

Phytodiversity and growth form in relation to altitudinal gradient in the Central Himalayan (Kumaun) region of India

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In this study, we examined plant species richness at altitudes between 200 and 5800 m asl, considering altitudinal gradients (200 and 1000 m asl altitudinal differences) in the Indian Central Himalaya. The low elevation appears to be drier than higher, although precipitation varies inconsistently with elevation. Low temperature and greater cloudiness at higher elevations might increase precipitation. In this study, a total of 2487 species were recorded, of which 276 were trees, 355 shrubs, 112 climbers and 1744 herbs. The deciduous trees were maximum at 600–800 m asl elevation and evergreen trees were maximum at 1200–1400 m elevation. Shrub species occurred in the altitude range of <200 to 4800 m asl. The total number of shrub species varied from 2 (4600 m asl) to 35 (1400 m asl). The total number of climber species was maximum at an altitudinal range of 800–100 m asl for deciduous as well as evergreen species. Along the altitude, the geographic and climatic conditions change sharply. The total number of species, including all growth forms was maximum near low altitude to mid altitude of tropical/subtropical belt due to overlapping of climatic conditions, but with further increase in altitude it decreased consistently, probably due to decrease in atmospheric temperature with increase in altitude. The number of deciduous species was relatively more than evergreen species irrespective of the plant form, i.e. trees, shrubs, and climbers, which may be due to spatial fluctuation in climatic conditions. The study concludes that the distribution and species richness pattern in this region largely depend on the altitude and climatic variables like rainfall, temperature.

Keywords: Altitude, Central Himalaya, phytodiversity, plant forms, species richness.

In the last decade, scientists have turned their attention towards biodiversity with its heterogeneous distribution across the earth¹. Pattern of species composition and turnover, both spatial and temporal, have received less attention². Yet the spatial and temporal dynamics is important, as local richness which determines the diversity at the regional scale². Hubbell *et al.*³ agreed that the dispersal limitation is an important ecological factor for controlling species distribution pattern and some focus has been given to local

biotic and abiotic ecological interactions to explain the distribution pattern of plant species. Earlier, Veenendaal *et al.*⁴ revealed that the distribution of plants is determined by climatic variables like rain, temperature, soil conditions, moisture, nutrients, historic events, palaeoclimatic changes, interactions with fauna, competition between tree species for crown and root space as well as human influence.

The latitudinal decrease in species richness has been known for over a century. Species diversity as a whole and its distribution along the altitudinal gradient had been a subject of ecosystem³. Earlier, Rahbek⁵ viewed that approximately half of the studies detected a mid-altitude peak in species richness, in a critical literature review on species richness patterns in relation to altitude. Grytnes and Vetaas⁶ have also reviewed these aspects in Nepalese Himalaya. Though the plant community of a region is a function of time, nevertheless, altitude, slope, latitude, aspect, rainfall and humidity had to play a role in the formation of community composition. In addition, vertical canopies also play a vital role in a forest ecosystem⁷.

A highly diverse compositional pattern of forests characteristic of this region in Central Himalaya, has been explored by Singh and Singh⁸. Besides other ecosystem functions, the distribution and occurrence of species had been affected by human interventions⁹. Among human influence, commercial exploitation, agricultural requirements, forest fire, and grazing pressure are the important sources of disturbance⁸.

The objectives of the present study were: (i) to find out species richness in relation to different altitudinal range, (ii) to analyse plant species variation between 200 and 1000 m altitudinal gradient and (iii) to examine variation in nature of plant forms with respect to altitude. The Central Himalaya is one of the hotspots of biodiversity in India. This region comprises several species of plants, with many of them being indigenous. Though several studies have been done on the plant communities in this region, an exclusive study on the variation of plant species composition along the gradient is lacking. In the present study, we try to understand the variations in tree, shrub, climber and herb species along the altitudinal gradient in Central Himalaya. The study will be helpful for future researchers by providing a comparison to ascertain any changes in species and species composition of plant communities in the gradient of Central Himalaya.

The study was conducted in Kumaun Himalaya (28°43'45"–30°20'12"N and 78°44'30"–80°18'45"E). The Himalayas are well outside the tropics, therefore, both climatic conditions and some of the vegetation types are close to those of more northerly latitude. This range is so vast a feature that it plays an important part in regulating climate over most of the country. The major effects of variation in aspect are related to the consequent variation in isolation per unit area surface⁷.

The rocks of Kumaun region consist of krol formation, carbonaceous and limestone rocks¹⁰. In broad terms, a majority of forest soils of the Himalaya belong to brown forest soil

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Table 1. Physico-chemical properties of soil at different altitudes

Altitude (m asl)	Sand	Silt	Clay	pH	Moisture	Source
280–350	78.6	14.5	6.67	6.7	18.5	Chandra ³⁰
500–750	81.0	11.3	7.66	6.7	20.2	Chandra ³⁰
800–1000	75.0	14.0	9.0	6.6	22.0	Chandra ³⁰
1000–1200	70.0	23.0	10.0	6.1	23.0	Chandra ³⁰
1200–1400	63.6	25.0	11.0	5.6	25.5	Chandra ³⁰
1580–1700	60.0	23.0	16.0	5.6	33.2	Kharkwal ³¹
1700–1800	61.0	20.0	17.2	5.9	32.0	Kharkwal ³¹
1800–1950	61.0	25.0	16.5	6.0	40.0	Kharkwal ³¹
2000–2300	53.5	32.0	11.6	7.4	44.3	Kharkwal ³¹
2300–2600	52.3	29.0	21.6	5.7	46.5	Kharkwal ³¹
2600–2800	54.2	27.3	18.5	6.6	37.4	Rawal ³²
2800–3000	50.7	33.3	15.9	6.5	44.5	Rawal ³²
3000–3300	50.3	31.4	18.3	6.4	42.3	Rawal ³²
3250–4200	42.8	39.9	17.2	4.9	50.2	Jeet Ram ³³

category. Calcium generally dominates the exchangeable bases in most soils of Central Himalaya, which is consistent with the character of brown earth. The pH rises with depth and in the surface horizons, it is acidic. Colour of forest soil in the surface horizons varies from dark brown to dark yellowish-brown and the surface soils generally have numerous fine roots, which may penetrate up to 30–40 cm depth¹¹.

Sandy loam soil is preponderant in lower elevation and clay loam in higher elevation (above 2200 m asl). The pH of the soil was slightly acidic (6.65) to neutral (6.5–7), but in higher altitudes (above 2800–3000 m asl) it was strongly acidic (5.5–6). Organic matter content ranged from less than 1 to 4%. Soil moisture content varied from 21 and 43% at –3 bar water potential and 7.6 and 14.8% at –15 bar water potential⁹. The physio-chemical data are given in Table 1.

In the present study, plant species of Kumaun region, Central Himalaya along the altitudinal gradient were studied based on floristic records^{12,13}. The entire altitudinal gradient (<200–5800 m asl; Table 2) supporting vegetation was divided into altitudinal belts of 200 m and 1000 m asl. The difference between evergreen (E) and deciduous (D) species here lies only in the extent of period when foliage is present on trees during the winter season. In this respect, evergreen species have over one year leaf longevity with concentrated summer leaf drop (around April) and simultaneous leafing, while deciduous species have less than one year longevity with summer leaf drop as well¹⁴. The mid-elevation data were calculated by taking the mean of the range (Table 1).

The simple bivariate Pearson correlation was applied following Snedecor and Cochran¹⁵, to determine the relationships among total number of species distributed in different plant form categories and other environmental variables. The mid-elevation data were used to determine the impact of elevation on other variables.

Himalayan forests extend from the lowest mountain slopes with nearly tropical to temperate timberline⁸. The low elevation appears likely to be drier although precipitation varies inconsistently with elevation¹⁶. Low temperature and

greater cloudiness at higher elevations could increase the effectiveness of precipitation.

A total of 2487 species were recorded in the present study, out of which 276 were tree species (35% E, 65% D), 355 shrub species (21% E, 79% D), 112 climber species (35% E, 65% D) and 1744 herb species (Table 2). Along the altitude, the geographic and climatic conditions change sharply. The entire region exhibited a relatively higher percentage of deciduous than evergreen species. Bongers *et al.*¹⁷ stated that drought-indicating factors (length of dry period and cumulative water deficit) were more important for determining species distribution. Plants do not depend on rainfall, but on water availability over the year in high rainfall areas the drought period is crucial. Veenendaal *et al.*⁴ showed that the length and intensity of the dry period determined soil water potential, the factor indicating water availability for the plants. In addition, elevation above 2000 m asl may accumulate snow and have persistent cold temperature in winter. It may be argued that spatial fluctuations in climatic conditions have led to the development of high percentage of deciduous species in Kumaun region. Nonetheless, in general, the prevalence of moist but cool and frost climate in greater parts of this region has also favoured luxuriant growth of evergreen vegetation⁹.

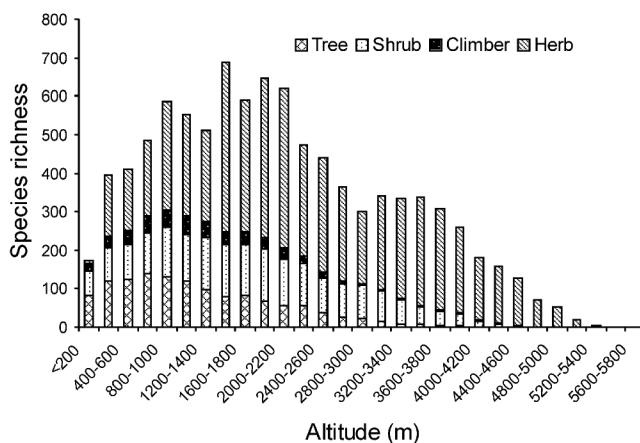
The study showed that tree vegetation was distributed between <200 and 4600 m asl. The total tree species richness (deciduous and evergreen) ranged between 2 and 138 species, being minimum at 3800–4600 m asl and maximum at 600–800 m asl (Figure 1). The upper limit of tree species ranged between 4000 and 4600 m asl (*Alnus nepalensis* and *Betula utilis*). A number of tree species found in the Himalaya showed varying patterns of distribution. The extension of climatic gradient enabled several species to realize their full-range of elevational adaptability. Distributional ranges of several species were segregated along the widened altitudinal ranges⁸.

At 200 m asl altitudinal difference for deciduous tree species, peak richness was recorded at a range between 600 and 800 m asl, and it varied from 2 (4200 m asl) to 71 species

Table 2. Impact of altitude on total species richness distributed in different growth form categories

Altitudinal range (m asl)	Total number of species							Total
	Trees		Shrubs		Climbers		Herbs	
	D	E	D	E	D	E		
<200	51	32	51	14	7	12	4	271
200–400	65	57	65	20	13	15	160	395
400–600	65	58	69	23	15	20	161	420
600–800	71	67	75	31	19	26	194	483
800–1000	69	63	90	36	22	29	283	592
1000–1200	56	66	88	32	22	26	263	553
1200–1400	54	71	98	35	18	24	236	536
1400–1600	42	57	103	32	14	20	440	708
1600–1800	38	42	100	30	15	19	341	585
1800–2000	40	43	106	26	14	17	414	660
2000–2200	31	38	96	24	14	16	413	632
2200–2400	27	29	95	16	8	10	288	473
2400–2600	28	28	81	11	7	9	296	460
2600–2800	20	16	77	10	4	3	243	373
2800–3000	15	11	80	7	5	2	186	304
3000–3200	13	9	72	7	5	–	243	346
3200–3400	6	8	60	5	3	–	262	344
3400–3600	2	4	42	5	3	–	282	338
3600–3800	2	2	39	2	2	–	225	274
3800–4000	2	–	30	1	2	–	162	197
4000–4200	1	–	13	1	1	–	146	162
4200–4400	–	–	9	–	–	–	126	135
4400–4600	–	–	1	–	–	–	71	72
4600–4800	–	–	–	–	–	–	51	51
4800–5000	–	–	–	–	–	–	20	20
5200–5400	–	–	–	–	–	–	2	2
5400–5600	–	–	–	–	–	–	1	1
5600–5800	–	–	–	–	–	1	1	

D, Deciduous; E, Evergreen.

**Figure 1.** Total plant species richness in relation to altitude.

(600 m asl). Species richness did not vary sharply between 200 and 1000 m asl. Above 1000 m asl, it decreased exponentially with increase in altitude and dropped to the minimum at 4200 m asl (Figure 2a). Evergreen tree species followed similar trend as that of deciduous species, but peak richness was encountered at an altitude range of 1200 to

1400 m asl (71 species). After this, it declined steadily till it reached its minimum level at 3600–3800 m asl (two species). At an altitudinal range of 2400–2600 m asl and from 3600 to 4200 m asl, the species richness of deciduous and evergreen tree species was similar (28 and two species each).

At 1000 m asl altitudinal differences, this pattern was a bit changed. The peak species diversity declined sharply beyond 2000–3000 m asl for evergreen and at 1000 m asl altitude for deciduous tree species. The peak richness was recorded between 1200 and 1800 m asl and 600 and 800 m asl respectively for evergreen and deciduous tree species (when data were separated at the difference of 200 m asl). However, the overall pattern for evergreen tree species remained similar, while for deciduous, it was slightly changed. The overall pattern of species richness showed a sharp decline as the altitude increased beyond 3000 m asl (Figure 2b). A similar pattern of tree species richness (deciduous) in timberline area was reported by Rawal *et al.*¹⁸. Along the altitudinal gradient, the upper limit of species richness remains high up to a considerable altitudinal level (2500 m asl) and tree richness increases with increasing moisture in the Indian Central Himalaya¹⁹. Considering tree species richness, a significant negative relation was found between evergreen

vs elevation, deciduous vs elevation and elevation vs total tree species ($P < 0.001$; Table 3).

Species richness of shrubs varied from <200 to 4600 m asl altitudinal range. The distribution pattern of total shrub species varied from 2 (4600 m asl) to 35 (1400 m asl) species. From 200 to 1000 m asl, species richness increased sharply with altitude, whereas above 2000 m, it declined towards 4600 m asl. Between 1000 and 2000 m asl, species richness fluctuated due to change in the climatic conditions (Figure 1).

At 200 m asl altitudinal difference, species richness of deciduous species varied from 1 to 106 species (4600–1800 m asl respectively). The pattern for evergreen species was approximately similar. Species richness was minimum (one species, *Achyranthes aspera*) at 4600 m asl, and maximum (36 species) between 800 and 1000 m asl altitude (Figure 2 a).

Distribution of species richness in the 1000 m altitudinal belt for total shrub species varied from 218 (1000–2000 m asl) to one species (> 5000 m asl). Peak richness for deciduous shrubs was found between 1000 and 2000 m asl (161 species) and minimum at 5000 m asl (one species). For evergreen shrubs, species richness varied between 12 and 57

species (4000 and 1000 m asl elevation respectively; Figure 2 b). The correlation coefficient for shrub with relation to different parameters is given in Table 3.

Climbers occurred between <200 and 4200 m asl. The total species richness of climbers ranged from 3 (3800 and 4200 m asl) to 51 species (800–2000 m asl). At 200 m asl altitudinal difference, species richness increased with increasing altitude till 1000 m asl and it declined thereafter, with increasing altitude for evergreen species. Maximum species richness for evergreen climbers was recorded up to 1600 m and remained more or less high up to 2200 m asl; thereafter, species richness slightly decreased. Beyond 3000 m asl, no evergreen climbers were found (Figure 2 a). Species richness of climbers peaked at an altitudinal range of 800–1000 m asl for deciduous as well as evergreen species (Figure 1).

At 1000 m asl altitudinal difference, it was observed that the altitude below 1000 m sustains maximum richness of climbers of both deciduous and evergreen species. The species richness slightly declined with increase in altitude till 2000 m asl. Sharp decline was observed in species richness for the next 1000 m asl, when the species number ranged from 36 to 17 for evergreen and 32 to 13 for deciduous climbers (Figure 2 b).

With further increase in altitude, a sharp decline in species richness was recorded (deciduous species was absent and only two evergreen species were present). Thereafter, evergreen species disappeared and only one deciduous species of climber (*Clematis orientalis*) was encountered at an elevation of 4000–4200 m asl²⁰. Beyond these altitudes,

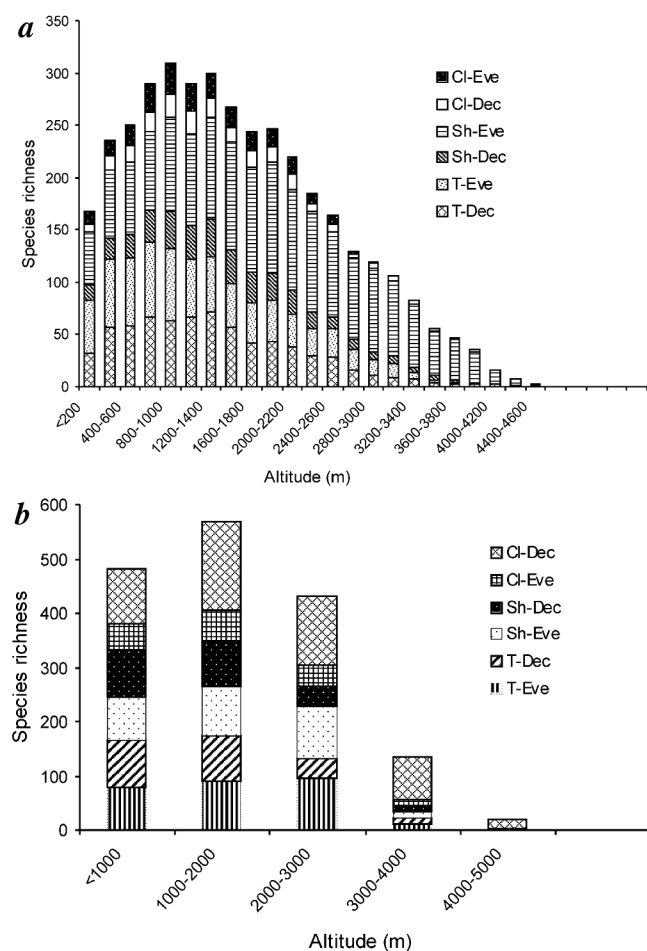


Figure 2. a, b. Species richness in relation to altitude (T, Tree; Sh, Shrub; Cl, Climber; Dec, Deciduous; Eve, Evergreen).

Table 3. Relationship between different parameters

Parameter	<i>r</i>	<i>P</i>
Elevation vs soil moisture content	0.954	0.001
Elevation vs soil pH	0.852	0.001
Elevation vs total plant species	-0.874	0.001
Soil moisture content vs total plant species	0.898	0.001
Soil pH vs total plant species	-0.098	0.001
Elevation vs total tree	-0.896	0.001
Elevation vs total shrub	-0.554	0.001
Elevation vs total climber	-0.762	0.001
Elevation vs total herb	-0.048	0.001
Tree vs shrub	0.619	0.001
Tree vs climber	0.852	0.001
Tree vs herb	0.097	0.001
Shrub vs herb	0.483	0.005
Shrub vs climber	0.703	0.001
Herb vs climber	0.236	0.001
Elevation vs evergreen tree	-0.766	0.001
Elevation vs deciduous tree	-0.867	0.001
Elevation vs total tree	-0.853	0.001
Elevation vs evergreen shrub	-0.431	0.005
Elevation vs deciduous shrub	-0.716	0.001
Elevation vs total shrub	-0.554	0.001
Elevation vs evergreen climber	-0.707	0.001
Elevation vs deciduous climber	-0.649	0.001
Elevation vs total climber	-0.709	0.001

no climber species was recorded. The correlation coefficient value for climber species with relation to different parameters is given in Table 3.

The plant forms (trees, shrubs, herbs and climbers) are distributed throughout this region between altitudes <200–5800 m asl. However, more than 60% plant species were either present below or at around 1500 m asl. Between these regions, the temperature covers a range from 10 to 24°C and rainfall decreases with increasing altitude up to 1200–1300 m asl²⁰. The winds have enough humidity, which induces greater physiological activities in the trees. It also brings about rapid decomposition of organic matter, resulting in greater mineralization of nitrogen and release of other nutrients.

At 200 m asl differences, a comparison among species richness of climbers, trees, shrubs and herbs was considered. It was observed that maximum richness of these forms differed at different altitudes. Negative correlation values indicate that as the elevation increases, significant decrease in tree, shrub and herb species occurred ($P < 0.001$; Table 3). Generally, between 200 and 2200 m asl, total plant richness, excluding climbers, was recorded to be maximum. However, maximum richness of climbers occurred between 1000 and 1200 m asl. Species richness of trees was high at an elevation of 600–800 m, while that of shrub species was between 1400 and 1600 m asl (Figure 1). Species herb richness declined insignificantly with increasing elevation. Significant positive relation in species richness was found between tree vs shrub, tree vs herb, shrub vs herb and shrub vs climber ($P < 0.001$; Table 3).

Herbs were the highest contributors of plant richness among the others forms and were distributed between < 200 and 5800 m asl. Herb richness was negligible at below 200 m asl, and increased with increase in altitude. Herb richness declined slightly at an elevation of 1000–2000 m asl; thereafter, it increased significantly to attain peak species richness (440 species) at an altitude of 1400–1600 m. It declined sharply to 341 species at 1600–1800 m asl and again increased with altitude. Thus, two peaks in herb species richness were observed. Altitudes of 2200–3400 m asl sustained comparatively low herb richness, while with further increase in altitude, species richness tended to increase forming minor peaks at elevations between 3600 and 3800 m asl and 4000 and 4200 m asl respectively. Thereafter it declines slightly up to 5800 m asl (Figure 1). The upper limit of herb species (*Stellaria decumbens* var. *pulvinata*) occurred between altitudinal ranges of 5600 and 5800 m asl²¹.

Plant richness was recorded maximum at mid-altitudes and as such, the peak richness was recorded at 1400 and 1600 m asl. In general, the richness was recorded high at 600–2600 m asl; however, below and above this altitudinal range it was low. Considerable decline in total species richness of all plant species was noticed above 4200 m asl. A sharp decline occurred after 5000 m asl, while it suddenly dropped beyond 5600 m asl. In the present study, species richness in relation to altitude clearly shows that

the former reaches maximum in middle elevations of the altitudinal gradient. The asymmetric curve has also been noticed by others^{4,5}. It was noticed that species richness declined towards higher limits of forests (i.e. sub-alpine zone). A pattern of species richness peaking in the middle part of the gradient of disturbance is consistent with observations²² for tropical savanna vegetation and for alpine meadows²³. Earlier studies reported a hump-shaped relationship between species richness and altitude^{24,25}. Evergreen broad leaf species are most suitably adapted to prevailing climate, broadly characterized by limited variations in day length and temperature and plenty of rainfall, with strong seasonal periodicity within an annual cycle. By allowing species to remain evergreen mild winters may contribute to diversity of species as well as plant traits. The interaction of air circulation pattern, topography, temperature and edaphic factors result in uneven distribution and availability of moisture. Seasonal patterns of precipitation, and of likelihood of rain during the dry season, may be more important than total precipitation in determining growth, and different species may react differently to the same soil moisture regime. This is consistent with the findings of Fritts²⁶.

The interesting feature of total plant richness at all elevations was that the herbs contributed maximum species richness, except at <200 m asl (Figure 3).

It is a well known fact that the altitude represents a complex gradient along which many environmental variables change concomitantly. However, in general, it has been suggested that an increase of 270 m asl altitudes corresponds to a fall of 1°C in mean atmospheric pressure up to 1500 m asl, above which the fall is more rapid¹³. Pangtey *et al.*²⁷ argued that the effect of monsoon is not substantially weakened at higher altitudes and also the amount of rainfall is not much different from that of the lower altitudinal range of Central Himalaya. One popular explanation for the decrease in species richness in relation to latitude is the decrease in productivity from equator towards the poles²⁸. This has also been used to explain the patterns in species richness decrease with altitude⁵. In the present study, there was pronounced

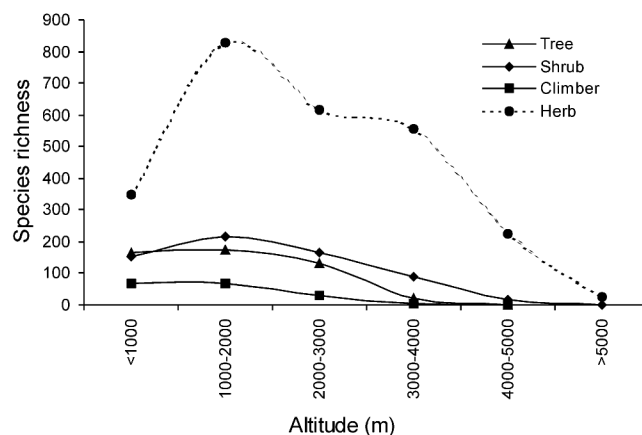


Figure 3. Total plant form species richness in relation to altitude.

effect of elevation on different edaphic factors (elevation vs soil moisture content, elevation vs soil pH) and total plant species richness. There was a strong positive relation between soil moisture content and plant species richness of the area, but there was no relationship between soil pH and plant species richness (Table 3). In the Indian Himalaya, Singh *et al.*¹⁶ found that productivity does not change between sea level and approximately 2500 m asl. However, several other explanations have been given for a linear relationship between species richness and altitude²⁹. Nevertheless, the distribution of plant species in this region depends largely on altitude and climatic variables like temperature and rainfall, which are the determinants of the species richness.

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