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PHYTO-CLIMATIC GRADIENT OF VEGETATION AND HABITAT SPECIFICITY IN THE HIGH ELEVATION WESTERN HIMALAYAS

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Abstract

Phyto-climatic gradient and ecological indicators can be used to understand the requirements, long term management and conservation strategies of natural habitats and species. For this purpose phytosociological attributes were measured using quadrats along transects on different slope aspects across an elevation range of 2450-4400 m. The 198 recorded plant species were placed in five Raunkiaer life form classes among which the Hemicryptophytes (51%) dominate the flora of the study area followed by Phanerophytes and Cryptophytes (Geophytes) with 15 and 13% dominance respectively. Therophytes and Chamaephytes are represented by smaller numbers (12 & 10% each). The phyto-climatic gradient of the vegetation was evaluated using Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA). Phyto-climatic relationships show that Phanerophytes especially tree species are widely distributed on northern aspect slopes whilst shrubs are more dominant on southern aspect slopes. Woody plants are dominant at lower altitudes (2450-2800 m), with a much smaller proportion occurring at middle elevations (2800-3300 m) whilst higher (3300-3900 m) and highest elevations (3900-4400 m) are dominated mainly by hemi-cryptophytes and cryptophytes. Our findings further elucidate that vegetation changes gradually from moist-cool temperate Phanerophytic and Chamaephytic elements to dry-cold subalpine and alpine herbaceous Cryptophytic and Hemi-cryptophytic vegetation in the upper elevations. Assessment of life forms and ecological gradient provide a basis for more extensive conservation studies on biodiversity in mountain ecosystems. Our findings further advocate that the Naran Valley appears to be at a transitional floristic position bridging the contrasting moist and dry temperate zones of the Sino-Japanese and Irano-Turanian floristic regions.

Introduction

The plant assemblage of a region is a function not only of time but also of altitude, slope, latitude, aspect, rainfall and humidity which play a role in its formation and composition (Kharkwal *et al.,* 2005, Ilyas *et al*., 2012). Variation in species diversity along environmental gradients is a major topic of ecological study in recent years and has been explained with reference to climate, productivity, biotic interaction and habitat heterogeneity (Currie & Francis 2004, Givnish 1999, Willig *et al.,* 2003, Shaheen *et al*., 2012b). In mountainous regions altitude has a much greater effect on temperature and the rate of decrease is much more rapid in summer, which ultimately causes the altitudinal limits of plant species and unique habitat types (Heaney 1989; Vázquez & G. Givnish, 1998; Shaheen & Shinwari, 2012). Vegetation zones based on elevation above sea level can be devised in the high altitude Himalayas as it becomes a strong limiting factor. Life forms of species also vary profoundly under the influence of such altitudinal variations. Life forms in an ecosystem indicate the adaptations of plant species' physiognomy to the surrounding climate (Patel *et al.,* 2010). It is, therefore, necessary not only to quantify the vegetation of these fragile ecosystems but also to evaluate their phyto-climatic gradient. Phyto-climatic diversity of a region is considered as a measure of the health of an ecosystem (McGrady-Steed & Morin 2000, Saqib *et al*., 2011). Through the Convention on Biodiversity (CBD), countries are making efforts to elaborate not only on the quantity of plant biodiversity but also its quality by identifying indicator species and measuring their abundance (Normander *et al.,* 2012). Indicator species allow the ecologist to evaluate critically the characteristics of specific habitats in relation to environmental conditions (Leveque, 2001).

It is impossible to count each and every plant present in a region for determining abundance and hence samples are taken with the assumption that these samples provide a good representation of that area. Choice of sampling methods depends on types of data desired, the objective of the study, the morphology of the vegetation, and the available time (Moore & Chapman, 1986). The most common quantitative sampling methods are the quadrat and line transects methods. The two methods are used together when sampling an area containing heterogeneous landscape and vegetation (Everson & Clarke 1987, Goldsmith *et al.,* 1986). Moreover, recent computer based methods of multivariate statistics have become very popular in community ecology in the last few decades. It helps ecologists to discover structure in the data sets (Anderson *et al.,* 2006; Clymo, 1980; Shaheen *et al.,* 2012a, Khan *et al.,* 2012a). Plant communities are commonly classified using robust software packages for vegetation assessments i.e., CANOCO and PCORD etc. The literature shows that classification and ordination based on various utilities of these packages has not been done before for high elevation Western Himalayan vegetation. The present paper is, therefore, the first to give a general account of the major vegetation assemblages in one high Himalayan valley (the Naran, in northwest Pakistan), with the crucial target of understanding the phyto-climatic gradient and to contribute to a better understanding of the vegetation of this part of Pakistan. Secondly, (and also for the first time) the abundance of plant species was used to analyse various life forms of plant species along environmental gradients. It is hoped that this study will help to open a new gateway to understand the conservation measures required to protect the range of specific life forms of plant species occurring in the study region.

Study area: Our study area, the Naran Valley is a mountainous valley in the western Himalayas, Pakistan, (34° 54.26´N to 35° 08.76´ N latitude and 73°.38.90´ E to 74° 01.30´ E longitude; elevation range 2450 to 5000 m) some 270 km from the capital, Islamabad. The entire area is formed by lofty mountains on either side of the River Kunhar which flows in a northeast to southwest direction down the valley. As a whole, the Naran Valley occupies a highly important geo-climatic, geological and geopolitical location (Fig. 1). It forms the northern boundary of the Province Khyber Pakhtunkhwa Pakistan. Geographically, it is located on the extreme western boundary of the Himalayan range, from where after the Hindu Kush range of mountains start to the west of the River Indus. Climatically, it is situated at the point where the summer monsoon is blocked by the lofty mountains of the lower Kaghan valley. Geologically, the area is very important as it is located on the extreme margin of the Indian Plate where it is still colliding with the Asian plate (Eurasian) (Khan, 2012, Khan *et al.,* 2011a, Wilke *et al.,* 2010). Its unique physiographic and geological history have contributed to make this area distinctive in floristic terms, but the harsh climatic and geopolitical situation in adjacent border areas has constrained intensive vegetation exploration. The present effort is one of the first ever systematic investigations of the area in terms of phyto-climatic gradient exploration.

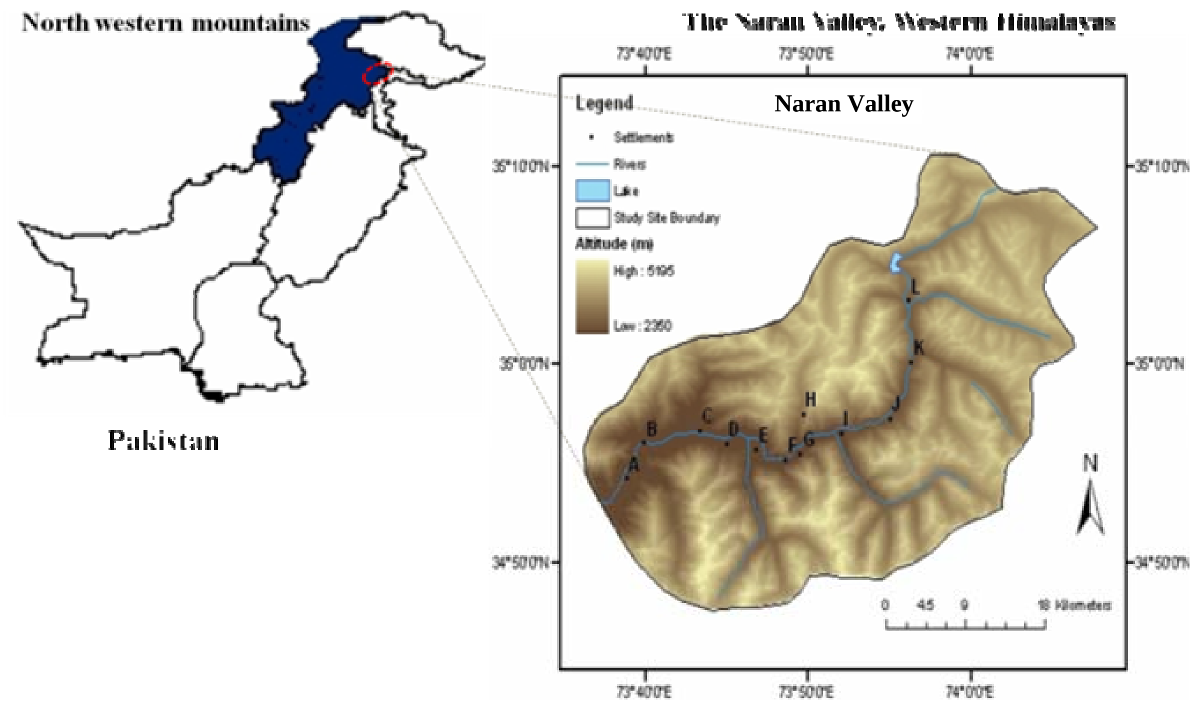

Fig. 1. Physiographic map (produced through Arch GIS) showing the position of the Naran Valley (project area); elevation zones, location of its settlements (A-L), the River Kunhar, originating lake (the Lake Lulusar) and the tributary streams.

Field work methodology: Field work was carried out during summer 2009, using phytosociological techniques. The abundance of each vascular plant species was measured using a quadrat method along 24 altitudinal transects following Khan, 2012 and Kent & Coker, 1994. The whole valley (about 60 km long) was divided into 12 sampling localities at about 5 km intervals (Fig. 1 & 2). For better understanding of vegetation structure and diversity, both altitude and aspect variations were kept in mind during sampling. To study both the northern and southern aspects, 12 altitudinal transects were launched on each of the aspects perpendicular to the River Kunhar at each locality (site), which covered as a whole an elevation range of 2450 to 4400 m.

Sampling procedure for data collection: A stratified random method was used to sample the area with rectangular quadrats of varied sizes for trees, shrubs and herbaceous vegetation, respectively. Aspect and altitude both have a great influence on vegetation structure in mountainous areas and hence a stratified random approach enabled the acquisition of maximum data along such environmental gradients. Considerable changes using minimal area methods were brought forward in quadrat sizes where felt necessary. The use of quadrats placed along transects is the best way to assess vegetation in such a varying landscape (Goldsmith *et al.,* 1986; Everson & Clarke, 1987; Cox, 1996). Each transect was started from the bed of the natural stream at the bottom of the valley (in most cases river Kunhar) at each study site and was established across the full altitudinal gradient (bottom to peak or ridge of the mountain; perpendicular to the River Kunhar). Along each transect stations were established at 200m elevation intervals (144 stations in total). The vegetation was sampled in three layers and at each station 3 quadrats (1 each for tree, shrub and herb species) were used. Two replicate sub stations were also established at 100m distance on either side of the first one, at the same altitude and with the same number of quadrats and hence 9 quadrats were recorded at each station (Fig. 2). As a whole a total of 144 stations including 1296 releves'/quadrats (432 each for tree, shrub and herb species) were recorded and analysed using phytosociological formulae following the methods proposed by McIntosh (1978).

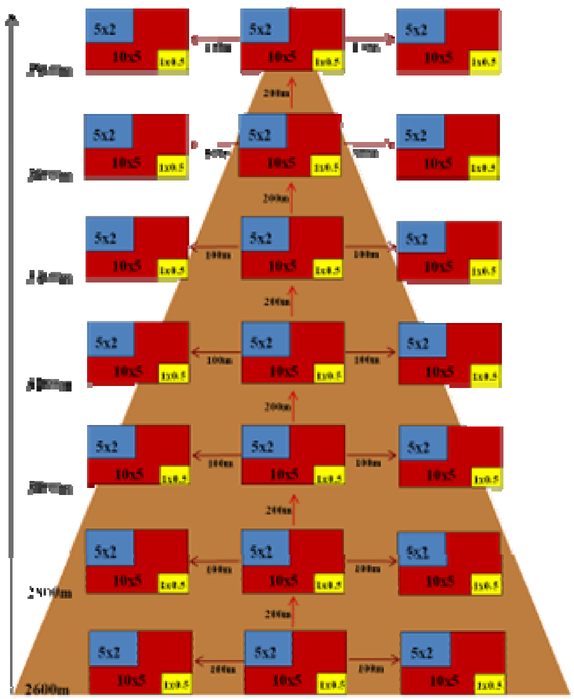

Fig. 2. Sketch of quadrat set up along each altitudinal transect on mountain slopes (a total of 24 transects) 12 each on northern and southern aspects: quadrat sizes, 10 x 5 = 50m^2 for the tree layer; 5 x 2 = 10m^2 for the shrub layer;1 x 0.5 = 0 .5m^2 for herb layer.

Identification of plant species and life forms: Herbarium specimens of all plant species were collected at each station and identified based on the Flora of Pakistan (Ali *et al.*, 1972-2009). These specimens were dried, processed, mounted on standard herbarium sheets and submitted to the Herbarium, Department of Botany, Hazara University Mansehra Pakistan. Plant life form assortment was done following the Raunkiaer's system of classification (Mueller-Dombois & Ellenberg, 1974; Raunkiaer, 1934) (Table 1).

Data analysis

Ordination analyses to identify phyto-climatic gradients using CANOCO: Ordination is a multivariate statistical method that summarizes community data by constructing a low dimensional space in which similar samples and species come closer together whilst dissimilar ones go further apart (Digby & Kempton, 2010; Gauch, 2010; Greig-Smith, 2010; Jongman *et al.,* 1995; Tüxen & Whittaker, 2010; Ter Braak, 1987; Khan *et al.,* 2012b; Khan *et al.,* 2011b). Keeping the objectives of the study in mind, DCA and CCA using CANOCO version 4.5 (Ter Braak & Barendregt, 1986; Ter Braak, 1986; Ter Braak & Prentice, 1988) were carried out consecutively.

Detrended correspondence analysis (DCA): DCA is highly valued by ecologists as it is carried out without the input of environmental data and hence results are free from distortion (Hill & Jr. Gauch, 1980; ter Braak, 1988). A life form abundance data matrix of species was used to describe the phyto-climatic gradient of the vegetation.

Canonical correspondence analysis (CCA): CCA is the most robust and widely used direct ordination gradient exploration technique and hence was adopted to treat floristic and environmental data matrices together in CANOCO. Its application to the data further authenticated the results of the DCA and ISA (Kent & Coker, 1994; Greig-Smith, 2010; Dufrêne & Legendre, 1997; McCune & Grace, 2002). Using CCA, abundance data of all the species and quadrats were analysed with the objectives to (i) evaluate the significance of relationships among species life form and environmental variable, (ii) reconfirm whether the DCA based pattern of plant community is due to the measured environmental variability or something else and (iii) authenticate the habitat specificity of indicator species.

Table 1. Raunkier Life form Classes; RC1-RC5.

RC	Description
1.	**Phanerophytes:** Woody species with perenating buds emerging from aerial parts
2.	**Chamaephytes:** Species with perenating buds born on aerial parts but close to the ground (no more than 25 cm above the soil surface).
3.	**Hemicryptophytes:** All above ground parts of the plant die back in unfavourable conditions and buds are born at ground surface.
4.	**Cryptophytes (Geophytes):** Plant species with buds or shoot apices which survive the unfavourable period below ground or water
5.	**Therophytes**: Plant species survive unfavourable condition as seeds (annuals)

Results

Raunkiaer life form classification: Based on the Raunkiaer system of classification, the 198 (12 tree, 20 shrub and 166 herb) plant species belonging to 150 genera recorded at the 144 stations (1296 quadrats) were placed in 5 life form classes (Fig. 3). The Hemicryptophytes (51%) dominate the flora of the region followed by Phanerophytes and Cryptophytes (Geophytes) with 15 and 13% dominance respectively. Therophytes and Chamaephytes are represented by smaller numbers (12 & 10% each). Most of the Phanerophytes, especially tree species, are widely distributed on northern aspect slopes whilst shrubs are more dominant on southern aspect slopes. As a whole woody plants are dominant at lower altitudes (2450-3200 m), with a much smaller proportion occurring at middle elevations (2800-3300 m). One of the highly selective Phanerophytic indicator species of timberline habitats is *Betula utilis* which occurs only on northern aspect slopes at an altitudinal range of 3100-3400 m. On the other hand higher (3300-3900 m) and highest elevations (3900-4400 m) are dominated mainly by hemi-cryptophytes and cryptophytes.

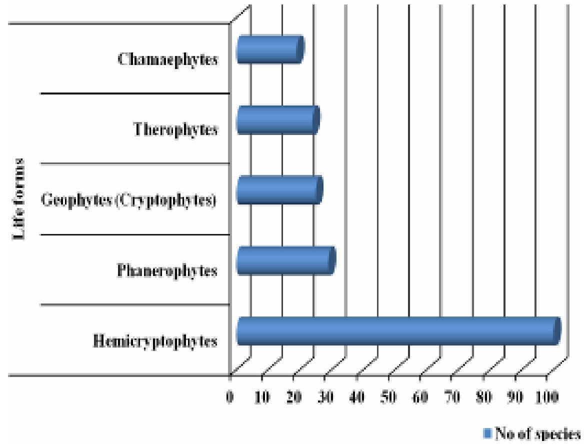

Fig. 3 Raunkiaer Life form classification.

Phyto-climatic gradient: DCA analyses of Raunkiaer life forms show a clear gradient (length of the 1st axis 5.076 SD) from lower altitude habitats of woody phanerophytic and chaemephytic (trees and shrubs) through to hemi-cryptophytic, and cryptophytic herbaceous vegetation at higher elevations (Table 2 & Fig. 4).

Table 2. Description of the first four axes of the DCA for the vegetation data (using Raunkiaer life form species matrix for 144 stations).

Axes	1	2	3	4	Total inertia
Eigen values	0.653	0.378	0.308	0.259	10.346
Lengths of gradient	5.076	3.767	4.097	3.607	
Cumulative percentage variance of species data	6.3	10.0	12.9	15.4	

The DCA scatter plot and CCA bi-plot show that the Raunkiaer life forms of plant species are a manifestation of the variation in the environmental gradients, mainly elevation i.e., Raunkiaer Classes (RC) 1, 2 and 5 were obviously under the influence of lower altitudes and higher soil depth whilst Class 3 and 4 (the hemi-cryptophytes and cryptophytes) are evident at higher to highest altitudes under the effect of elevation range (p value $\leq$ 0.002). Aspect has a partial effect on life form distribution as Classes 1, 2 and 3 are inclined mainly to slopes with a northern aspect and Class 5 to the southern ones whilst there is limited effect of aspect on the distribution of class 4 (Geophytes). Furthermore class 3 (the hemi-cryptophytes) is somehow inclined to northern aspect slopes as compared to the southern slopes. The CCA ordination diagram for species further indicates that the first axis is primarily correlated with altitude and soil depth whilst the second axis is correlated mainly with aspect and to a lesser extent to grazing pressure (Table 3 & Figs. 4 & 5). Overall the vegetation of the Naran Valley shows a gradient from Phanerophytic and Chamaephytic forms to Hemicryptophytic forms (left to right in the DCA and CCA plots) (Figs. 4 & 5).

Table 3. Summary of the first four axes of the CCA for the vegetation data (using Raunkiaer life forms in a species matrix for all 144 stations and 5 measured environmental variables).

Axes	1	2	3	4	Total inertia
Eigen values	0.536	0.267	0.101	0.076	10.346
Species-environment correlations	0.921	0.875	0.631	0.615	
Cumulative percentage variance of species data	5.2	7.8	8.7	9.5	
Species-environment relation	51.4	77.0	86.6	94.0	
Summary of Monte Carlo test (499 permutations under reduced model)					
Test of significance of first canonical axis		**Test of significance of all canonical axes**			
Eigen value	0.536	Trace		1.044	
F-ratio	7.544	F-ratio		3.099	
P-value	0.0020	P-value		0.020	

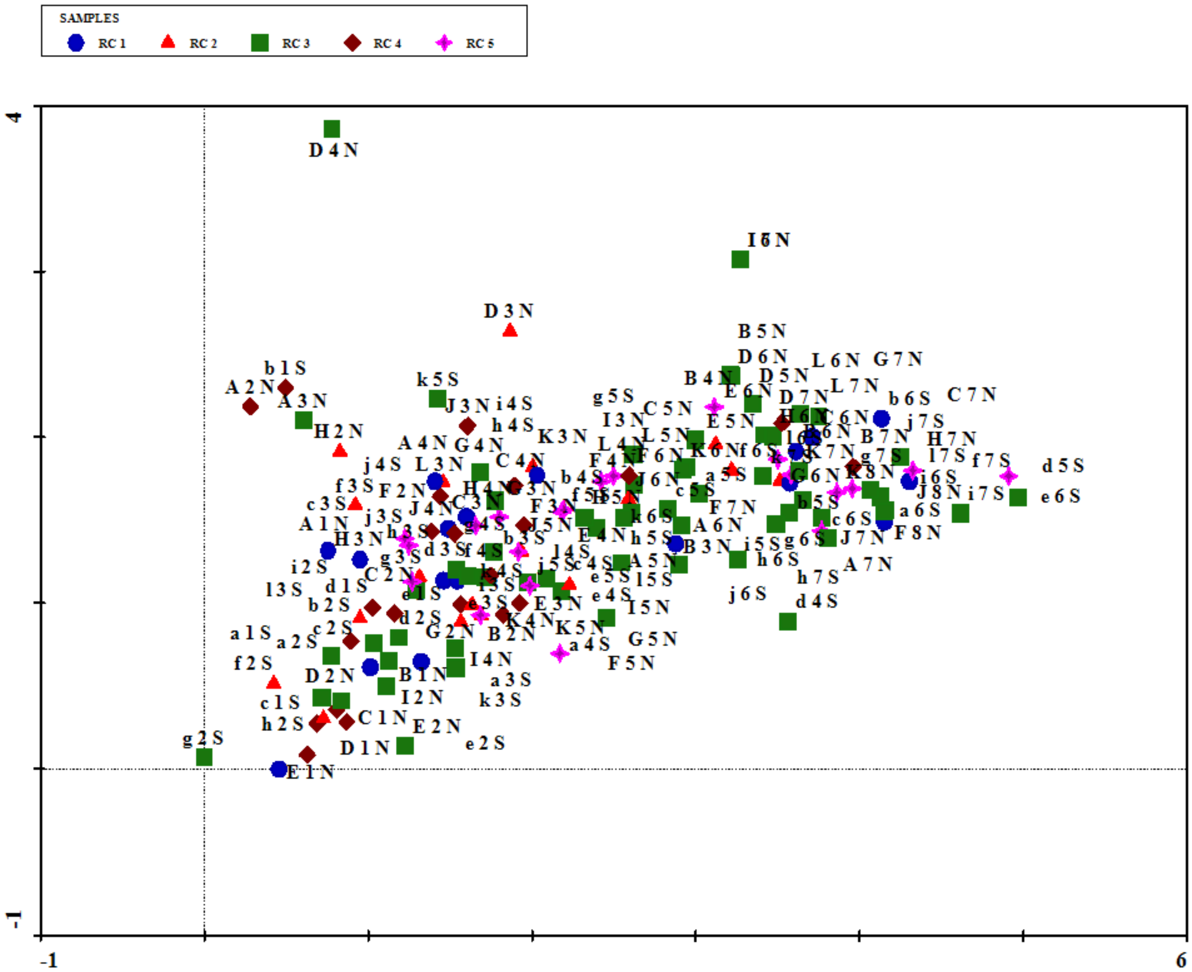

Fig. 4 Detrended Correspondence Analysis (DCA) diagram showing distribution of 5 Raunkiaer life forms among 144 stations/habitat types.

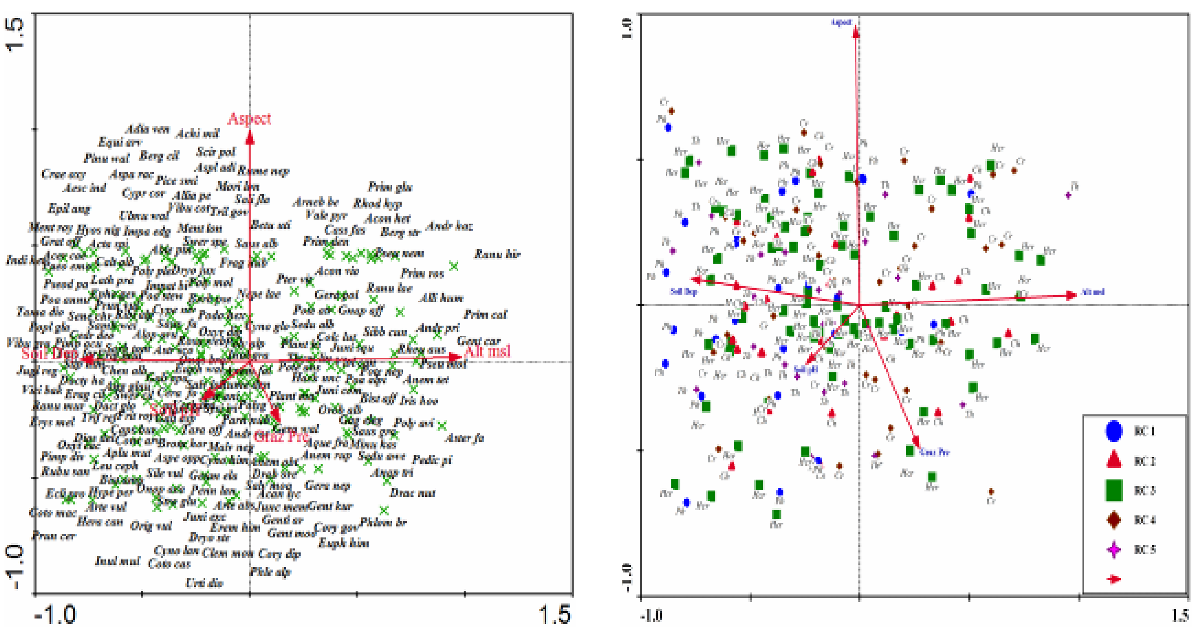

Fig. 5. Canonical Correspondence Analysis (CCA) bi-plots, showing the phyto-climatic gradient of 5 Raunkiaer life forms among 198 plant species and 5 environmental variables.

Discussion

Evaluation of mountainous habitat and vegetation types is the prerequisite for their long-term conservation management (Ewald, 2003; Mucina, 1997; Shinwari & Qaisar, 2011). The complex and dynamic Himalayas with their varying climate and topography exhibit diverse vegetation that provides a range of ecosystem services. The biodiversity of these mountains is also under the influence of diverse human cultures and thus ecosystem services provided by the vegetation need extensive exploration at local as well as at regional levels (Zobel & Singh, 1997; Khan *et al.,* 2012a). The distribution of individuals of the same and different plant species in an association and habitat type is the function of micro environmental pattern, time and biotic relationships. Plant species assemble in an association in a definite fashion and hence can be quantified strategically to assist conservation policies.

The life form of vegetation in a region is always indicative of plant-environment interactions. In our study, the dominance of hemi-cryptophytic and cryptophytic vegetation indicates the harsh and cold xerophytic climate of this high mountain region. The stations/samples data indicated a phyto-climatic gradient from mild monsoon belt at the mouth of the valley to the harsh dry alpine zone at the end of the valley and high altitudes on the mountain slopes. Modern statistical tools overcome problems of comprehension by summarizing field data in a low-dimensional space with similar samples and species near together and dissimilar ones far apart (Greig-Smith, 2010). Classification and ordination analyses of Raunkiaer life forms in this regard further communicates the nature of the habitat types that gradually turns from moist temperate to dry temperate ecosystems along the valley and to alpine ones along the elevation gradient. At the opening of the valley species richness especially of Phanerophytes and Chamaephytes is higher as the soil is deeper, altitude is lower and snow melts earlier as compared to the upper reaches of the valley. Additionally and most importantly the monsoon winds also provide a considerable summer rainfall for these habitats as compared to the inner valley and northern ends of the valley which are much drier. The inner valley and the closing parts towards the North West are dominated by herbaceous vegetation of Hemi-cryptophytes and Cryptophytes where the monsoon winds have no reach at all due to the blockage of high mountains at the opening of the valley. This sort of phyto-climatic gradient exhibited by sparse vegetation dominates the upper sections of the valley and regions westwards from here to the Hindu Kush range of mountains. Such life forms can also be found in high elevation zones of other Himalayan regions (Khan, 2012; Khan *et al.,* 2012b; Saima *et al.,* 2009; Wazir *et al.,* 2008).

The results further reveal that the vegetation at the southern opening of the valley at lower altitudes has considerable similarity with the moist temperate vegetation of the adjacent southern and eastern Himalayan regions e.g., *Pinus wallichiana, Aesculus indica, Prunus cerosioides, Indigofera heterantha, Viburnum grandiflorum, Viburnum cotinifolium, Paeonia emodi, Bistorta amplexicaulis* and *Trifolium refens* etc. A similar vegetation pattern has also been observed by a few authors in adjacent moist temperate locations elsewhere in the Himalaya (Khan, 2012; Saima *et al.,* 2009; Wazir *et al.,* 2008; Dasti *et al.,* 2007; Shaheen *et al.,* 2011). In the inner valley, where the monsoon winds have no or greatly reduced influence, moist temperate vegetation disappears gradually along the latitudinal gradient, and dry temperate elements i.e., *Artemisia brevifolia, Bistorta affinis, Anemone tetrasepala, Hackelia uncinata, Thymus linearis* and *Verbascum thapsus* become more dominant; this vegetation is comparable to the dry habitats of the adjacent Hindu Kush range of mountains (Peer *et al.,* 2001; Sharma *et al.,* 2010; Hamayun *et al.,* 2006). At the northern end of the valley and on the high peaks, the climatic conditions are increasingly xeric, with similarities to the Tibetan Plateau of the Karakorum Mountains (Eberhardt *et al.,* 2007; Khan & Khatoon, 2007; Marston, 2008). Thus the vegetation of the Naran Valley appears to bridge between the contrasting moist and dry temperate zones of the Sino-Japanese and Irano-Turanian floristic regions. On the basis of the definition of ecotone provided by Lloyd *et al.,* (2000), as 'a zone where directional spatial change in vegetation is more rapid than on either side of the zone' we advocate that the Naran Valley occupies a transitional floristic position between these two regions. Studies of adjacent mountain ranges e.g., the Karakorum and the Hindu Kush (Eberhardt *et al.,* 2007; Sheikh *et al.,* 2002; Nüsser & Clemens ,1996; Haserodt, 1980; Chawla *et al.,* 2008), add weight to this valley's transitional location on the edge of the moist temperate zone of the Western Himalayan Province and adjacent to the dry temperate zone of the eastern Hindu Kush and the southern Karakorum. At the same time our study establishes strong alpine floristic elements within the vegetation, with the overall dominance of herbaceous species (84%). Such vegetation features can be expected in the significantly varying Himalayas (Zobel & Singh, 1997; Shaheen *et al.,* 2012a) and indicate that most North Western parts of the Himalayas like the Naran Valley becomes more identical to the Hindu Kush and the Karakorum than the southern and the eastern Himalayas.

If we look from the ecosystem services perspective the region plays host not only to present day food, fodder, fuel, timber and medicinal plants, but also to the wild relatives of cultivated plants which may possess useful stress and disease resistant characteristics or provide germplasm resources. Furthermore, species which are not important economically might and must have a significant ecological role in controlling erosion, flood, avalanche movements and over all ecosystem regulating services. Conservation of biodiversity and ecosystems and their sustainable use in the scenario of climatic change can only be possible if the important species and habitats are carefully examined, managed and safeguarded. A review of current literature also shows a very limited and fragmented range of published work on IUCN red list of plant species (Ali, 2008) therefore such indicators can provide a strong basis for further conservation studies. Notably several plant species reported in this study were endangered either globally or regionally. Four (4) of the species listed by CITES i.e., *Dioscorea deltoidia, Podophyllum hexandrum, Cypripedium cordigerum* and *Dactylorhiza hatagirea* were recorded in the valley. Among other species *Acer caesium, Betula utilis, Ephedra gerardiana*, *Fritillaria roylei, Gentiana kurro, Hyoscyamus niger, Inula grandiflora, Rheum australe* and *Rhododendron hypenanthum* are endangered species in the region and also need speedy consideration (Khan, 2012, Khan *et al.,* 2012a, Ahmad *et al.,* 2009). Summarizing the overall narrative for future management of the Naran Valley or similar mountain ecosystems to preserve ecological as well as cultural diversity, measures should be taken for the restoration of plant biodiversity through reforestation, developing protected areas and domestic cultivation of rare species. Studies like the present one can be used as a source of basic data for the management of mountainous regions in the larger-scale conservation planning of the Himalayas and adjacent ranges.

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