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Species richness patterns of different life-forms along altitudinal gradients in the Great Himalayan National Park, Western Himalaya, India

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ABSTRACT: A plant life-form in a particular ecosystem is the sum of its all life processes and evolved directly in response to the prevailing environment. It is considered as a potential indicator of phytoclimatic conditions of the ecosystem in which it populates. The spatial distribution patterns of life-forms vary from one ecosystem to another due to variation in the environmental gradients. The present study was aimed to assess the distribution patterns of different life-forms along the altitudinal gradients in the Great Himalayan National Park (GHNP) situated in Kullu district of Himachal Pradesh (Western Himalaya, India). We prepared a checklist of flowering plants of the park (945 taxa, 470 genera, 188 families) using both primary (field surveys) and secondary data (earlier published literature) sources. The entire altitudinal range was classified into seven altitude classes. The presence/absence (1/0) species data matrix was prepared using local altitudinal distribution range of each species to investigate the similarity in species composition and patterns of life-forms across the seven altitudinal classes. The Cluster analysis classified the seven altitudinal classes into four distinct plant communities at different altitudes. Maximum similarity (43.77%) in species composition was recorded between 3000–3500 m and 3500–4000 m altitude classes. In terms of number of species, Asteraceae (101 taxa) and *Potentilla* (11 taxa) revealed as dominant family and genus respectively. The species richness peaks at middle altitude (1500–3000 m) in the GHNP. The phytoclimate of GHNP can be termed as 'phanero-therophytic' (<1500 m), 'thero-phanerophytic' (1500–3000 m) 'thero-hemicryptophytic' (3000–4000 m) and 'crypto-hemicryptophytic' (>4000 m) at different altitudes.

KEY WORDS: Altitudinal gradient, growth-form, India, life-form, phytoclimate, species richness, Western Himalaya.

INTRODUCTION

Spatial patterns of species diversity and determining drivers are major research themes in ecology and biogeography (Colwell and Lees, 2000; Grytnes *et al*., 2006). In this context, Himalaya is an ideal site which represents the widest bioclimatic gradient in the world (Grytnes and Vetaas, 2002; Khan *et al*., 2012). The Himalayan mountains have complex topography and wide altitudinal range which provide large gradients in climate and other variables to habitat heterogeneity. In recent years, altitudinal patterns of species richness in mountain ecosystems have drawn considerable attention of researchers (Rahbek, 1995; Wang *et al*., 2002; Guo *et al*., 2013; Xu *et al*., 2017). Among various species richness patterns along the altitudinal gradients, a bell-shaped distribution with peak species richness at middle elevations is reported as the most common pattern in mountain regions (Rahbek, 2005). Some of the studies in the parts of Indian Himalaya on this subject are: Saxena *et al*. (1985), Bhandari *et al*. (1997), Klime (2003), Kharkwal *et al*. (2005), Chawla *et al*. (2008), Sharma *et al*. (2009), Acharya *et al*. (2011), Khuroo *et al*. (2011), Ahmad *et al*. (2018) and Rawal *et al*. (2018). But, the distribution patterns of growth-forms and life-forms along the altitudinal gradients in Indian Himalayan region are poorly known.

The life-form of a plant species in a particular ecosystem is the sum of its all life processes and evolved directly in response to the environment (Cain, 1950). Life-form characteristics are said to be the indicators of micro and macroclimate (Shimwell, 1971; Saxena *et al*., 1982). It is the ultimate manifestation of the sum of all the adaptations undergone by a plant to the climate in which it resides (Meher-Homji, 1964; Meera *et al*., 1999). Position (from ground level) and degree of protection of the perennating buds are main criteria used for plant life-form classification (Raunkiaer, 1934).The statistical expression of the ratio of different life-forms in a community is termed as life-form spectrum or biological spectrum (Cain, 1950; Mueller-Dombois and Ellenberg, 1974). 'Raunkiaer's normal spectrum' is often used as a null model to compare different life-forms spectra from different regions. The occurrence of similar biological spectra in different region indicates similar phytoclimatic conditions (Klimes, 2003; Batalha and Martins, 2004). In Himalaya, montane and alpine vegetation zones are ideal sites to study life-forms and biological spectra, as these zones represent pronounced seasonal changes (summer, monsoon and winter) in the phenology and growth of plants.

Biological spectra are useful to explain both the life-forms distribution in a flora and the phytoclimatic conditions under which the prevailing life-form evolved (Batalha and Martins, 2004). Some fragmentary studies are available on biological spectrum from the different parts of the Indian Himalaya (Kaul and Sarin, 1976; Gupta and Kachroo, 1983; Rajwar and Gupta, 1984; Dhar and Koul, 1986; Bhandari *et al*., 1999; Rana *et al*., 2002; Korner, 2007; Subramani *et al*., 2007; Dobhal *et al*., 2010; Ghildiyal and Juyal, 2010; Pharswan *et al*., 2010; Thakur *et al*., 2012), but there is dearth of studies focusing life-form distribution patterns along altitudinal gradients. Thus, the present study aims to investigate the patterns of plant species richness and life-forms along the altitudinal gradient in the Great Himalayan National Park (GHNP) in the Indian territory of Western Himalaya. The study will be helpful in understanding the vegetation distribution across the Western Himalaya and from other part of the mountain ecosystems with similar phytoclimatic conditions and can be used as an essential part of future policies and programmes leading to conservation of biodiversity.

MATERIALS AND METHODS

Study Area

The Great Himalayan National Park (GHNP), a UNESCO World Heritage Natural Site, is located in Kullu district of Himachal Pradesh, India. It is well known for its rich biodiversity, *in-situ* conservation of many endemic and threatened species of high altitude, aesthetic value and eco-tourism. Geographically, it stretches between 31°38'28" to 31°51'58"N latitude and 77°20'11" to 77°45'52"E longitude, covering an area of 755 km^2 with altitude range of ca. 1300 m to above 6000 m asl. The Park shares its boundary with Rupi Baba Wildlife Sanctuary in the east, Pin Valley National Park in the north east and Kunawar Wildlife Sanctuary in the west and with a number of village ecosystems in the south western fringe. Agricultural activities, development of human settlements, poaching and extraction of fodder, fuel-wood, timber, medicinal plants, etc. are prohibited in the park. But, sometimes illegal extraction of medicinal plants, seasonal grazing (by migratory sheep and goats) and wood-cutting (by the migratory shepherds and tourists) can be noticed (Singh and Rawat, 2000). The Forest Department permits eco-tourism, research and monitoring activities in the area for sustainable development, biodiversity conservation and livelihood growth purposes.

Tirthan and Sainj are the two main rivers flowing across the park through the deep gorges in east-west direction. The park exhibits typical Western Himalayan temperate and alpine climate. Most of the park area (ca. 68%) is covered by alpine vegetation and permanent snow. Following the revised forest classifications of India (Bahuguna *et al*., 2016), the forest types found in the Great Himalayan National Park are 'west Himalayan broadleaved temperate forest', 'west Himalayan mixed coniferous forest', 'west Himalayan dry temperate coniferous forest', 'west Himalayan deodar forests' and 'west Himalayan alpine pastures'. The floristic composition of the park is summarized in Table 1. The underlying rocks found in the area are largely quartzite, schist, phyllite, dolomites, limestone, shale, slate, gneiss and granites (Singh and Rawat, 2000). Loam, clay, sandy-loam and podzolic soils are the major soil types found in the park.

Methodology

An inventory of plant resources of Great Himalayan National Park was made as a baseline data using both primary and secondary sources. Extensive field surveys were conducted in the park for collection of plant specimens during the years 2016–2018. The specimens processed for herbarium following traditional methods (Jain and Rao, 1977), identified and deposited at Central National Herbarium (CAL), Howrah, which were considered as primary data source. Our floristic explorations also contributed some notable distributional records from the GHNP (Das *et al*., 2017, 2018, 2019). Earlier published flora of the National Park (Singh and Rawat, 2000) and its subsequent additions (Singh *et al*., 2015) were accounted as secondary data sources. To access the distributional patterns of growth-forms and life-forms and their relation with altitude, we classified the entire altitudinal range into seven altitude classes (AC), viz. AC1 (up to 1500 m), AC2 (1500–2000 m), AC3 (2000–2500 m), AC4 (2500–3000 m), AC5 (3000–3500 m), AC6 (3500–4000 m) and AC7 (above 4000 m). To study the similarity in species composition and patterns of life-forms across the seven altitudinal classes in Great Himalayan National Park, Western Himalaya, a presence/absence (1/0) species data matrix was prepared using local altitudinal distribution range of each species. The recorded plant species were categorized in growth-forms (GF) and life-forms (LF) for further analysis. The general habit of growth (structural category) like climber, herb, shrub and tree was considered as growth-form while life-form categorization is based on the position of the perennating vegetative bud in relation to the ground level (Raunkier, 1934).

Annual seed bearing plants were categorized into therophyte (Th) e.g. *Silene* spp., *Impatiens* spp., *Bupleurum* spp.; plants with perennating buds buried in the ground and aerial parts die back in winter were considered as cryptophytes (Cr) e.g. rhizomes and bulbs bearing species; plants with perennating buds close to the ground surface and covered with leaf litter were as hemicryptophyte (H) e.g. *Arcyosperma primulifolium*, *Rheum* spp., *Primula* spp.; plants which have perennating buds at ground surface to about 25 cm above the surface were considered as chamaephyte (Ch) e.g. *Cassiope fastigiata*, *Smilax vaginata*, *Salix lindleyana*, *Strobilanthes atropurpureus* while all the woody species

Table 1. The floristic composition of GHNP at different altitudes.

Altitude range (m)	Code given[a]	Climatic zone[b]	Forest type[c]	Dominant/ common floral element
<1500	AC1	LT	MBL, MCF, CF	**Tree**: *Pinus roxburghii*, *Quercus leucotrichophora*, *Juglans regia*, *Alnus nepalensis* and *Aesculus indica*. **Shrub**: *Euphorbia royleana*, *Berberis* spp., *Debregeasia saeneb*, *Prinsepia utilis*, *Desmodium* spp., *Sarcococca saligna* and *Reinwardtia indica*. **Herb**: *Cynoglossum lanceolatum*, *Dicliptera bupleuroides, Micromeria biflora*, *Polygonum amplexicaule*, *Bupleurum* spp., *Hedychium spicatum*, *Urtica* spp., species of grass and Fern.
1500–2000	AC2	LT	MBL, MCF, CF	**Tree**: *Abies pindrow*, *Aesculus indica*, *Juglans regia*, *Quercus floribunda* and *Machilus* spp. **Shrub:** *Jasminum humile*, *Berberis* spp., *Thamnocalamus spathiflorus*, *Sorbaria tomentosa*, *Viburnum mullaha*, *Myrsine africana* and *Rubus ellipticus*. **Herb**: *Boenninghausenia albiflora*, *Agrimonia pilosa*, *Bergenia ciliata*, *Senecio rufinervis*, *Polygonatum multiflorum*, *Heracleum nepalense*, *Cautleya spicata* and *Polygonum* spp.
2000–2500	AC3	T	MBL, MCF, CF	**Tree:** *Abies pindrow*, *Quercus semecarpifolia*, *Pinus wallichiana*, *Acer* spp. and *Betula alnoides*. **Shrub:** *Hypericum* spp., *Rubus pedunculosus*, *Cotoneaster acuminatus*, *Thamnocalamus spathiflorus*, and *Berberis* spp. **Herb**: *Geranium* spp., *Viola* spp., *Cardiocrinum giganteum*, *Calanthe tricarinata*, *Impatiens glauca*, *Strobilanthes atropurpureus* and *Senecio* spp.
2500–3000	AC4	T–UT	MCF, CF	**Tree:** *Abies pindrow*, *Cedrus deodara*, *Pinus wallichiana*, *Taxus wallichiana* and *Acer* spp. **Shrub:** *Rhododendron campanulatum*, *Rosa macrophylla*, *R. sericea*, *Spiraea* spp. and *Syringa emodi*. **Herb**: *Cremanthodium arnicoides, Dipsacus inermis*, *Polygonum amplexicaule*, *Fragaria vesca*, *Prunella vulgaris*, *Primula denticulata*, *Senecio* spp., *Polygonum vacciniifolium*, and *Pleurospermum angelicoides*.
3000–3500	AC5	UT–SA	MCF, CF	**Tree:** *Abies pindrow*, *Betula utilis*, *Cedrus deodara*, *Taxus wallichiana* and *Picea smithiana*. **Shrub:** *Rhododendron* spp., *Rosa* spp., *Spiraea canescens*, *S. bella*, *Cotoneaster microphyllus* and *Lonicera* spp. **Herb**: *Dipsacus inermis*, *Trillium govanianum*, *Trigonella emodi*, *Viola biflora*, *Strobilanthes atropurpureus*, *Ligularia amplexicaulis*, *Potentilla* spp. *Anemone* spp. and *Geranium* spp.
3500–4000	AC6	SA–A	CF, ASF, AG	**Tree**: *Betula utilis* and *Sorbus* spp. **Shrub:** *Rosa sericea*, *Juniperus communis*, *Artemisia* spp. and *Rhododendron* spp. **Herb**: *Impatiens* spp., *Allium wallichii*, *Lilium* spp., *Fritillaria roylei*, *Juncus* spp., *Thermopsis barbata* and *Swertia* spp.
>4000	AC7	A	ASF, AG	**Shrub:** *Rhododendron anthopogon*, *R. lepidotum*, *Gaultheria trichophylla*, *Salix* spp., *Cassiope fastigiata* and *Lonicera* spp. **Herb**: *Impatiens sulcata*, *Allium* spp., *Gymnadenia orchidis*, *Potentilla* spp., *Corydalis* spp., *Pedicularis* spp., *Primula* spp., *Arenaria* spp., *Anaphalis* spp., *Astragalus* spp. and *Saxifraga* spp.

a: AC= Altitude class. **b**: LT= Lower temperate, T= temperate, UT= Upper temperate, SA= Sub-alpine, A= Alpine. **c**: MBL= Mixed broad leaved forest, MCF= Mixed coniferous forest, CF= coniferous forest, ASF= Alpine scrub forest, AG= Alpine grassland.

with leaf producing buds above 25 cm from ground surface were classified as phanerophyte (Ph).

The hierarchical cluster dendrograms were constructed from presence (1)/absence (0) species matrix (distribution of 945 taxa into 7 altitude classes) using PC-ORD, version 4.34 (McCune and Mefford, 1999) with Jaccard similarity (Eq.1) and nearest neighbor linkage method. Total number of species (or species count) of any growth-form and life-form within a community was considered as species richness (SR) of that particular community in this study (Eq.2). To visualize the correlation tendency between altitude (the median altitude of each community) and species richness (no. in each community) of growth-forms and life-forms in the study area, the graph (heatmap) was generated using R Software version 3.3.1 (R Development Team, 2016) from the normalized (Log_{10} + 1) data (Table 2, n=4).

Eq. 1: $\text{Jaccard similarity index} = \frac{C}{C+A+B} \times 100,$

Where; C= No. of common species between two altitude classes, A= No. of species unique to first altitude class, B= No. of species unique to second altitude class.

Eq. 2: Species richness (SR) of growth-forms or life-forms= Total species count (No. of species) in given altitude class.

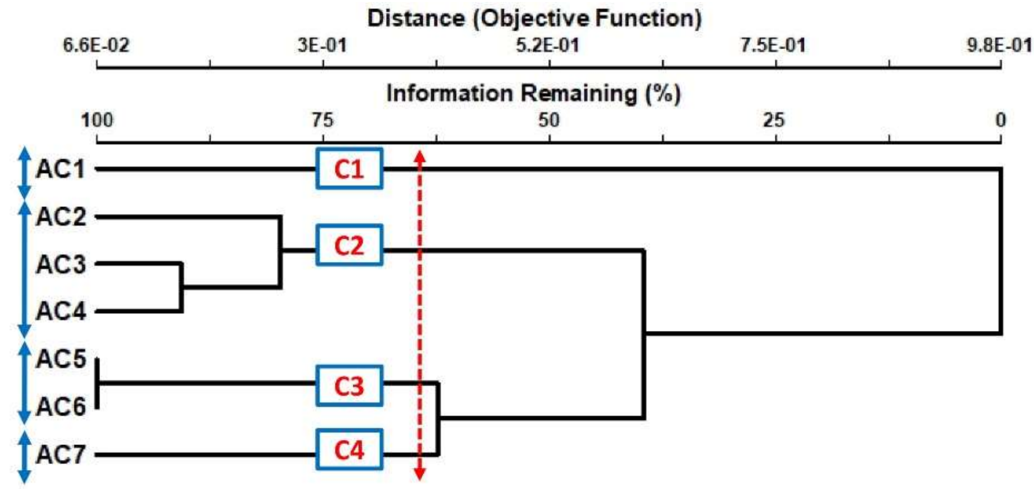
Table 2. Floristic analysis and distribution of life-forms along the altitudinal gradient in GHNP.

Attributes	Plant community (C)				GHNP
	C1	C2	C3	C4	(Total)
Floristic analysis					
No. of taxon	123	784	455	128	945
No. of genus	107	426	237	86	470
No. of family	52	118	68	32	188
S/G ratio	1.15	1.84	1.91	1.49	2.01
S/F ratio	2.37	6.64	6.69	4	5.03
Growth-forms					
No. of tree	18	78	14	0	81
No. of shrub	36	121	39	5	133
No. of herb	62	546	392	122	692
No. of climber	7	39	10	1	39
Life-forms					
No. of chamaephyte	6	43	25	8	54
No. of cryptophyte	11	119	81	52	229
No. of hemicryptophyte	18	155	118	41	205
No. of phanerophyte	56	215	55	4	312
No. of therophyte	32	252	176	23	145

RESULTS

Plant communities

Hierarchical cluster analysis using species matrix (presence/absence data) and Jaccard similarity, classified



	AC2	AC3	AC4	AC5	AC6	AC7
AC1	29.56	17.07	9.23	3.55	1.32	0.79
AC2		39.95	30.12	15.75	8.31	0.36
AC3			42.50	29.04	19.78	4.66
AC4				39.75	30.42	10.66
AC5					43.77	25.14
AC6						35.93

Fig. 1. Dendrogram and Jaccard similarity index for different altitude classes (AC) in GHNP

seven altitude classes into four distinct clusters (Fig. 1). First cluster (C1) is represented by AC1 only; AC2, AC3 and AC4 together grouped in second cluster (C2); AC5 and AC6 in third cluster (C3) while fourth cluster (C4) by AC7 only. Highest similarity (43.77%) in species composition was observed between AC5 and AC6, while lowest similarity (0.79%) between AC1 and AC7.

Floristic composition

A total of 945 taxa (917 species and 28 infraspecific taxa) belonging to 470 genera and 188 families were found in Great Himalayan National Park (GHNP). The genera with most numbers of taxa were *Potentilla* (11), *Carex*, *Saussurea*, *Saxifraga* (10 each), *Primula*, *Nepeta*, *Silene*, *Thalictrum* (9 each) and 8 taxa each of *Artemisia*, *Corydalis* and *Gentiana*. Asteraceae with 101 taxa revealed as dominant family followed by Poaceae (67), Ranunculaceae (49), Rosaceae (49), Lamiaceae (44), Fabaceae (34), Brassicaceae (30), Apiaceae and Cyperaeeae (28 each). Forest types and dominant species at different altitudes in GHNP are given in Table 1, while consolidated results for floristic analysis, growth-forms and life-forms are shown in Table 2. Maximum taxa and genera were recorded within 1500 to 3000 m altitude (C2) of the park (Fig. 2). The S/G ratio (species-to-genus ratio) and S/F ratio (species-to-family ratio) for GHNP were found 2.01 and 5.03 respectively.

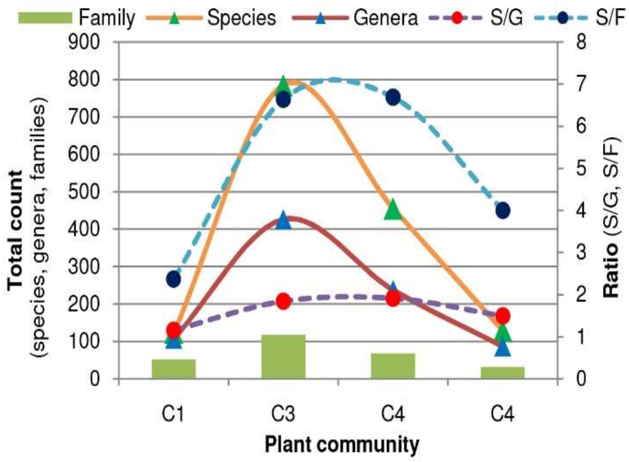


Fig. 2. Number of species, genera, families and ratio of S/G and S/F along the altitudinal gradient in GHNP, western Himalaya.

Growth- form pattern

The present study revealed that the middle altitude class (1500–3000 m) has highest species richness of growth-form (Table 2). The percentages of tree, shrub and climber species decreases with increase in the altitude while reverse trend was observed for herbs (Fig. 3). Herbs represent 60% (at C1) to 95% (at C4) of the total growth-forms in the GHNP at different altitudes. The correlation graph (Fig. 4) revealed that the species richness of trees,

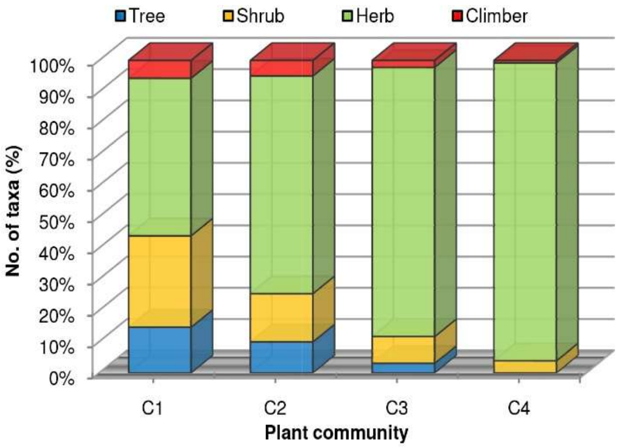


Fig. 3. Pattern of growth-forms distribution at various altitudes in GHNP.

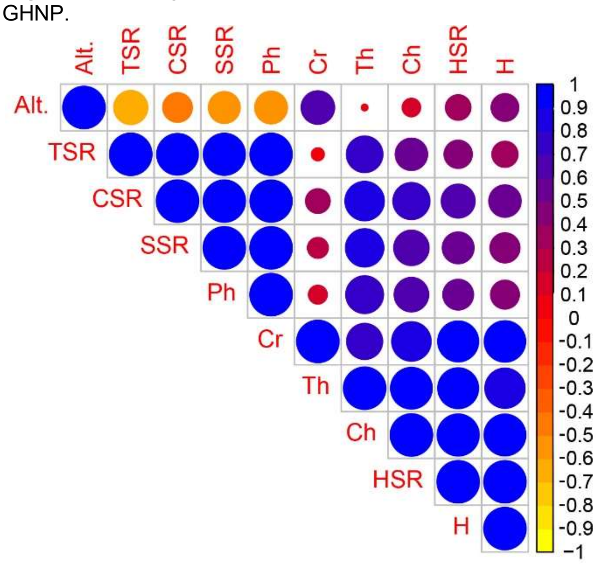


Fig. 4. Heatmap showing bivariate correlation between altitude, life-form and growth-form in GHNP (Alt= altitude, TSR= tree species richness, SSR= shrub species richness, HSR= herb species richness, CSR= climber species richness. Ch= chamaephyte, Cr= cryptophyte, H= hemicryptophyte, Ph= phanerophyte Th= therophyte).

shrubs and climbers tend to decrease with increasing altitude (partial negative correlation) while partial positive correlation was observed between altitude and herb species richness.

Life-form pattern

The study of the total life-forms (945 taxa) revealed 5.71% of chamaephytes (Ch), 15.34% of cryptophytes (Cr), 21.69% of hemicryptophytes (H), 24.23% of phanerophytes (Ph) and 33.02% of therophytes (Th) in GHNP. The peaks of species richness for all the life-forms are observed at middle altitude (1500–3000 m). However, the percentages of phanerophytes in total life-forms are found high at lower altitudes (Fig. 5), contrarily the percentages of cryptophytes and hemicryptophytes life-form which increase towards higher altitude.

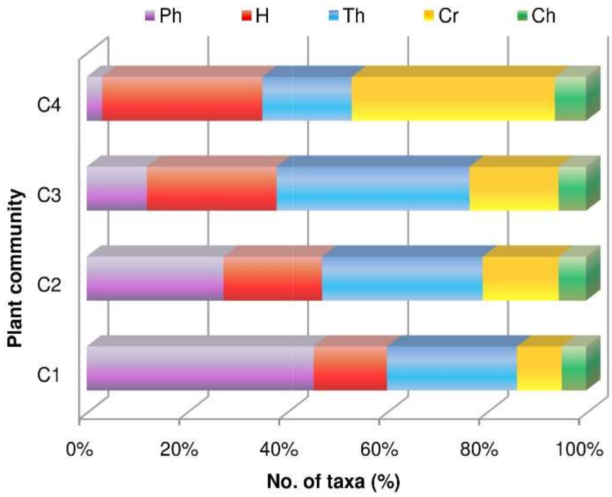


Fig. 5 Pattern of life-forms distribution at various altitudes in GHNP.

Phytoclimate pattern

As phanerophytes and therophytes together represent 71% of the total life-forms at C1, thus, the phytoclimate of this lower altitudinal zone may be termed as ‘phanero-therophytic’. At middle altitude (C2), therophytic (32%) and phanerophytes (27%) reveal as dominant life-forms which indicate the ‘thero-phanerophytic’ climate. At the higher altitudes (C4) the phytoclimate can be termed as ‘crypto-hemicryptophytic’ climate as cryptophytes and hemicryptophytes together represent 72% of the total life-forms in this altitude class.

DISCUSSION

The hierarchical cluster analysis (Fig. 1) shows that the adjacent altitude classes (AC2, AC3 and AC4) have higher degree of similarity in species composition than the distant classes (AC1 and AC7). This trend corresponds to the probability of strong similarity of environmental conditions and species composition (Table 1) with neighboring altitudinal belts (AC5 and AC6) where each mid class is a transition zone for its immediate upper and lower altitude classes. Dissimilarity with distant altitudinal classes could be caused by increase in environmental heterogeneity containing additional species which differ in their niches (Scheiner *et al*., 2011).

The present study reports highest plant species richness (784 species) between 1500–3000 m altitudes and gradual decrease in species richness towards both upper and lower altitudes from C2 (Fig. 2) which could be attributed to the phytoclimatic conditions. The declining pattern of species richness with increasing altitude was also observed in other parts of Indian Himalaya (Grytnes and Vetaas, 2002; Vetaa and Grytnes, 2002; Rahbek, 2005; Acharya *et al*., 2011; Zhang *et al*., 2015; Rawal *et al*., 2018). The present finding is in agreement to Rahbek (2005), who claimed that a bell-shaped distribution with peak species richness at middle elevations is the most common pattern in mountain regions. The proportion of geographical area and topographic features could be the major reasons of low species richness in lower altitude (C1) which received high temperature and precipitation as the proportion represented at <1500 m of the park is small and mainly represented by dry and steep slopes with species poor Chir-pine forests. Besides, this fringe area also experienced frequent forest fires and other anthropogenic pressures (grazing, collection of timber, fuel wood and fodder). The significant decrease in species richness from middle to higher altitudes in this study (Table 2) could be attributed to the altitude and other related factors. Altitude (together with latitude, longitude, distance to ocean and others) is a climate factor that yields changes upon climate elements (such as temperature, precipitation, wind, clouds, solar radiation, air humidity and others). The temperature, precipitation, solar radiation, etc. act as ecological factors. The altitudinal gradients are creating variation in species richness of which temperature is thought to be the most important factor controlling range limits of phytodiversity along elevation and latitudinal gradients (Ramsay and Oxley, 1997; Lomolino, 2001; Normand *et al*., 2009; Halbritter, 2013).

The present study reports higher species to genus (S/G) ratio and species to family (S/F) ratio for the middle altitude (C2 and C3) and lower for the lowest altitude (C1) (Fig. 2), which corresponds to the phylogenetic clumping. According to Floeter *et al*. (2004) the spatial variations of S/G ratio and S/F ratio are parts of evolutionary dynamics which are related to speciation or diversification rates. This study supports Rawal *et al*. (2018) who observed the increasing S/G ratio (for shrubs and herbs) towards higher altitudes in Uttarakhand.

This study revealed that the percentages of tree, shrub and climber species in total growth-forms decreases with increase in altitude (Fig. 3) while reverse trend reported for herb. Physiographic and phytoclimatic variations could be major forces behind this trend of growth-forms. In GHNP, the conifer mixed and broad leaved mixed forests at lower and middle altitudes (Table 1) especially on northern slopes provide favorable habits for large number of woody species (tree, shrub and liana) or phanerophytes but towards the higher altitude, the frost kills the tree seedlings and act as controlling factor for expansion of woody species and for the perpetuation of alpine meadows. Herbs are the most advanced and successful growth-forms due to their adaptability to a high range of habitat conditions. Whereas, the species richness of climbers depends on various factors such as climate, perturbation history, host specificity and variables of community structure (DeWalt *et al*., 2006; Sfair and Martins, 2011).

There are four phytoclimate classes (i.e. phanerophytic, chamephytic, hemicryptophytic and therophytic) in the usual classification practice (Raunkiaer, 1934; Cain, 1950) which is based on the predominant life-form. We found it difficult to categorize the phytoclimate of the study area into straight four classes because none of the life-form classes represent above 45% of the total life-forms at any altitude class (Fig. 5) and first two dominant life-form classes together represent above 59–73% of the total life-forms at different altitudes. Thus, a modified classification of Raunkiaer's phytoclimate is followed (viz. phanero-therophytic, thero-phanerophytic, thero-hemicryptophytic and crypto-hemicryptophytic), based on first two dominant life-forms. Similar, classification have been practiced by some other workers in the recent studies (Al-Yemeni and Sher, 2010; Reddy *et al*., 2011; Sharma *et al*., 2014; Arila and Gupta, 2016; Shahid and Joshi, 2018). Based on the distribution patterns and percentages of different life-forms across the altitudinal classes in GHNP (Fig. 5), the phytoclimate of the area can be termed as 'phanero-therophytic' at lower altitudes, 'thero-phanerophytic' to 'thero-hemicryptophytic' at middle and 'crypto-hemicryptophytic' at higher altitudes. According to Ricklefs (1979) and Smith (1980), communities with high percentages of phanerophytes and therophytes are the characteristics of warm climate and deserts conditions respectively, whereas cryptophytes and hemicryptophytes characterize colder climate. The biotic disturbances and relative dryness tend to increase the percentage of therophytes (Cain, 1950; Daubenmire, 1968; Vashistha *et al*., 2011). The decrease in woody species towards higher altitudes and dominance of the cryptophytes and hemicryptophytes was also reported by Saxena *et al*. (1982) for the vegetation of Kumaun Himalaya. The correlation graph between altitude and species richness of growth-forms and life-forms (Fig. 4) showed that the woody species tend to decrease towards higher altitudes in the study area. The forests and alpine meadows are two main plant formations that dominate the natural vegetation of Indian Himalaya. The climax vegetation in India (including Indian Himalayan region) is either forests or deserts (Champion, 1936; Bor, 1947).

The percentages of cryptophytes and hemicryptophytes showed significant increase with increase in the altitude (Fig. 5). The dominance of cryptophytes and hemicryptophytes in high altitudes of GHNP indicates prevailing desert-steppe and steppe vegetation. Similar trends were also reported in alpine zones of NW Himalaya by Ram and Arya (1991), Klimes (2003) and Vashistha *et al*. (2011). Such patterns of cryptophytes and hemicryptophytes at different altitudes in Indian Himalaya can be understood through temperature lapse rate (the rate at which temperature changes with altitude) hypothesis (Stone and Carlson, 1979), as altitude and temperature have strong inverse correlation in mountain ecosystems. Thus, low temperature at higher altitude plays a role as controlling factor for phanerophytes and therophytes. Recent studies have reported significant variations in the temperature lapse rate at near-surface (slope) to those of the free-air (Thayyen *et al*., 2005; Bhutiyani *et al*., 2007; Kirchner *et al*., 2013; Thayyen and Dimri, 2018). Thus, the phanerophytes and therophytes tend to dominate the lower altitudes with warm climate and disturbed habitats while hemicryptophytes and cryptophytes tend to dominate the cold climate of higher altitudes (desert conditions) of the Great Himalayan National Park.

CONCLUSION

The present study reports a comparative account of species similarity index, distribution patterns of growth-forms and life-forms for various altitudinal zones (with different plant communities) in Great Himalayan National Park, Western Himalaya. It can be concluded from the results that a) middle altitudinal zone (1500–3000 m) favors large number of species in this area; b) percentages of tree, shrub and climber species in total growth-forms decreases with increase in the altitude while percentage of herb species increases towards high altitudes; c) phanerophytes and therophytes are dominant life-forms in low altitude, whereas hemicryptophytes and cryptophytes in high altitude; d) the phytoclimate patterns of the GHNP can be termed as ‘phanero-therophytic’ and ‘thero-phanerophytic’ at lower to middle altitudes with warm, drier and disturbed conditions while ‘thero-hemicryptophytic’ to ‘crypto-hemicryptophytic’ at higher altitudes with harsher climatic conditions. The present findings will be helpful to botanist, naturalist, conservationist, policy maker and forest personals in expanding the knowledge pool and understating about vegetation of the Western Himalaya, and in carrying out management activities.

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