Adaptation strategies should be prepared keeping in view that they will help the community to understand the effect of such changes. Recording and inventorying these changes will be the first step towards developing adaptation strategies.

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ADITYA K. JOSHI
P. K. JOSHI*

Department of Natural Resources,
TERI University,
New Delhi 110 070, India
**For correspondence.*
e-mail: pkjoshi@teri.res.in

Elevational reduction of plant species diversity in high altitudes of Garhwal Himalaya, India

Pioneer work of Humboldt in the 19th century initiated interest among the scientists, to collect plants from high altitudes throughout the world[1]. The Himalayan high altitudes having the highest located alpine zones on earth were also explored. Many plant collectors have collected plants from high altitudes of Garhwal Himalaya[2], and the altitudinal distribution of higher plants in the Himalaya has been discussed by some workers[1,3–9].

The term 'high altitude' is used here to indicate land above 3000 m altitude in the Garhwal Himalaya. This land includes the uppermost montane zone, subalpine zone and alpine zone, and constitutes a floristically rich area least disturbed by anthropogenic activities due to inaccessibility and sparse human settlement. The high altitudes are the uppermost vegetated areas on the mountains. Here, the rich higher plant diversity (angiosperms and gymnosperms) of the montane zone gradually reduces to zero through treeline ecotone, alpine zone and nival zones (Figure 1).

The richness of organismic taxa declines with elevation and alpine plant diversity decreases with increasing altitude[2,10,11]. Along altitudinal gradient in subalpine–alpine zones, reduction in the number of species is calculated as 40 species per 100 m elevation[12] for vascular plants; this rate ranges between 15 and 45 species per 100 m in Europe[13]. This rate, surprisingly, does not differ greatly across a wide range of mountains. However, the rate of decline in Indian Himalayan region is not known which we have attempted to find here.

The altitude range of a species is the upper and lower limit of its occurrence[6] on mountain slopes. The altitudinal range or vertical distribution of species occurring above 3000 m asl (high-altitude areas) was determined for various plant species on the basis of: (i) field surveys during 1992–2008 in various high-altitude areas of Garhwal Himalaya; (ii) consultation of three important regional herbaria, viz. Forest Research Institute, Dehradun (DD); Botanical Survey of India Northern Circle, Dehradun (BSD) and Garhwal University Herbarium, Srinagar Garhwal (GUH), and (iii) consultation of authentic literature about high-altitude plants of Garhwal Himalaya[5,6,14–33].

Altitudinal distribution of all plants (angiosperms and gymnosperms) was recorded at an interval of 200 m, from 3000 to 5400 m asl. Plant species also occur above 5400 m, but explorations and collections above this altitude are few, making available data less reliable. Above this altitude, which is almost above the snowline, vegetation in the form of stable populations is absent and only individual plants are found in specialized niches[4]. These isolated individuals found up to 6400 m asl often profit from local microclimatic peculiarities and their natural uppermost limits are 1000 m lower[11]. A total of 690 species belonging to 272 genera and 74 families were studied for altitudinal distribution by two different approaches.

In one, following Korner[12], the number of species, genera and families above a particular altitude was plotted against different altitudes (Figure 2 *a*). Figure 2 *a* gives a trend indicating continuous decline in the number of species, genera and families with increasing altitude. However, decline in genera is less steep and least steep in families, indicating the presence and persistence of specialized genera and families in high altitudes. Three different rates of decline between 3200 and 5400 m are apparent: (i) steep decline between 3200 and 4600 m, 38.5 species/100 m, (ii) less steep between 4600 and 5200 m, 21.16 species/100 m and (iii) least steep decline between 5200 and 5400 m, 4 species/100 m. Above 5400 m altitude very few species are known to occur, but considering the records of highest distributed species *Christolea himalayensis* (Cambess.) Jafri, Brassicaceae; *Ranunculus lobatus* Cambess., Ranunculaceae[34] and *Saussurea gnaphalodes* (Royle ex DC.) Sch.-Bip., Asteraceae[35] up to 6400 m asl, the rate of decline can be easily assumed even lower than (iii). The overall rate of decline between 3000 and 5400 m is 28.25 species/100 m (4.09% species/100 m), which comes under the indicated range[13]. Since the standard rate (40 species/100 m) of decline[12] applies for alpine zones, the rate of decline between two alpine locations, i.e. 3600 and 4600 m is 39.3 species/100 m, much closer to the standard rate. Upwards, it reduces gradually. The overall rate of decline between 3600 and 5400 m is 22 species/100 m, 11.77 genera/100 m and 2.94 families/100 m.

In the second and more traditional approach, the number of species potentially present at a particular altitude (considering altitude range of species) is plotted against the altitude (Figure 2 *b*). The number of species increases from 3000 m, peaks at 3400 m and declines upwards. The decline above 3400 m is non-uniform and wavy, as also noticed elsewhere[36], which indicates zonation of alpine vegetation[11]. Above 3600 m, the approximate altitude of timberline, there are four distinct waves, first between 3600 and 4000 m with a rate of decline 14.5 species/100 m; second between 4000 and 4400 m with a rate of decline 38.25 species/100 m; third between 4400 and 5000 m with a rate of decline 27.16 species/100 m, and fourth above 5000 m with the lowest rate of decline. Comparison with standard reference line[12] (40 species/100 m) indicates that the rate of decline between 4000 and 4600 m is almost equal to the standard rate; but in other parts it deviates from the standard rate. The overall rate of decline above timberline, i.e. between 3600 and 5400 m is 24.05 species/100 m (3.48% species/100 m), falling in the range of 15–45 species/100 m (ref. 13), but far deviates from the suggested[12] standard rate of 40 species/100 m. In this zone the rate of decline for genera is 11.05 genera/100 m and for families, it is 2.94 families/100 m.

In both these approaches, the rate of decline in species is not uniform either above 3000 m (high altitude) or above 3600 m altitude (alpine zones); rather it changes in different altitude bands. However, the overall rate of decline (28.25 or 24.05 species/100 m) fairly falls within the range of European mountains (15–45 species/100 m)[13], but differs significantly from the standard rate (40 species/100 m)[12]. In both cases, the rate of decline around the altitude range 4000–4600 m is close to 40 species/100 m, but differs from it above 4600 m in the first case and at all altitudes, except 4000–4600 m in the second. Invariably, the rate of decline is less steep in genera and least steep in families compared to species. Greater contribution by few specialized high-altitude taxa (genera and families)[12] and their broader altitudinal distribution ranges compared to species (Table 1) are two apparent reasons for this slower decline along altitudinal gradient.

There are many broad-range (> 1500 m), high-altitude specialist genera having five or more species like *Delphinium*, *Ranunculus*, *Thalictrum*, *Corydalis*, *Arenaria*, *Astragalus*, *Potentilla*, *Saxifraga*, *Rhodiola*, *Sedum*, *Gentiana*, *Swertia*, *Pedicularis*, *Bistorta*, *Salix*, *Juncus*, *Carex*, *Kobresia*, *Festuca*, *Poa*, etc. Species of these genera are more abundant in high-altitude areas compared to adjacent low-altitude areas. Similarly, there are some broad range (> 2400 m) high-altitude specialist families like Ranunculaceae, Brassicaceae, Caryophyllaceae, Fabaceae, Saxifragaceae, Crassulaceae and Asteraceae.

There are several factors that determine the altitudinal range of a seed plant species, with complex relationships (further varying from species to species). The responses of the available gene pool of species to these factors determine the vertical distribution range. However, in a study related to altitudinal distribution of plants, factors determining the response of all species taken as an integrated community instead of individual species can better explain the variation. It has also been suggested that rejecting strict individualistic theory will allow ecologists to better explain variation occurring at different spatial scales, synthesize more general predictive theories of community dynamics, and develop models for community-level responses to global change[37]. The decline in species richness with increasing elevation is widely accepted as a general pattern[10]. This decline may be monotonic or may have a mid elevation hump[38]. Different hypotheses have been proposed to explain the factors behind elevational reduction in a number of taxa. These can be grouped into four categories: climate hypothesis based on current abiotic conditions, spatial hypotheses of area and spatial constraint, historical hypotheses and biotic hypotheses (e.g. community overlap or ecotone, source–sink dynamics and habitat heterogeneity)[39]. In the Himalaya and adjacent mountains, elevational reduction in species richness is distinctly hump-shaped with a mid-elevation peak distinctly below 3000 m altitude, which may be due to mid-domain effect (MDE)[9,40–42] or climatic variables[9,43]. Since the area considered here is above 3000 m altitude, MDE may be excluded as a major determinant of species richness.

Above 3000 m altitude, a distinct peak of species richness occurs at 3400 m (Figure 2 *b*). This is the altitude which either coincides or lies close to the timberline in this part of the Himalaya.

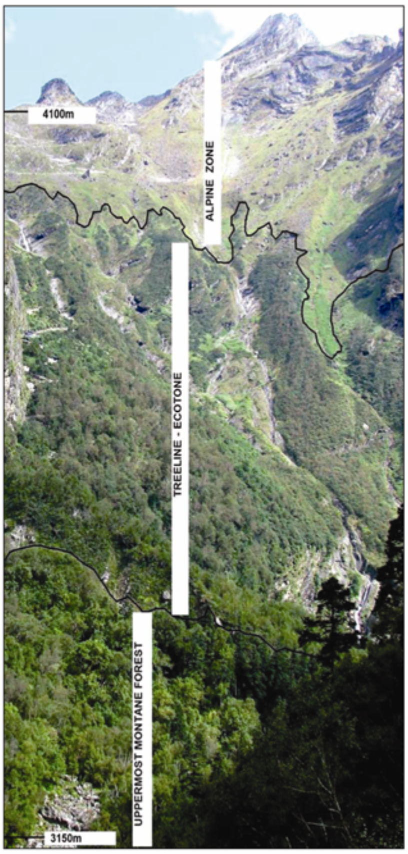

Figure 1. A view of high-altitude area in Garhwal Himalaya depicting change in vegetation along altitudinal gradient. Rich plant diversity of montane zone reduces to almost zero (at peaks, ± 5000 m asl) through treeline ecotone and alpine zone.

Table 1. Altitudinal distribution range of species, genera and families

Altitudinal distribution in high altitudes (above 3000 m)	Species		Genera		Families	
	Number	Percentage	Number	Percentage	Number	Percentage
< 1000 m	396	57.39	114	41.91	23	31.08
1000 m or more	294	42.60	158	58.08	51	68.91
1500 m or more	73	10.57	78	28.67	33	44.59
2000 m or more	9	1.30	24	8.82	18	24.32
2400 m or more	2	0.28	7	2.57	7	9.45

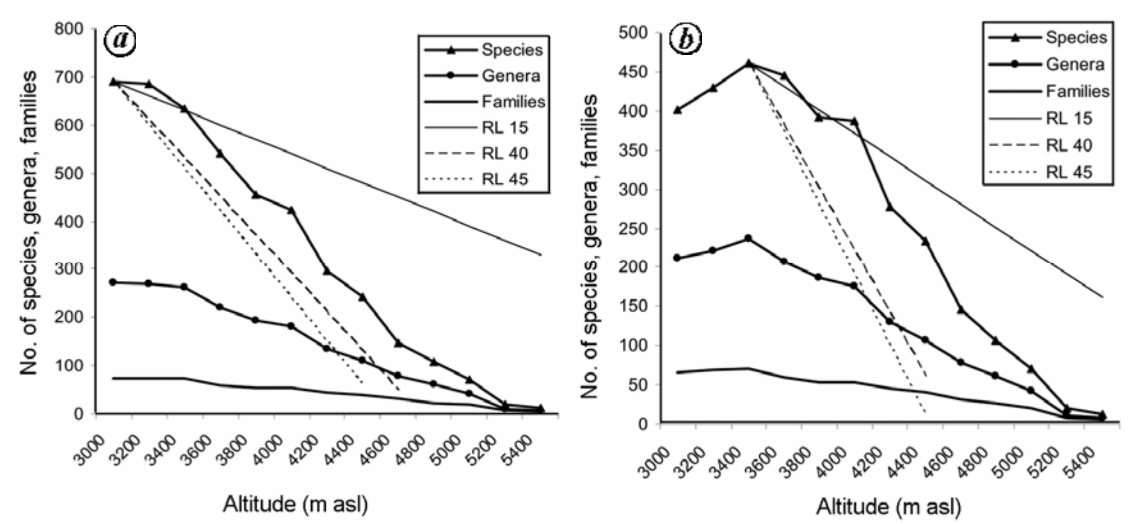

Figure 2. Elevational reduction of seed plant diversity in high altitudes. ***a***, All taxa present at and above a particular altitude. ***b***, Taxa present at a particular altitude. RL 15, Reference line indicating reduction rate of 15 species/100 m, RL 40, 40 species/100 m; RL 45, 45 species/100 m.

Also, maximum inter-fingering of open alpine community and closed montane forests exists around this altitude. This overlapping of two contrasting communities may be responsible for high species richness. A similar peak in species richness was also recorded at 3300–3600 m in another study[9]. Above this 'treeline ecotone'[11] (Figure 1), distinct alpine vegetation starts at around 3800–4000 m. In alpine zones with increasing altitude, reduction in available land area is almost linear in Central Himalaya[44]; but with this decrease the area occupied by barren rocks and snow banks increases (Figure 1). In addition, the 'snowline' in this part of the Himalaya lies within or close to 5400–5600 m altitude[7]. This indicates that beyond this altitude, barring exceptional habitats like 'rock-base niches'[4] or steep rocks, the area remains snowbound throughout the year, therefore being unavailable for seed plant growth. Based on these changes with elevation, it may be concluded that above the treeline (and not 'timberline' which is far too lower at around 3400 m), the area available for plant growth reduces more sharply than the geographical area and reaches almost nil at the snowline. A similar general trend is also found in the reduction of the number of taxa, which at 5400 m becomes < 3% (12 species) of the total species present at and above 3800 m (456 species). This suggests that available land area for plant growth, and not simple geographical area as suggested earlier[44], may be a major determining factor for species richness at different altitudes in the alpine zone.

Though the number of species reduces at a rate of 24–28 species (3–4% species) in the high altitudes of Garhwal Himalaya per 100 m elevation, the increasing altitude and thus increasing stress (lowering of temperature and pressure, thinning of air, etc.) may not be the only reasons for the overall diminishing number of taxa at higher elevations. Consistent reduction in land area with elevation[10,44–46], climatic variables[9,43], alpine island size, distance to gene source and latitude are also known to be correlated with it[47,48]. But the exact factor(s) for decrease in the number of taxa with increasing altitude in the high altitudes of Indian Himalaya need further studies.

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D. S. RAWAT

Department of Biological Sciences,
College of Basic Sciences and Humanities,
G.B. Pant University of Agriculture and Technology,
Pantnagar 263 145, India
e-mail: drds_rawat@yahoo.com