartzite, inter-bedded biotite schist
6.	Dhakuri	2550 - 2700	NE, SE, SW	34 - 73	37.3 ± 2.9	6.0 ± 0.35	Quartzite, inter-bedded biotite schist
7.	Dhakuri	2500 - 3000	SE, NE, NW	23 - 65	36.9 ± 3.4	5.7 ± 0.07	Gneisses schist, shale, slates
8.	Phurkia	3000 - 3300	W, SW, E	53 - 67	30.0 ± 0.8	6.6 ± 0.11	Psammite gneisses schist

*1. Alder (*Alnus nepalensis*)
2. Mixed deciduous-evergreen
3. Mixed evergreen-deciduous
4. Silver-fir (*Abies pindrow*)
5. Maple (*Acer cappadocium*)
6. Burans (*Rhododendron arboreum*)
7. Kharsu oak (*Quercus semecarpifolia*)
8. Birch (*Betula utilis*)

The various structural features were (a) life form – megaphanerophyte (>30 m high) and meso/microphanerophyte (2 - 30 m high); (b) leaf size- nanophyll (25 - 225 mm^2), microphyll (225 - 2025 mm^2), mesophyll (2 025 - 18 225 mm^2), macrophyll (18 225 - 16 4025 mm^2), and scale leaves (Raunkiaer 1934); (c) bark thickness measured 1.37 m above the ground on mature trees, < 5 mm, 6 - 10 mm, 11-15 mm, 16 - 20 mm, > 20 mm. Functional features included were: (a) flowering season – vernal (before 15 June), aestival (15 June - 15 September), autumnal (after 15 September); (b) pollination mechanisms – biotic (insect, birds, animal, etc.), abiotic (wind); (c) seed dispersal – biotic (animal, birds, etc.), abiotic (wind); (d) leaf persistence – evergreen (persisting > 1 y), deciduous (persisting <1y); (e) shade tolerance – sun demanding, shade demanding/shade tolerant (species occupying the shady habitats and under canopy/growing in open places but could survive in shady habitats and under canopy). These structural/functional features were based on field observations (Troup 1921, Osmaston 1927, Champion & Seth 1968, Singh & Singh 1987). To obtain a measure of a given feature (structural/functional) for a stand, the relative density values of all tree species having that feature in the stand were summed.

The stands were ordinated according to the polar ordination method (Muller-Dombois & Ellenberg 1974) based on species composition (IVI) and structural/functional (autecological) features based on density. Values were double standardised before computing percentage similarity.

Species diversity was calculated following Shannon and Weaver (1963). Beta diversity for different forests was calculated following Whittaker (1975), i.e. $B = Sc/s$, where Sc is the total number of species encountered in all the stands, counting each species once whether or not it occurs more than once and s is the average number of species per stand.

Analysis of variance (ANOVA) and least significant differences (LSD) were applied following the method of Snedecor and Cochran (1967). Correlations were established between elevation vs. total basal area and diversity, and total basal area vs. diversity.

Results and discussion

Species composition

Based on the IVI (Table 2), the following forests were recognised from lower to higher elevation (2000 - 3300 m asl): (1) alder (*Alnus nepalensis*) from 2000 to 2450 m asl along streams and rivers on landslide damaged sites (newly exposed soil); (2) mixed deciduous-evergreen from 2100 to 2190 m asl in moist shady ravines on rich soil where deposition of organic matter occurs from upper hill slopes; (3) mixed evergreen-deciduous from 2100 to 2350 m asl; (4) silver-fir (*Abies pindrow*) forest from 2390 to 2700 m asl; (5) maple (*Acer cappadocium*) from 2350 to 2550 m asl; (6) burans (*Rhododendron arboreum*) from 2550 to 2700 m asl; (7) kharsu oak (*Quercus semecarpifolia*) from 2500 to 3000 m asl; and (8) birch (*Betula utilis*) from 3000 to 3300 m asl up to the timber line. Because of the marked variability in the micro-climatic conditions, altitude, slope, and landslides, the co-dominant and other species differed on different aspects/sites of the same forest (Table 2). The greatest micro-climatic differences have been recorded between north and south aspects (Upreti *et al.* 1985).

Table 2. IVI (importance value index) of different species in different forests

Species	Stand number 1	2	3
		Alder forest	
Alnus nepalensis	180	210	150
Juglans regia	42	-	-
Litsea umbrosa	-	-	12
Lyonia ovalifolia	54	-	18
Quercus floribunda	9	-	21
Q. leucotrichophora	-	-	21
Rhododendron arboreum	-	-	45
Symplocos chinensis	-	-	15
Others	15	90	18
		Mixed deciduous-evergreen	
Acer cappadocium	66	62	-
Aesculus indica	70	94	93
Fraxinus micrantha	-	56	-
Ilex dipyrena	-	-	24
L. ovalifolia	59	-	-
Q. floribunda	54	-	87
R. arboreum	-	58	30
S. chinensis	51	-	18
Ulmus wallichiana	-	30	-
Others	-	-	48
		Silver-fir	
Abies pindrow	165	172	168
A. cappadocium	15	-	-
I. dipyrena	-	-	21
L. umbrosa	42	-	-
L. ovalifolia	-	36	-
Meliosma dillonaefolia	-	-	36
Q. floribunda	-	36	-
Q. semecarpifolia	-	18	-
R. arboreum	24	-	75
S. chinensis	-	38	-
Others	54	-	-
		Maple forest	
A. cappadocium	207	185	168
I. dipyrena	-	-	39
J. regia	-	40	-
L. ovalifolia	-	21	-
Q. floribunda	12	36	-
R. arboreum	81	18	93

(continued)

Table 2 (continued)

Species	Stand number 1	2	3	4
		Burans		
A. pindrow	-	12	51	
A. cappadocium	-	18	-	
A. nepalenis	-	33	-	
I. dipyrena	-	33	24	
L. ovalifolia	78	51	33	
M. dillonaefolia	-	-	36	
Q. semecarpifolia	75	-	-	
R. arboreum	147	135	142	
Salix wallichii	-	-	14	
Others	-	18	-	
		Mixed evergreen-deciduous		
A. pindrow	15	24	-	-
A. cappadocium	34	-	12	-
A. indica	-	-	30	-
Carpinus viminea	-	-	42	-
L. umbrosa	29	21	30	-
L. ovalifolia	34	-	15	93
Q. floribunda	70	-	39	9
Q. lanuginosa	-	30	-	87
Q. leucotrichophora	-	-	-	15
R. arboreum	79	75	93	96
S. chinensis	39	-	-	-
Taxus baccata	-	60	-	-
Others	-	90	39	-
		Kharsu oak		
A. pindrow	-	27	-	-
Q. semecarpifolia	162	195	225	168
R. arboreum	138	45	75	99
R. barbatum	-	-	-	33
S. chinensis	-	33	-	-
		Birch		
Betula utilis	228	300	300	220
Rhus wallichii	42	-	-	-
Viburnum erubscens	30	-	-	-
Pyrus foliosa	-	-	-	46
Prunus nepalensis	-	-	-	34

ANOVA indicated significant differences ($p<0.05$) for total density and basal area of trees in different forests (Table 3) as a result of changes in site characteristics. Total density and basal area fall within the range of earlier reports for various forests of lower elevation (300-2500 m asl); however, the value of basal area for the birch forest was far lower than those of earlier reports (Saxena & Singh 1982, Singh & Singh 1987). Total basal area decreased with increasing elevation ($Y = 152.25 - 0.035X$; $r = -0.406$; $p < 0.05$; where Y is the basal area in m^2 ha^{-1} and X is the elevation in M) indicating that severity of the climate at higher elevation does not favour survival and growth of the trees. The lower value of basal area for birch forest may be related to the higher elevations beyond which scrubland was dominated by *Rhododendron campanulatum* and alpine meadows. It is apparent that arboreal species in this part of the Himalaya form an important component of the vegetation due to the favourable effects of relatively higher moisture and relative humidity as a result of decrease in temperature and, consequently, evapotranspiration that compensates for the limiting effects of low temperature.

Table 3. Some features of the studied forests (average of all the stands for a given forest type)

Forest type	Tree density (no. ha^{-1})	Basal area ($m^2 ha^{-1}$)	Shrub density (no. ha^{-1})	Tree biomass (t ha^{-1})	Tree* productivity (t $ha^{-1} y^{-1}$)
Alder	920 ± 342	59.3 ± 12	0	93.8 ± 30	12.1 - 24.2
Mixed deciduous-evergreen	467 ± 84	71.0 ± 14	4896	432.7 ± 26	17.6
Mixed evergreen-deciduous	820 ± 175	71.3 ± 17	5358	345.3 ± 83	-
Silver-fir	520 ± 81	81.5 ± 19	2831	443.4 ± 53	17.5
Maple	427 ± 138	46.3 ± 10	5030	222.1 ± 29	15.9
Burans	643 ± 48	51.3 ± 21	0	201.7 ± 38	-
Kharsu oak	728 ± 170	77.4 ± 12	5888	630.7 ± 105	23.4
Birch	240 ± 29	10.5 ± 3	9264	49.3 ± 14	11.1

*Sharma & Ambsht (1991) for pure alder plantations of 7 to 56 y located in eastern Himalaya; Adhikari *et al.* (1995); Garkoti & Singh (1995).

The total shrub density varied between 0 and 9264 individuals ha^{-1} (Table 3). The birch forest with the lowest basal area had the highest shrub density and a different composition (Table 4). This is possibly due to the availability of greater light at the ground. By and large, the shrub layer in other forests was poorly developed and/or absent due to severe competition for resources with trees and deep shade under the canopy. Similar observations have been made by Champion and Seth (1968). *Arundinaria falcata,* a soil binding species found in moist and shady areas, dominated all the forests. However, *Thamnocalamus spathiflorus* was the predominant species in birch forest.

Table 4. Density (individuals ha^{-1}) of shrub species in studied forests (average of all the stands for a given forest type)

Species	Forest type*							
	1	2	3	4	5	6	7	8
Arundinaria falcata	-	4680	5133	2595	4333	-	4560	385
Anaphalis contorta	-	-	-	-	-	-	290	-
Berberis asiatica	-	13	8	23	-	-	73	198
Daphne papyracea	-	-	-	-	-	-	475	-
Gaultheria trichophylla	-	-	-	-	-	-	-	140
Princepia utilis	-	23	38	73	-	-	110	-
Rhododendron campanulatum	-	-	-	-	-	-	290	
Rosa webbiana	-	-	-	-	-	-	-	408
Rubus duthianus	-	-	-	-	-	-	-	150
R. saxatalis	-	-	-	-	-	-	-	70
Salix elegans	-	-	-	-	-	-	-	13
S. lindleyana	-	-	-	-	-	-	-	1070
Sarcococca hookeriana	-	-	23	-	697	-	-	-
S. saligna	-	-	-	-	-	-	270	-
Spiraea arcuta	-	-	-	-	-	-	-	180
S. contomiance	-	-	25					
Thamnocalamus spathiflorus	-	-	-	-	-	-	-	6360
Viburnum cotonifolium	-	180	18	-	-	-	-	-
V. mulaha	-	-	-	-	-	-	110	-
Wikstroemia canescens	-	-	113	140	-	-	-	-

*See Table 1 for explanation.

Biomass and productivity

Total tree biomass and productivity have been recorded in the ranges of 49.3 - 630.7 t ha^{-1} and 11.1 - 24.2 t ha^{-1} y^{-1} respectively (Table 3). It seems that tree physiognomy, age of the dominant tree species, basal area, site quality, and the successional nature of a forest determine tree biomass accumulation. The lower biomass for alder forest is possibly due to the early successional nature of the dominant species. High biomass values indicate that the Central Himalaya has the potential for accumulating large biomass up to 3000 m asl whereafter it declines abruptly and reaches a minimum. While rainfall does not vary within the watershed along the elevational gradient, the temperature drops from 2000 m asl up to 3300 m asl; as a result, the water balance becomes more favourable as elevation increases. These values of biomass and productivity fall within the ranges (biomass: 113 - 782 t ha^{-1}; productivity: 7.6 - 25.1 t ha^{-1} y^{-1}) reported for tree layer of low altitude forests (Singh & Singh 1987).

Structural/functional features

The predominance of meso/microphanerophytes (average of all the forests= 89%) (Table 5) is different from the lower altitude forests where vegetation is mainly composed of megaphanerophytes and supports the notion that megaphanerophytes decreased with increasing elevation (Singh & Singh 1987).

Table 5. Percentage (average of all the stands for a given forest type) of structural/ functional features for tree species of different forests

Feature	Forest type*								LSD
	1	2	3	4	5	6	7	8	
Life forms									
Megaphanerophyte	5.6	22.6	6.5	47.6	2.6	4.2	0.9	0	10.5
Mesophanerophyte	94.4	77.4	93.5	52.4	97.4	95.8	99.1	100.0	10.5
Leaf size									
Nanophyll	0	0	0	0	2.6	0	0	9.0	2.0
Microphyll	7.5	38.5	15.7	11.5	57.2	12.2	0.7	91.0	15.0
Mesophyll	91.0	54.3	77.4	30.0	32.5	80.8	97.5	0	18.8
Macrophyll	1.5	7.1	2.4	10.9	7.7	2.7	0	0	12.0
Scale	0	0	4.5	47.6	0	4.2	1.8	0	5.0
Bark thickness									
< 5 mm	0.8	0	0	0	0	0	0	87.0	3.2
6 - 10 mm	0	12.8	10.4	11.4	8.0	8.7	0	0	9.8
11- 15 mm	19.6	47.3	61.8	31.5	30.0	59.6	44.9	13.0	19.3
16 - 20 mm	0	8.1	0	0	35.2	0.9	0	0	3.3
> 20 mm	79.6	16.7	27.8	57.1	28.8	30.8	55.1	0	28.2
Flowering season									
Vernal	66.6	100.0	100.0	100.0	100.0	98.0	100.0	100.0	-
Autumnal	33.4	0	0	0	0	2.0	0	0	-
Pollination mechanism									
Abiotic	12.4	55.4	45.2	58.5	61.0	35.6	52.7	83.0	21.1
Biotic	87.6	44.6	54.8	41.5	39.0	64.4	47.3	17.0	21.1
Leaf persistence									
Evergreen	14.4	32.3	67.5	84.3	31.3	77.0	99.4	0	19.5
Deciduous	85.6	67.7	32.5	15.7	68.7	23.0	0.6	100.0	19.5
Seed dispersal									
Biotic	11.7	61.4	52.0	29.4	16.7	36.5	52.0	16.5	26.7
Abiotic	88.3	38.6	48.0	70.6	85.3	63.5	48.0	83.5	26.7
Shade tolerance									
Shade demander	22.4	64.8	76.1	33.2	89.6	69.2	47.3	8.0	28.8
Light demander	77.6	35.2	23.9	66.8	10.4	30.8	52.7	92.0	28.8

*See Table 1 for explanation; - = not applicable.

This is possibly related to the severity of environmental conditions as elevation increased. Mesophyll leaves (average of all the forest, about 58%), followed by microphyll leaves (about 29% across all the studied forests) predominated in different forests, with few exceptions. Thick (>20 mm) and intermediate barked (11-15 mm) trees were equally dominant in different forests. Vernal flowering was common in all the forests and this enables species to take advantage of adequate moisture in the rainy season (Singh & Singh 1987). The forest vegetation is characterised by evergreen and deciduous broad-leaved forests throughout the elevational zones. Prevalence of deciduous elements corresponds best to the cool temperate vegetation of the Himalaya (Ohsawa *et al.* 1973). Abiotic and biotic modes of pollination and seed dispersal, and sun and shade demanding species were more or less equally represented.

Ordination

Indirect ordination of forest stands based on IVI indicates a continuity of communities along the elevational gradient in the three dimensional ordination graph with the exception of the birch forest (Figure 2a). The X-axis separates the stands of different forests along the elevational gradient; stands of alder and mixed deciduous-evergreen forests occurring in the lower elevations (2000-2450 m asl) occupy the lower extremity and those of kharsu oak occupy the higher extremity of the elevation (X-axis). However, birch forest in higher elevations occupies the lowest extremity of the X-axis. The stands subjected to a number of environmental forces, viz. natural disturbances and subsequent progress of secondary succession, are separated on the Y-axis. The stands of early successional alder are located farther apart on the Y-axis with respect to the stands of mixed deciduous-evergreen forests which are intermediate stages of succession (Singh & Singh 1987). The stands of the climax community (kharsu oak) are separated from the remaining forests by their high X- and Y- values and low Z-values.

In indirect ordination based on structural/functional features of tree species, forest stands are mainly divisible into three categories (Figure 2b): (I) characterised by a preponderance of tree species with the megaphanerophyte life form, light demanding in nature, small seeds and winter deciduous characterised by low X-, Y- and Z-values; (II) characterised by an equal preponderance of megaphanerophyte and mesophanerophyte life forms, light/shade demanding in nature, large/small seeds and winter deciduous characterised by intermediate X-, Y- and Z-values; (III) characterised by a preponderance of evergreen megaphanerophyte life forms, light demanding in nature, heavy seeds with few exceptions. In the ordination based on structural/functional features of forest stands, the length of the X-axis was shorter than in the ordination based on IVI. This indicates that species resembled each other more in autecological features. For example, stands of alder and birch forests were not distinctly separated in this ordination, because the dominant species in both the forests were winter deciduous, light demanders with small seeds. Similarly, stands of kharsu oak were well separated in the ordination based on species composition but they did not separate in the ordination based on structural/functional features because most of the characters of dominant species were shared with the dominant species of other forests.

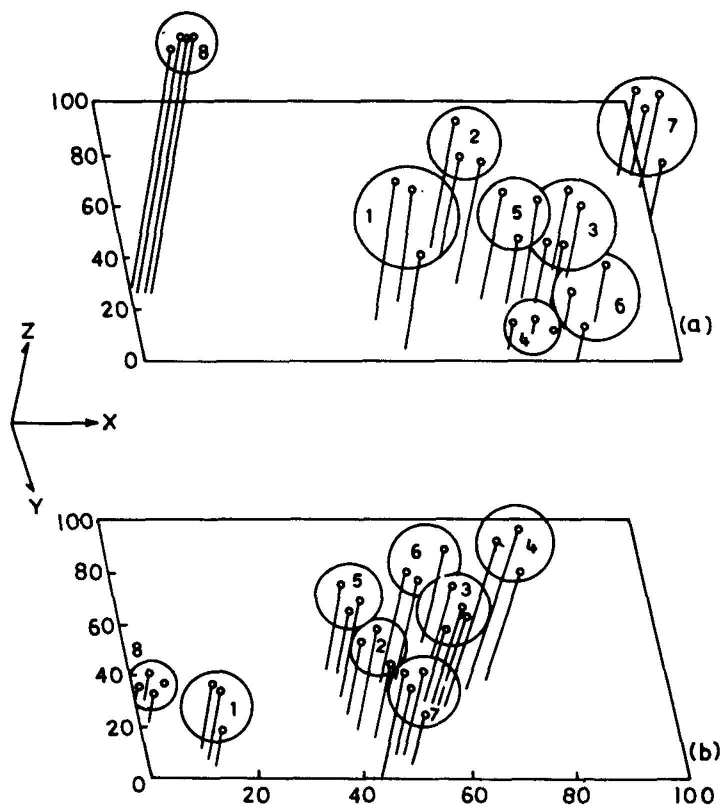

Figure 2. Three dimensional-ordination based on (a) species composition, and (b) structural/ functional features. (1) Alder forest; (2) Mixed deciduous-evergreen forest; (3) Mixed evergreen-deciduous forest; (4) Silver-fir forest; (5) Maple forest; (6) Burans forest; (7) Kharsu oak forest; (8) Birch forest

Diversity and related parameters

A total of 31 tree species and 20 shrub species were recorded from the entire study area. Higher species richness and diversity (Table 6) for trees compared to shrubs indicate lower diversification of the shrub layer due to deep shade and competition for resources with trees. Dominance of one stratum may affect the diversity of another stratum (Whittaker 1975, Saxena & Singh 1982). The tree and shrub diversity values are comparable with the values (0.00 - 2.95 for trees; 0.00 - 3.05 for shrubs) reported for the forests of lower elevations (Singh & Singh 1987, Singh *et al.* 1994).

Table 6. Species richness (*s*), diversity (*H*) and beta diversity (*B*) for trees and shrubs

Forest type	Trees			Shrubs		
	s	*H*	*B*	*s*	*H*	*B*
Alder	3 - 8	0.81 - 2.34	2.06	-	-	-
Mixed deciduous-evergreen	5 - 7	2.23 - 2.65	2.12	2 - 4	0.05 - 1.02	1.50
Mixed evergreen-deciduous	5 - 9	0.94 - 2.59	2.80	2 - 3	0.06 - 1.33	2.55
Silver-fir	4 - 5	1.59 - 1.89	2.36	2 - 3	0.14 - 0.54	1.71
Maple	3 - 5	1.13 - 2.20	1.80	2 - 3	0.51 - 0.64	1.29
Burans	3 - 7	1.36 - 2.06	1.69	-	-	-
Kharsu oak	2 - 7	0.88 - 1.32	3.40	1 - 4	0.00 - 1.42	2.55
Birch	1 - 3	0.00 - 1.29	2.00	2 - 7	0.23 - 1.06	2.44

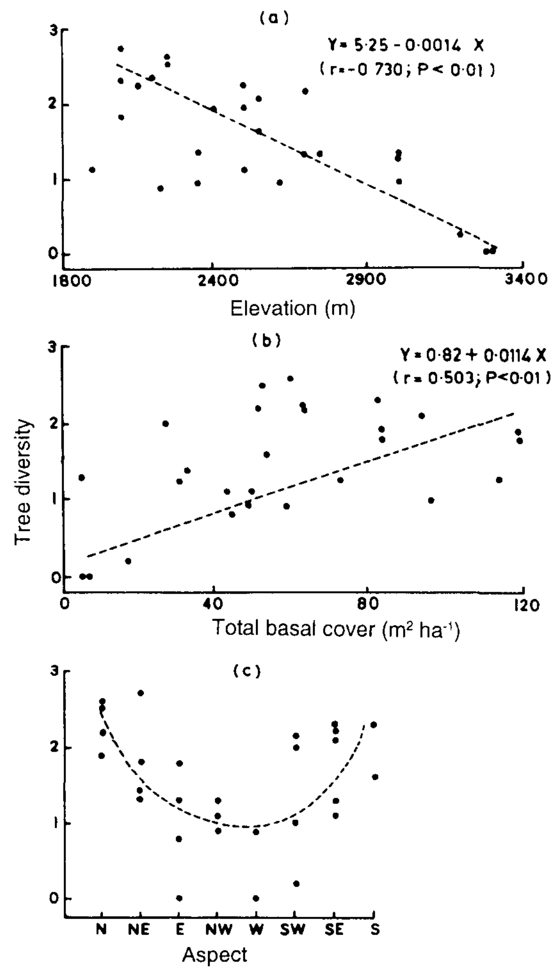

Figure 3. Relationships between (a)elevation and diversity, (b) basal area and diversity, and (c) aspects and diversity

Diversity decreased with increasing elevation and increased with increasing basal area (Figures 3 a,b). This indicates that as elevation increases, severity of the climate also increases, which does not allow diversification of tree layer. Current models of succession suggest a positive relation between biomass (here biomass is represented by basal area) and diversity (Saxena & Singh 1982). The tree diversity has been found to be lowest on aspects having intermediate temperature and moisture and it inclined both towards the north (cooler and wetter) and south (warmer and drier) exposures (Figure 3c). This indicates that intermediate temperature and moisture are less favourable for diversification. and thus, are in contrast to the earlier reports (Whittaker 1975, Saxena & Singh 1982) .

Beta diversity was higher for trees compared to shrubs for different forests (Table 6). This indicates rapid changes in species composition from one stand to another of a given forest for trees in comparison to shrubs. The higher change for trees was possibly due to the changes in aspect, elevation, topography, soil pH and nutrient status, landslides, etc. The lower rate of change for shrub species was mainly related to the uniform availability of light at the ground due to canopy closure. For the entire elevational gradient, beta diversity values for trees (6.81) and shrubs (7.50) were very high and similar, indicating that they responded in similar fashions to changes with site characteristics in regard to degree of change in species composition.

Thus, the present area is rich in forest types and they are structured by diverse forms of plants, e.g. conifers, broadleaf deciduous and evergreens. In the three-dimensional ordination based on species composition, forest types were arranged along the elevational gradient with few exception. However, they were less separated in the three-dimensional ordination based on structural/ functional features. Tree diversity and beta diversity for different forest types were higher for the tree layer compared to those of the shrub layer.

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