VEGETATION DYNAMICS IN THE WESTERN HIMALAYAS, DIVERSITY INDICES AND CLIMATE CHANGE

SHUJAUL M. KHAN¹, SUE PAGE², HABIB AHMAD³, HAMAYUN SHAHEEN⁴ AND DAVID HARPER⁵

¹Department of Botany, Hazara University, Mansehra, Pakistan.
²Department of Geography, University of Leicester, UK
³Department of Genetics, Hazara University, Mansehra, Pakistan.
⁴Department of Botany, Azad Kashmir University, Muzaffarabad, Pakistan.
⁵Department of Biology, University of Leicester, UK

Abstract

Vegetation provides the first trophic level in mountain ecosystems and hence requires proper documentation and quantification in relation to abiotic environmental variables both at individual and aggregate levels. 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 land uses. The present paper is not only first of its kind but also quite unique because of the use of modern statistical techniques for the quantification of Diversity Indices of plant species and communities. The vegetation was sampled in three categories, i.e., trees, shrubs and herbs, as follows: a height of ≥ 5 m were classified in the tree layer, shrubs were all woody species of height 1 m and 5 m and, finally, the herb layer comprised all herbaceous species less than 1 m in height. The presence/absence of all vascular plants was recorded on pre-prepared data sheets (1, 0 data). For the tree layer, the diameter of trees at breast height was measured using diameter tape. Coverage of herbaceous vegetation was visually estimated according to Daubenmire and Braun Blanquet methods. It gives overall abundance of vascular plants on one hand and composition of these species on the other. Data was analysed in Canonical Community Coordination Package (CANOCO) to measure diversity indices of plant communities and habitat types. Results for five plant communities/habitat types indicated that plant biodiversity decreased along the altitude. Shannon Diversity Index values range between 3.3 and 4. N² index and Index of Sample Variance were also designed. All of these Diversity Indices showed the highest values for the communities/habitats of north facing slopes at middle altitudes. Higher plant diversity at these slopes and altitudes can be associated to the period of snow cover which is longer and a relatively denser tree cover as compared to the southern slopes and hence the soil has high moisture which supports high biodiversity in return. Global warming causes desertification in number of fragile mountain ecosystem around the globe. These findings suggest that species diversity decreases along the measured ecological gradient under the influence of deforestation coupled with global climatic change.

Keywords: Biodiversity, Diversity Index, Climate, Mountain Ecosystem, Western Himalayas, Vegetation.

Introduction

Mountains are the most remarkable land forms on earth surface with prominent vegetation zones based mainly on altitudinal and climatic variations. Variations in aspects also enhance habitat heterogeneity and bring micro-environmental variation in vegetation pattern (Clapham, 1973; Khan et al., 2011b). In north-western Pakistan, three of the world’s highest mountain ranges, i.e., the Himalayan, Hindu Kush

*Author for correspondence E-mail: shuja60@gmail.com
and Karakoram, come together, ensuring high floral diversity and phytogeographic interest. Plant biodiversity survives at the edge of life at these high mountains where climatic changes are more visible and species extinction very rapid. Studies on mountainous vegetation around the globe show that ecological amplitude of alpine species shifted to even higher elevations over the recent decades. Species preferred temperatures in higher altitudinal zones. Therefore, many alpine species are under the risk of extinction due to their requirements for germination and reproduction (Grabherr et al., 1994; Holzinger et al., 2008). Unlike the eastern Himalayas, where monsoon-driven vegetation predominates under higher rainfall and humidity (Chawla et al., 2008; Dutta and Agrawal, 2005; Anthwal et al., 2010; Behera et al., 2005; Roy and Behera, 2005), the vegetation in the western Himalayas in general (Chawla et al., 2008; Kukshal et al., 2009; Shaheen et al., 2011; Ahmad et al., 2009; Dickoré and Nüsser, 2000; Shaheen et al., 2012) and in the Naran Valley (Khan et al., 2011b) in particular have closer affinities with that of the Hindu Kush mountains, which have a drier and cooler climate (Ali and Qaiser, 2009; Wazir et al., 2008; Noroozi et al., 2008). A recent study showed that with the passage of time, homogeneity takes place in the vegetation of a region due to continuous dominance of certain resistant and vigorous species. This phenomenon is further enhanced by selective utilisation of species by human intervention (Del Moral et al., 2010). Similarly, the tree-line vegetation and indicator species shift upwards due to climate change.

Mountainous vegetation has manifold functions, not only within the system where it exists regionally in the lowland ecosystem by regulating floods and flow in streams and globally in combating the climate change and greenhouse effects. Regionally, shrubby vegetation of high altitude regulates avalanche movements and protects soil but in majority of places, it is threatened due to human and climatic influences (Hester and Brooker, 2007). Plant biodiversity is necessary for regulation of overall system in the mountain, e.g., the Himalayas is the birth place for 10 largest rivers in the Asia and a big and important carbon sink. Ecological changes in the Himalayas affect global climate by bringing changes in temperature and precipitation patterns of the world. Himalayan Vegetation is diverse and range from tropical evergreen species in the south east to thorn steppe and alpine species in the north western parts (Behera and Kushwaha, 2007). Melting of its snow in a regular fashion is related to its vegetation cover. Irregular loss of its ice might have dangerous rise in world sea-levels (Xu et al., 2009). These mountains are extremely sensitive to global climatic change. Such hazardous glimpses have already been observed in the form of flood in Pakistan, India, China and Thailand in the last three years.

The Naran Valley is located at the far west of the Western Himalayas on the border with the Hindu Kush range which lie to the west and near to the Karakorum Range to the north (Figure 1). Due to this transitional location the valley host representative vegetation types from all three mountain ranges. Monsoon winds are main source of precipitation and also a primary force of controlling erosion and climatology over millions years of time and thus modify its climate, topography and vegetation of Himalayas but in the western Himalaya, especially in Naran Valley, high mountains situated at the opening of the valley act as barriers to the incoming summer monsoon from the south and limit its saturation into upper northern parts. Thus, summers remain cool and relatively dry and make most of the valley as a dry temperate-type of habitat. There are clear seasonal variations. Total average annual precipitation is low at only 900-1000mm but there is heavy snowfall in winter which may occur any time from November to April (average annual snowfall 3m). The range reflects a sharp increase in depth of snow with increasing altitude. There is a distinct wet season in January-April whilst the driest months of the year are June-November. As far as temperature of the area is concerned, most of the year, it remains below 10°C. December, January, February and March are the coldest months of the year in which temperature remains around the freezing point or even below most of the times. June to August is the main season for growth, with average daytime temperatures in the range 15-20°C. Geologically, the valley is located where the Eurasian and Indian tectonic plates meet and where the arid climate of the western Eurasian mountains gives way to the moister monsoon climate of the Sino-
Japanese region (Qaiser and Abid, 2005; Takhtadzhian and Cronquist, 1986; Kuhle, 2007). The valley thus occupies a unique transitional position in the region. In remote mountainous valleys like the Naran, the complexity of ecosystems, their inaccessibility and the cost and time factors make it extremely difficult to observe each and every aspect of vegetation features. Perhaps those were the reasons that in spite of its high phytogeographic importance, there have been no previous quantitative studies of the vegetation in this valley. The present study is not only the first of its kind but also quite unique because of the use of modern statistical techniques for the quantification of plant species and communities along geo-climatic environmental gradients that has limited comparator studies in this region (Wazir et al., 2008; Saima et al., 2009; Dasti et al., 2007). The Naran Valley, which is floristically located in the Western Himalayan province of the Irano-Turanian region, forms a botanical transitional zone between the moist temperate (from the South East) and dry temperate (from the North West) vegetation zones of the Hindu Kush and Himalayan mountain ranges, respectively. A phyto-climatic gradient of vegetation based on life forms further emphasizes the nature of the area and makes apparent the transitional position of the region, though predominated by alpine species (Khan et al., 2011b & c).

The quantitative approaches to vegetation description and analyses deployed in this study not only fill methodological deficiencies (Khan, 2012) and gaps in the literature, i.e., evaluation of diversity indices but also provide a firm basis for extending this approach to the adjacent mountain systems that are in need of up to date vegetation mapping (Fosaa, 2004; Mucina, 1997). In addition, the present study documents and provides suggestions for the conservation of mountain plant biodiversity under a scenario of continuous human exploitation and climate change. It is necessary to maintain ecosystem services in general and food security in particular, not only within mountain system but also for the people and ecosystems of the lowlands that depend on those mountains (Rasul, 2010; Manandhar and Rasul, 2009; Sharma et al., 2010; Khan et al., 2011a).

---

Fig. 1. Physiographic map showing the elevation zones and position of the Naran Valley, western Himalayas (study area) in relation to Karakorum and Hindu Kush mountains
Methodology

In total of 432 quadrats in 144 replicates, the vegetation was sampled in three layers i.e., trees, shrubs and herbs. Quadrats sizes used in this study were 10x5 (for trees layer), 5x2 (for shrubs layer) and 1x0.5 (for herbs layer). Trees had a height of $\geq 5$ m, shrubs were all woody species of height in the range 1-5 m and the herb layer comprised all herbaceous species less than 1m in height. The presence of all vascular plants was record on pre-prepared data sheets (1, 0 data). For the tree layer, the diameter of trees at breast height was measured using diameter tape (Figure 2). This enabled an assessment of tree cover values in the quadrats. For the shrub and herb layers, abundance/cover values were visually estimated according to a regulated Braun-Blanquet scale later on modified by Daubenmire (Table 1) (Braun-Blanquet et al., 1932; Daubenmire, 1968). Absolute and relative values of density, cover and frequency of each vascular plant species at each station were calculated using phytosociological formulae to finally calculate Important Value Index (McIntosh, 1978).

Fig. 2. Measuring diameter of tree species through diameter tape in a 10x5m quadrat in the field at Lalazar, Naran.

<table>
<thead>
<tr>
<th>Cover Class</th>
<th>Range of Percent Cover</th>
<th>Midpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-5%</td>
<td>2.5%</td>
</tr>
<tr>
<td>2</td>
<td>5-25%</td>
<td>15.0%</td>
</tr>
<tr>
<td>3</td>
<td>25-50%</td>
<td>37.5%</td>
</tr>
<tr>
<td>4</td>
<td>50-75%</td>
<td>62.5%</td>
</tr>
<tr>
<td>5</td>
<td>75-95%</td>
<td>85%</td>
</tr>
<tr>
<td>6</td>
<td>95-100%</td>
<td>97.5%</td>
</tr>
</tbody>
</table>
In the past, it was a very common technique to classify plant communities based on Important Value Index (IVI) of plants species. In this sort of characterization and classification in phytosociology, the species with the highest Importance Values IV are considered as dominant plant species and communities are attributed with them. Even today, it is a very common method of classifying plant communities. The present day revolution of computer based technology in every field of science has modified the older techniques. The IVs were calculated by adding the values of relative density, cover and frequency and then dividing by 3. In our study, we use IV data mainly for ordination purposes.

**Data analysis**

Ecologists use number of diversity indices for measuring the plant species diversity in different habitat types and plant communities. CANOCO version 4.5 (Ter Braak 1988, Ter Braak 1989, Ter Braak and Smilauer 2002) was used to analyse IVI data to assess diversity indices. The main objective of these statistical packages is to formulate the study more precisely. As phytosociology is concerned with vegetation itself, the sites in which it occurs and the environmental variables related with those sites hence need to be examined in a statistical framework (Kent and Coker, 2002; 1995, Lambert and Dale, 1964). Plant biologists often need to test hypotheses regarding the effects of investigational factors on whole groups of species (Khan et al., 2011b; Shaheen et al., 2011; Anderson et al., 2006). CANODRAW is a utility of CANOCO and was used to generate data attribute plots (graphic forms) of indicator/characteristic species. It also gives the opportunity to utilise index of number of species, Shannon Weiner index, index of species richness, evenness, sample variance, etc. Diversity indices were calculated at the community through data attribute plot under the DCA function of CANODRAW.

**Results**

**Floristic composition of the Naran Valley**

A total of 198 plant species belonging to 150 genera and 68 families were recorded at the 432 replicates of relives/quadrats. The division into major taxonomical groups (Table 2) indicates that dicotyledonous angiosperms are the most abundant. Five plant communities were identified and discussed in our first paper from this project (Khan et al., 2011b). There is a clear altitudinal zonations, i.e., (i) the lower altitude (2450-3250 m) dominated by temperate vegetation and (ii) the higher altitude (3250-4100 m) dominated by subalpine and alpine vegetation. The most abundant plant family was Asteraceae (Compositae) with seventeen species and a 25% share of all species. Rosaceae represented by fourteen species (with a 21% share) was the second most species rich family in the study area. Lamiaeceae, Ranunculaceae, Poaceae and Polygonaceae were represented by 13, 12, 11 and 10 plant species respectively. The remaining families all had less than 10 species each. Importance Values of the top 15 abundant species are given in Table 3.

<table>
<thead>
<tr>
<th>Taxonomic divisions of recorded plant species.</th>
<th>No. of Families</th>
<th>No. of Species</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dicot</strong></td>
<td>53</td>
<td>161</td>
</tr>
<tr>
<td><strong>Monocot</strong></td>
<td>9</td>
<td>23</td>
</tr>
<tr>
<td><strong>Subtotal of Angiosperms</strong></td>
<td>62</td>
<td>184</td>
</tr>
<tr>
<td><strong>Gymnosperms</strong></td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td><strong>SUBTOTAL OF SPERMATOPHYTA</strong></td>
<td>65</td>
<td>192</td>
</tr>
<tr>
<td><strong>Pteridophyta (Ferns and allies)</strong></td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td><strong>TOTAL NO. OF PLANT SPECIES</strong></td>
<td>68</td>
<td>198</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name of the Species</th>
<th>Importance Value (IVI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Abies pindrow</td>
<td>584</td>
</tr>
<tr>
<td>2</td>
<td>Betula utilis</td>
<td>582</td>
</tr>
<tr>
<td>3</td>
<td>Sambucus weghtiana</td>
<td>446</td>
</tr>
<tr>
<td>4</td>
<td>Juniperus communis</td>
<td>338</td>
</tr>
<tr>
<td>5</td>
<td>Pinus wallichiana</td>
<td>323</td>
</tr>
<tr>
<td>6</td>
<td>Salix flabillaris</td>
<td>160</td>
</tr>
<tr>
<td>7</td>
<td>Rosa webbiana</td>
<td>137</td>
</tr>
<tr>
<td>8</td>
<td>Artemisia absinthium</td>
<td>135</td>
</tr>
<tr>
<td>9</td>
<td>Rhododendron hypenanthum</td>
<td>116</td>
</tr>
<tr>
<td>10</td>
<td>Fragaria nubicola</td>
<td>112</td>
</tr>
<tr>
<td>11</td>
<td>Berberis pseudoambellata</td>
<td>111</td>
</tr>
<tr>
<td>12</td>
<td>Thymus linearis</td>
<td>109</td>
</tr>
<tr>
<td>13</td>
<td>Iris hookeriana</td>
<td>104</td>
</tr>
<tr>
<td>14</td>
<td>Cedrus deodara</td>
<td>103</td>
</tr>
<tr>
<td>15</td>
<td>Viola canescens</td>
<td>96</td>
</tr>
</tbody>
</table>

Based upon plant growth habit, 12 trees, 20 shrubs and 166 herbs shared 6, 10 and 84%,
respectively, in the plant diversity of the vegetation of the Naran Valley (Figure 3).

Species richness along environmental gradients

Analyses show that the main influencing environmental variables are altitude, aspect (slope direction) and soil depth and that both species richness and diversity vary along these gradients. Analysis of the elevation gradient showed that species richness was higher at lower altitudes and lower at higher elevations. Species β-diversity gradually decreased along the altitudinal gradient as soil depth and temperature decreased. Similarly species richness on slopes with a northern aspect was slightly higher than those with a southern aspect (Fig. 4).
Diversity indices using DCA analysis

Data attribute plots using Detrended Correspondence Analysis (DCA) were used to calculate diversity indices. The first sort of diversity index based on species richness was the calculation of species number per community (Figure 5). The highest number of plant species was reported in community 2 at middle altitude northern aspect habitats followed by lower altitude valley bottom habitats. The high diversity of these habitat types can be attributed to high soil depth with high moisture retaining capacity and relatively high temperature at those somewhat lower altitudes. The lowest number of species scored in the index was for the community number 5 at peak elevations above the tree line habitats.

The Shannon Diversity index values range between 3.3 and 4. Being constituted of both Northern and Southern aspect stations, community 1 has the highest value of 3.98 amongst all the groups whilst community 5 has the lowest value due to narrow ecological amplitude (Figure 6). High values of index are due to the inclusion of considerable number of stations in a single community.

Fig. 5. Index of species number (alpha diversity) amongst all community types through DCA data attribute plots along the gradients.

Fig. 6. Shannon Weiner diversity index at community level through DCA data attribute plots show the gradient of the community.
The $N_2$ index is the reciprocal of Sampson diversity index and is available in the CANODRAW utility of CANOCO. This index showed the highest value for community 2 followed by community 1 (Figure 7).

Index of sample variance showed the highest variance at community 2 amongst the groups. As the altitudinal pattern (Figure 4) showed that species richness is optimum at the middle altitude especially on north facing slopes. This index reconfirmed the phenomenon of species richness phenomenon through sample variance index (Figure 8).

![Fig. 7. $N_2$ diversity index at community level through DCA data attribute plots along the gradient of the community.](image)

![Fig. 8. Index of Sample Variance amongst all community types through DCA data attribute plots along the gradient.](image)

The pattern of plant communities in the valley is largely determined by aspect and altitude. Four plant communities can be separated on the basis of these two variables, whilst one community is established under the combined effect of lower altitude and greater depth of soil (the third most important variable). Relatively higher summer temperatures and soil moisture are the co-variables associated with the low elevation and deeper soil. Predominantly, community 1 reflects the latitudinal gradient of vegetation from moist temperate to dry temperate along the valley on either side of the River Kunhar at lower altitudes. Species diversity and richness are
optimal at the middle altitudes (2800-3400m), in contrast to the lower altitudes (2400-2800m) where direct anthropogenic activities have had their greatest impact.

Discussion

Diversity amongst plant communities/habitat types

Short summer, deep snow, low temperature, intense solar radiation and cold speedy winds in the valley in general and higher altitude and special slope orientation in particular result xeric condition for plant growth and hence the β-diversity is gradually decreasing both along the altitudinal and latitudinal gradients of the valley. Though drawing a sharp line in any natural ecosystem of mountains is difficult as the rapid micro climatic and edaphic variations overlap each other due to number of driving agencies and historical perspectives but based on some indicator species, vegetation zonation and association can be established. Both at habitat and community level, the plant species richness and diversity is strongly influenced by elevation, aspect and soil depth which in turn are associated with precipitation and soil moisture. Various diversity indices including number of species, Shannon Weiner, sample variance and N at show maximum values for the middle altitude northern aspect plant community (Com. 2) followed by the subalpine (Com. 4) and middle altitude southern aspect plant communities (Com. 3). Similar patterns of diversity across altitudinal gradients have been observed in other studies in the Himalayan regions (Kharkwal et al., 2005; Tanner et al., 1998; Vázquez and Givnish, 1998).

Implications of the present project for future studies

Observing biodiversity is a lifelong process and needs inputs from various disciplines from the natural as well as the social sciences. For better ecosystem management and protection, plant biodiversity should be studied at species, community and ecosystem levels. The mountainous valleys need more botanical exploration for the complete description of their plant taxa, abundance and conservation status. There are also extensive gaps in information on ecosystem services in the Himalayan region. Most of the vegetation studies have been carried out solitarily either based on scientific approaches or public perception for making inventories. We also believe and propose that such approach must be statistically sound and communicable to conservationists, planners, politicians and policy makers. Furthermore, we suggest that the identification of indicator species for specific habitats will assist in monitoring and assessment of the biological diversity on the one hand and the effects of climatic change on the other. In addition, a broad scale deterioration of the natural ecosystems due to agriculture, expansion of roads, increases in population and deforestation cause enormous losses to the natural vegetation. In spite of IUCN recommendations, there is very limited and small scale documentation on Red List Categories for plant species in the Himalayas as well as in Pakistan more generally (Ali, 2008; Pant and Samant, 2006; Chettri et al., 2008). Being a member state of the CBD, Pakistan should give top priority to this issue as addressed by Khan (2012) and Khan et al., (2011b & c).

The three mountain ranges i.e., the Himalayas, Hindu Kush and Karakorum, provide essential ecosystem services to millions of people across 10 countries of the world (Dong et al., 2010; Khan et al., 2007). These services include provisioning, regulating, supporting and cultural services. In the present study, the main focus was on vegetation mapping and provisioning services in one of the Himalayan valley. Most of the provisioning services considered in the present study can further be evaluated at molecular and biochemical levels in the future. Beyond the direct role of plant biodiversity in the socioeconomics of the mountain people, it is indispensable for the people living in the plains and hence this mountain valley can be studied for the evaluation of the other kinds of services, including those of regulatory nature, that it provides on a broader level, e.g., flood control, erosion control, irrigation water and hydropower development. These mountains also provide Supporting Services, e.g., soil formation, biogeochemical and nutrient cycling, etc. These mountain systems host characteristic biodiversity on the one hand and a long established and unique cultural diversity on the other. Preservation of their indigenous knowledge and its utilization in environmental management can also be potential topics for future studies (Fig. 9).
**Vegetation Dynamics in the Western Himalayas, Diversity Indices and Climate Change**

**Fig. 9.** Sketch showing the potential topics for future to study different aspects of biodiversity of the western Himalayas

**References**


Kukshal, S., B.P. Nautiyal, A. Anthwal, A. Sharma and A.B. Bhatt. 2009. Phytosociological investigation and life form pattern of grazinglands under pine canopy in


