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Continuous or discrete-an altitudinal transect of vegetation and soil on a de-glaciated Valley, Western Himalaya, Pakistan

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Abstract

The study area is a Himalayan forest-alpine ecotone extending over a 100 km north to south transect. The altitudinal change in vegetation was studied between 2000 m, a.s.l. and 4100 m, a.s.l. to test the vegetation pattern either continuum or zonation. A total of 300 species of vascular plants occurred in 280 repeated samples of 0.1ha at 14 sites. Ordination (DCA) and classificatory techniques were used to examine these data. The major axes brought out by DCA were related to altitude and its associated climatic factors, although it is possible to relate the units of classification to broad soil types. The overlay of the classification groups on the ordination axes indicated that the vegetation closely followed a topographic sequence and the vegetation composition changed continuously with altitude. No clearly disjunct vegetation patterns emerged and the distribution of samples and species along two axes of ordination resemble more closely to the continuous nature of the vegetation than to the grouping produced by classification. The distribution of plant species along the altitudinal transects support the individualistic hypothesis of community organization.

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Introduction

Mountain masses largely generate their own climate. With their steep gradients, differences in altitude and geomorphology, mountain ranges play a great part in regulating climate over most part of the area. Many climatic factors change with increasing altitude. The most obvious of which is the steady decrease in temperature and precipitation with altitude but snowfall accumulation shows opposite trends in the study area. The basic pattern of vegetation distribution along the altitudinal gradient is controlled by these environmental factors which creates large contrasts in climates and soils (Grubb and Tanner, 1976; Bellingham, 1991; Hashim and Dasti, 2019) on comparatively small areas (Korner, 2007). The gradually changing environmental conditions along the elevation gradients create vegetation zonation (Champion *et al.* 1965; Kessler, 2001; Mahdavi *et al.* 2013) which is common on the slopes of Himalaya. The main problem with identifying the climatic and edaphic factors that influence vegetation zonation and upper timberline formation is that numerous variables co-vary with altitude. Thermal boundaries imposed by elevation are not the only factors that establish the vegetation zonation in mountain landscape.

The causes of altitudinal zonation and formation of upper most boundaries of trees are extremely complex (Holtmeir, 2000). Factor complexes include climate (temperature, rainfall, snow accumulation, frozen soil), disturbance (grazing and competition, wind and snow damage), reproduction (regeneration and recruitment, seed development and dispersal, seed germination and seedling establishment) and topography and pattern of down slope movement water and soil nutrients. The altitude (as a proxy of climate) influences the community composition, structure and properties (Klimes, 2003; Moles *et al.* 2009) due to concomitant changes in soil conditions. Again, the pattern of down-slope movement of run-off creates niches of diverse habitats which have decisive impact on the structure and composition of vegetation (Orshan, 1986). Vegetation structure at high altitude might be related to frozen soil, winter accumulation and strong winds (Vazquez and Givinish, 1998; Peer *et al.* 2001). In mountain landscape climates is probably a more important cause of vegetation pattern than the edaphic ones.

The intricate gradients in soil and climatic conditions that are associated with elevation provide an opportunity to look into the processes that maintain the community composition and properties. Recently, several studies have reported elevational trends in species assemblage and diversity in Himalayan forests (Gairola *et al.* 2008; Hashim and Dasti, 2019). Most of these studies have involved sampling at rather low altitude, it is not possible to describe with precision the way in which temperate forest attributes change with elevation and non-have investigated the transition from timberline to treeline-alpine ecotone in the study area. Knowledge of habitat associations and the factors that determine the community composition particularly for alpine region is limited (Peer *et al.* 2001). The integrated view of horizontal and vertical distribution of the vegetation on Himalaya in general and study area in particular is still lacking. In the study area, detailed information on the altitudinal distribution of species and families is lacking; neither do we know whether changes in species composition and assemblage are continuous or discrete; nor we know how the impact of edaphic and environmental variability along the elevation gradient have shaped plant communities. All these community properties are altogether required to address to fill the gap in the overall picture of the vegetation in these areas. The present study attempts to address the following questions:

How do community composition vary with altitude and how do the altitudinal distribution of vegetation correlate with different climatic and edaphic factors induced by altitude, do they react simultaneously?

Do the elevational distribution patterns of vegetation in species rich temperate mountains follow Gleasson's individualistic concept of continuous vegetation or provide evidence for vegetational discreteness as has been claimed by Beals (1969)?

Study area

Himalayan forest-alpine ecotone provides opportunity to study the effect of altitudinal gradients on vegetational changes because of its unique topography. The study area (73.5 °E, 34.81 °N to 74.42 °E, 35.45 °N), beginning below the village of Kaghan (North Pakistan) and extended northward up to the town of Babusar (Fig. 1).

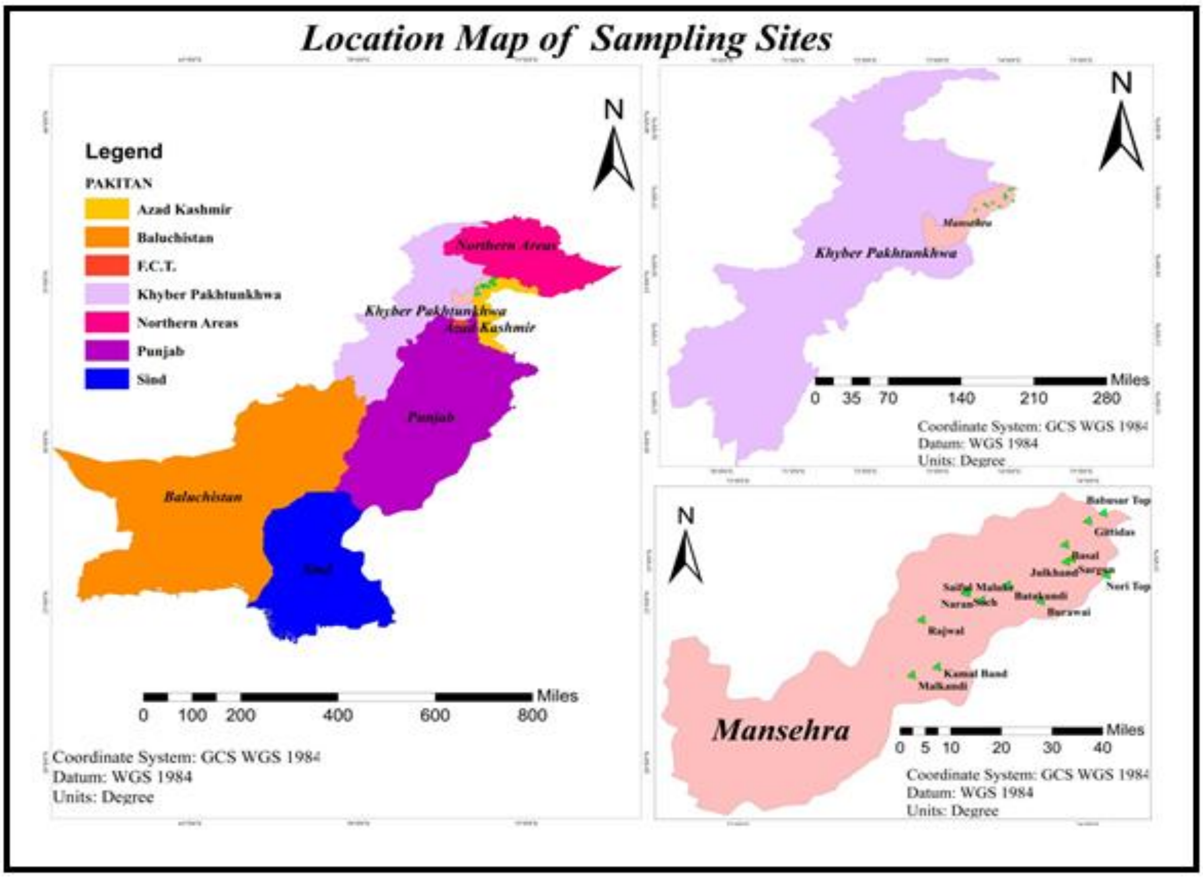

Fig. 1. Map of the study area (Kaghan Valley, Pakistan) showing location of study sites along the elevation transect.

This altitudinal gradient extended from 2000 to 4100 m (a vertical change of 2100 m) in about 100 kilometers horizontal transect along the Kunhar River. The landscape, except for a few isolated peaks, is gently rolling to flat.

The major part of the area had undergone a number of glacial advances and recessions over time. There are several glaciers and glaciated lakes in the area of which two lakes: Saif-ul-Maluke and Lake Lulusar are located in the study area. The most common of glaciers are locally named as: Kuch glacier (3962 m, a.s.l.), Draham Sar glacier (3833 m, a.s.l.), Sabal Khari glacier (3500 m, a.s.l.), Sargum – Nori top glacier (3352 m, a.s.l.), Nila glacier (3240 m, a.s.l.) and Saif-ul Maluke glacier (3200 m, a.s.l.). The soils developed primarily from glacial tills have apparently various textures ranging from coarse-textured to medium-textured and fine-textured.

The conifers (*Abies pindrow*, *Pinus wallichiana*, *Picea smitheana* and *Cedrus deodara*) not broad-leaved species are climax dominants that constitute the timberline. In this area elevation gradients are associated with gradual changes in physiognomy from close forests to open parklands to shrub-line and ultimately the alpine meadows. At lower altitudes the forests are sufficiently dense and the proportion of forest cover drop gradually and becoming increasingly scattered. Eventually the scattered trees of *Abies pindrow* are confined to steep slopes. The alpine zone is solely treeless scrub.

Topography

The high mountain landscape of the study area included a noticeable altitudinal zonation which resulted in climatic and vegetation gradient. Based on topographic gradient that was visually apparent from north to south, the study area can be divided successively in to alpine (3200-4000 m, a.s.l.), subalpine (2400-3000 m, a.s.l.) and montane temperate forest (2000-2400 m, a.s.l.) zones. However, within the area thus delineated there were wide variety of physical and environmental gradients which resulted in biological gradients. Between 2000-3000 m, the slopes are generally steep but fairly regular, and locally dissected by many shallow to deep ravines that run often parallel to each other. On the plateau above 3000 m, slopes are much gentler. Considering the wide variety of alpine landscape, it was difficult to come to any sort of classification. The classification adopted here is given in table (Table 1).

Climate

The climatic data (Fig. 2) shows that precipitation diminishes gradually from south to north along the elevation, falling to around 500 mm in extreme north end of the transect. The mean annual temperature decreased with an increase in elevation. Consequently, the temperature characteristics of the climate are different at two ends of the scale: much lower in upper alpine region than for lower montane forest sites. The overall snow accumulation increases along the altitude. Based on the amount and monthly pattern of precipitation and temperature the overall climate of the area is *Cwb* or *Dwb* type following Koeppen's (1923) rating. In broad outline, climate of lower woodland zone may be classified as *Cwb* with annual precipitation above 800 mm and winter temperature falls below freezing. This category may be divided in to lower and upper zones with average temperature above and below 10^{o}C respectively. Alpine meadow zone has continental temperate (microthermal) climate (*Dwb*) with annual precipitation below 600 mm and winter precipitation often falls as snow. Alpine area may be divided in to upper and lower zones with average temperature above and below 4 ^{o}C respectively.

Geology

The large part of the area is underlain by gneisses and composed of Himalayan crystalline nappes of the Indian plate (Greco and Spencer, 1993). The main rocks are granite and graphitic metapelites belonging to Paleozoic to early Mesozoic age. They are black in appearance and contain minor graphite. Other minerals include quartz, biotite and muscovite.

The northern end of the study area is composed of amphibolites and coesite-bearing rocks. Metapelites predominated in mountain ranges of south west section of the study area (Lombardo *et al.* 2000). The importance of geological substrate seemed to be of little importance in determining the types of vegetation in the study area. However, individual species might be affected but not the forest type (Polunin and Stainton, 1984). The coarse-medium textured soils with low- moderate permeability are largely formed of glaciated sediments of various origins.

Field methods

The vegetation and environmental study was carried out on a series of sampling points along a 100 km long transect established across the entire transitions from treeless alpine mosaic (4000 m) to typical montane forest (2000 m) located between latitude 34.81-35.45 and longitude 73.51 74.42 along the Kunhar river (Fig. 3). As the main vegetation changes were essentially unidirectional, a single transect was used rather than discrete plots. Elevation transect was delimited into sections of 10 km to mark the sites along the entire length of the central transect. Eleven sites roughly from north to south were marked with pegs and longitude, latitude and altitude for each site were obtained using GPS. At each site, a peg mark was fixed at 50 m along the elevation transect. Sections of 100 m were used as sampling subunits (subplot) for floristic inventory and soil sampling. To complete the picture of vegetation of the area, three additional alpine sites located in the vicinity of the central transect were also sampled. The final sample size was therefore 280 sampling units that cover almost 28 ha belonging to 14 sites (Fig. 1). The topographic profile of the elevation transect was measured using a clinometers (Suunto, Vantaa, Finland). A simple compass was used to maintain the north-south direction of the long transects.

All vascular plants species within 2.0 m to the right side of transects were tallied by presence/ absence. The vegetation data obtained from five consecutive subunits were fused to obtain 280 sampling units (plots) with an effective size of 0.1ha (500 x 2 m). All vegetation and soil data is based on observations made during summer (July – August, 2016-18) which was the most appropriate for vegetation and soil sampling after the snow melt. Soil samples (top soil) were taken from each subunit used for vegetation inventory. Samples obtained from five consecutive subunits (one from each) were mixed to get a single composite sample. Finer than 2mm air dried soil samples were used for various analyses following Allen *et al*. (1974). Soil pH was recorded by a pH meter ((*HM-10k Digital, England*), Conductivity was determined by using Digital Conductivity Meter *(CM-30 ET)*. Organic carbon and available soil nitrogen were estimated following Jackson (1958). The soil soluble salts, i.e. Potassium and Phosphorus, were analyzed by atomic absorption spectrophotometer. All observations were in triplicate.

Data analysis

A single database was compiled from all inventories that encompass the entire altitudinal ranges of the region. In order to determine and describe the variation in species composition across different spatial scales, we used two complementary approaches: classification as well as ordination. Classification of all the observations into community types and vegetation groups were derived by using cluster analysis with default option of Minimum Variance. Similarity among communities was estimated using Squared Euclidean. The associations obtained by classification were interpreted ecologically. The species having $\leq$ 10 percent frequency were excluded from all the multivariate analyses performed in the present investigation. Ordination was performed to depict the gradient of greatest variation along the ordination axes and to identify environmental factors controlling the vegetation patterns along the ecological gradients. Detrended Correspondence Analysis (DCA) was used. Finally, scatters of classification groups obtained from cluster analysis were plotted on overlays of the ordination to assess the compatibility of the two methods of data simplification (Causton, 1988).

The relationships between environmental variables and DCA were determined using simple correlation. The multiple range test (Duncan, 1955) was used to assess and compare any significant difference in soil parameters between the means of different vegetation types identified by cluster analysis.

The 5% level of significance was adopted. The percent data were transformed using arcsine transformation and subjected to analysis of variance (One-way) between the vegetation types for each variable. All statistical analyses were performed using software 'MVSP version 3.2' and 'MINITAB version 3.2.

Results

Classification

The complete set of vegetation samples was classified into nine community types belonging to three vegetation groups (Fig. 4, Table 2). The three vegetation groups, defined at two hierarchical division levels, were: I: alpine meadows and scrubs, II: subalpine timberline-treeline ecotone, III: montane canopied forests (Table 1). The alpine meadows and scrub vegetation (group I) incorporated five communities (1.1-1.5) while, subalpine and montane forests (group II and III) which favor cooler northern slopes, had two communities each. High number of vegetation types in alpine zone indicated more variation in alpine landscape than either in subalpine or montane forest regions.

The most noticeable feature indicated by cluster analysis was the separation of the woodland communities of the area from communities of alpine region (Fig 4) at first level by *Abies pindrow* and characterized also by *Pinus wallichiana*, *Cedrus* *deodara* and *Picea smitheana*. In the alpine region, the high alpine community (1.1) was separated at level two from the rest by *Cortia depressa*, association 1.1 being characterized by *Cortia depressa, Kobresia capillifolia, Androsace mucronifolia, Chesneya depressa, Gentianodes argentia, G. cashemerica, Comastoma falcatum*. The communities of the mid alpine scrub region (1.2-1.4) are separated from that of morainal community (1.5) by *Cotoneaster microphyllus* at third level of division. Among the scrub zone the alpine-treeline ecotone is dominated by Juniperus excelsa while J. squamota harbor glacial tills carpeted with *Bistorta affinis*.

Table 1. Physiographic zones along the elevation transects in the study area.

Physiographic zones	Description
High alpine (74.06 -74.42 °E, 34.96-35.45 °N)	Peak zone (3800-4100 m) dominated by grasses and small forbs and lies above the effects of glacial erosion and the surface is a little more stable than in some of the zones below.
Mid alpine (73.94-74.0 °E, 34.12-35.02 °N)	Mid alpine glacial zone (3400-3800 m) characterized by having alpine Juniper scrub. .Within it lays all the glaciers and many large snow-packs. Between the glaciers are large rocky ridges extending in a radial pattern down from the peak zone.
Low alpine (73.69 °E,34.88 °N)	Lower alpine moranic zone (3200-3400 m) is the most unstable zone in the study area. Most often the area between the ice front and the moraine frequently contains a lake and there are a number of such lakes in the area.
Sub-alpine parkland (73.82-73.91 °E, 34.91-34.95 °N)	This is the widest zone that extends down to 2500 m. The ridges in this zone are well drained and a large amount of material has been carried down from the moraines above. Boulders, gravel, and pebbles cover much of the slopes except where the ridges protrude.
Sub-alpine Timberline ecotone (73.75-73.78 °E, 34.92-34.93 °N)	The top limit of the forest (2500-2800 m) and defined as an area between parkland and subalpine forest. In Himalayan uplands, it is a transition zone between forest and park land ecosystem.
Montane temperate Forests (73.55-73.60 °E, 34.82-34.85 °N)	At the middle and lower elevations (2000-2400 m) a fairly complete forest cover with shrubby under growth and diverse ground layer vegetation. This zone receives and retains more run-off than the zones above.

The composition of each plant association delineated by clustering analysis is provided in Table 3. The vegetation types are named after the dominant (the most frequent) species which are quite evident in most groups. If several co-dominant species occurred, the one most restricted to the vegetation type was chosen. A brief description of the composition of three groups and nine plant associations is given below. For this purpose the area has been subdivided in to three broad regions based on physiographic and climatic features.

Alpine zone

Group I (associations 1.1-1.5)

Group I is marked by having alpine meadow vegetation which favors warmer slopes in 3200- 4100 m elevation range. Alpine region is characterized by annual rainfall between 500 and 600 mm and vegetation benefits largely from snowmelt. Based on numerical classification (Fig. 4, Table 2), it was found that alpine meadow vegetation separated broadly into 5 clusters: high alpine *Kobresia capillifolia* (1.1) and *Bistorta affinis* (1.2), mid-alpine *Juniperus squamata* (1.3), *Juniperus excelsa scrub* (1.4) and low alpine *Cotoneaster microphyllus* moranic scrub (1.5).

The five communities recognized in alpine region may be interpreted as serial stages representing a transition from mesophyllous meadows to alpine scrubs where either creeping (*Juniperus squamata*) or upright (*Juniperus excelsa* and *Cotoneaster microphyllus*) shrubs were dominant.

Table 2. Vegetation groups, association, and elevation along the transect (m, a.s.l.) number of sampling units (*N*) and list of sampling units in each association identified by cluster analysis.

Vegetation zone (groups)	Sub groups	Associations	Elevation	*N*	Sampling units
Alpine zone (group 1)	1.1	*Kobresia capillifolia* High alpine meadows	4000-4100	20	1-20
	1.2	*Bistorta affinis* High alpine open pastures	3800-4000	60	21-60, 81-100
	1.3	*Juniperus squamata* mid-alpine prostrate scrub	3600-3800	20	61-80
	1.4	*Juniperus excelsa* mid alpine upright scrub	3400-3600	20	101-120
	1.5	*Cotoneaster microphyllus* Low alpine moranic scrub	3200-3400	20	121-140
Subalpine zone (group 2)	2.1	*Tree-line Abies pindrow* krummholz	2800-3200	60	141-200
	2.2	Timberline *Abies pindrow* Forest	2500-2800	20	201-220
Montane Forests zone (group 3)	3.1	*Pinus wallichiana* Forest	2200-2400	40	221- 260
	3.2	*Cedrus deodara* Forest	2000-2200	20	261-280

The high or peak zone (3800-4100 m, a.sl.) which located entirely above the glaciers, *Kobresia capillifolia* and *Bistorta affinis* were frequent with wide variety of mat forming species such as *Androsace mucronifolia, Cortia depresas, Sibbaldia cuneata* and *Chesneya depressa*. *Bistorta affinis* achieved dominance on convex snowfields, while *Kobresia capillifolia* was the characteristic species of concave moist tussocks where *B. affinis* was almost replaced by alpine sedges and grasses such as *Carex pseudofoetida*, *C. navlis*, *C. infuscata*, *Helictotrichon virescens*.

The mid-alpine glaciated zone (3400-3800 m, a.s.l) in which lies all the glaciers and many large snow-packs harbor *Juniperus scrub* which favors warmer slopes, was found to harbor 2 communities (1.3 and 1.4). In this alpine scrub, continuous plant cover is replaced by a much shorter, often sparse cover of small (<1m tall) sward forming grasses, forbs, mats and dwarf shrubs.

The dominant *Juniperus squamata* is prostrate shrub while *J. excelsa* is upright in habit. Both the associations occupy unconsolidated slopes and glacial tills of various textures ranging from gravely loam to clay loam. *Aconitum violaceum, Bistorta affinis, Euphrasia himalayica, Geranium wallichianum, Hylotelephium ewersii, Iris hookeriana, Leontopodium jacotianum, Rosularia alpestris* are most frequent in these associations.

The scrub vegetation is quite extensive and occupies large areas throughout the alpine region. Low alpine morainal zone (3200-3400) is a narrow, unstable zone and consists of glacial moraine located below the glacial zone. It harbor dwarf *Cotoneaster microphyllus scrub*. Vegetation is predominantly of the bushy steppe type. *Carex pseudofoetida, Sibbaldia cuneata* and *Plantago lanceolata, Swertia cordata, Iris hookeriana, Trifolium pratense* and *Verbascum thapsus* are the prominent species.

Subalpine zone

Group II (associations 2.1- 2.2)

Group II harbor the widest zone that extends from timberline to treeline-alpine ecotone. The vegetation is like a forest steppe: groves of trees interspersed with areas of prairie grassland. It receive about 700 – 900 mm of average annual rainfall and is marked by having *krummholes* of *Abies pindrow* with *Pinus wallichiana* and *Cedrus deodara*. Two associations are recognized in this group (Table 2): Himalayan parkland vegetation (association 2.1) occupied the upper timberline (treeline) and is characterized by having *Ciracea alpine* and *Alopecurus hemicuseus* with clumps of *Sambucus wightiana*. Broad-leaved species are altogether absent.

Table 3. The vegetation of Kaghan Valley (W. Himalaya, Pakistan)**;** percentage occurrence of each species within each association segregated through cluster analysis. Species codes are those used in DCA. Nomenclature followed Flora of Pakistan (Nasir and Ali, 1970 – 1975).

Species	Code *	Associations								
		1.1	1.2	1.3	1.4	1.5	2.1	2.2	3.1	3.2
Abies pindrow Royle	Ap	0	0	0	0	0	95	80	25	20
Acer caesium Wallich ex Brandis	Ac	0	0	0	0	0	0	20	23	0
Achillea millifolium L. Yarrow	Am	0	32	55	0	10	40	80	58	0
Aconitum chasmanthum Stapf ex Holmes.	Ah	10	22	25	10	0	7	0	0	0
Aconitum violaceum Jacquem. Ex Stapf.	Av	0	38	75	0	0	0	0	0	0
Adiantum venustum D. Don	Ae	0	0	0	0	0	0	40	43	80
Aesculus indica (Wall.ex Camb.) Hook.f.	Ai	0	0	0	0	0	0	10	18	20
Agrimonia pilosa Ledebour	Api	0	8	0	0	0	0	35	5	50
Ajuga parviflora Benth.	Aa	0	0	0	0	0	0	0	10	0
Alliaria petiolata (M. Bieb.) Cavara & Grande	-	0	0	0	25	0	3	0	0	0
Alopecurus arundinaceos Poir.	-	0	0	0	0	0	7	0	0	0
Alopecurus hemicuseus Hook.f.	-	0	0	0	5	0	8	0	0	0
Amaranthus spinosus L.	-	0	0	0	0	0	17	45	3	0
Anaphalis margaritacea (L.) Benth.	Ag	45	17	0	0	40	0	0	0	0
Anaphalis nepalensis (Spreng) Hand. - Mazz.)	An	0	0	0	0	0	0	10	18	0
Androsace baltistanica Y. Nasir	Ab	0	0	0	0	0	0	45	18	20
Androsace mucronifolia Watt	Au	0	0	0	0	30	27	35	20	20
Androsaceae foliosa Dcne.ex Duby	-	55	0	0	0	0	0	0	0	0
Androsaceae rotundifolia Hardwicke	Ar	0	0	0	65	0	0	0	0	0
Anemone tetrasepla Ryle	At	0	2	0	0	0	7	45	0	0
Aqualigea pubiflora Wall. Ex Royle.	Ao	30	33	0	0	0	0	0	0	0
Arabidopsis Thaliana L. Heynh	Az	0	0	0	0	0	0	0	13	15
Arabis nova Vill.	-	0	0	0	0	0	0	0	18	20
Aralia cachemirica Dcne.	Al	10	5	0	0	10	2	0	0	0
Arctium lappa L.	Aj	0	0	0	0	0	0	25	8	35
Arcyosperma primulifolium (Thoms.) Schulz	-	20	45	0	0	0	0	0	0	0
Arenaria festucoides Benth.	Af	0	0	0	0	20	13	20	0	0
Arenaria neelgherrensis Wight & Arn.	-	45	0	0	0	0	0	0	0	0
Arenaria serpyllifolia L.	Aq	0	0	0	0	0	10	40	18	0
Arisaema jaquemontii Blume	Aj	0	0	0	0	0	0	35	0	0
Arisaema utile Hook. f. ex Schott	-	0	0	0	0	0	7	35	0	0
Artemisia amygdalina Decne.	Ad	0	0	55	25	0	22	20	8	0
Artemisia japonica Thunb.	Ax	0	0	0	0	0	0	0	28	0

Asitible rivularis Ham.ex D.Don	-	0	0	0	0	0	0	0	18	0
Asplenium varians Wallich ex Hooker & Greville	Av	0	0	0	0	0	3	40	35	50
Aster falconeri (C. B. Clarke) Hutch	Aw	0	0	0	35	0	7	30	20	0
Aster molliusculus (DC.) C. B. Clarke	Am	0	0	0	0	0	8	40	0	35
Astragalus amherstianus Royle ex Benth	Ak	0	10	0	25	30	12	15	0	0
Astragalus candolleanus Royle ex Benth.	As	0	0	0	20	25	25	0	0	0
Astragalus chlorostachys Lindl.	Ay	0	0	0	0	0	20	30	0	0
Astragalus himalayanus Klotzsch	An	0	0	0	80	55	20	0	0	0
Astragulus grahamianus Royle ex Benth.	-	0	0	0	0	0	0	10	13	0
Barbarea intermedia Boreau	Bi	0	0	0	0	0	20	75	0	0
Berberis brandisiana Ahrendt	Bb	0	0	0	0	40	7	0	0	0
Berberis lyceum Royle	Bl	0	0	0	0	0	5	35	18	35
Bergenia ciliata (Ham.) Sternb.	Bc	0	0	0	0	0	0	70	23	0
Bistorta affinis (D. Don) Green.	Bf	65	85	65	0	5	2	0	0	0
Bistorta amplexicaulis (D.Don) Green	Ba	0	7	60	10	15	27	80	38	30
Bromus japonicas Thunb. ex Murr.	Bj	0	0	0	0	0	7	40	0	0
Bunium persicum (Boiss.) Fedtsch.	-	0	12	0	10	0	0	0	0	0
Bupleurum condollii Wallich ex DC.	-	0	0	0	0	0	0	0	8	0
Bupleurum falcatum L.	-	0	0	0	0	0	0	45	0	0
Bupleurum lanceolatum Wallich ex DC.	-	0	0	0	0	0	0	0	18	0
Calamentha hydaspidis (Falconer ex Benth.) Hedge	Ct	0	0	0	0	0	0	45	35	0
Callianthemum pampinelloides (D. Don.) Hook	Cm	30	3	0	0	15	0	0	0	0
Caltha palustris (Camb. & Jacq.) Hook.f. & Thoms.	Cl	0	0	50	10	0	0	0	0	0
Campanula aristata Wallich	Ca	30	0	0	0	25	2	0	0	0
Campanula cashmeriana Royle	-	0	0	0	15	0	12	0	0	0
Campanula latifolia L.	-	0	0	0	0	0	0	0	20	10
Campanula pallida Wallich	Cp	0	0	0	40	0	22	0	0	0
Cannabis sativa L.	Cs	0	0	0	0	0	0	55	0	0
Capsilla bursa-pastoris (L.) Medik	Cb	0	0	0	15	0	23	15	15	0
Carduus edelbergii Rech. F.	Ce	0	0	0	30	10	8	15	13	0
Carex infuscata L.	Ci	55	22	35	25	40	33	45	0	0
Carex nivalis Boott.	Cn	40	33	50	35	60	37	0	0	0
Carex pseudofoetida Kük.	Cu	0	80	50	40	90	17	0	0	0
Carpesium nepalense Less	-	0	0	0	0	0	0	0	15	0
Catabrosa aquatica (Linn.) P. Beauv	Cq	0	0	0	0	0	18	20	0	0
Cedrus deodara (Roxb. ex D. Don)	Cd	0	0	0	0	0	7	35	43	85
Cerastium cerastioides (L.) Britton	Cc	85	8	0	0	0	0	0	0	0
Cerastium dahuricum Fisch	Ch	0	0	0	0	0	28	40	3	0
Cerastium glomeratum Thuill.	Cg	0	0	0	0	0	8	60	5	0
Chaerophyllum reflexum Lindl.	-	0	0	0	0	0	0	30	0	0
Chenopodium album L.	Ch	0	0	0	0	0	43	40	10	0
Chenopodium botrys L.	Co	0	0	0	0	0	32	20	15	10
Chenopodium foliosum (Moench) Asch.	Cf	0	0	0	20	0	20	20	0	15
Chesneya depressa (Oliver) Pop.	-	15	0	0	0	0	0	0	0	0

Chorispora sabulosa Camb.	Csa	0	0	0	0	30	18	0	0	0
Cicerbita macrorhiza (Royle) Beauv.	-	35	0	0	0	0	0	0	0	0
Cichorium intybus L. Chicory	-	0	0	0	0	0	0	0	5	20
Circaea alpine L.	-	0	0	0	0	0	10	0	0	0
Circaea cordata L.	Cco	0	0	0	0	0	0	0	25	45
Cirsium falconeri (Hook.f.) Petrak	Cfa	0	0	0	0	0	52	35	45	35
Clematis grata Wallich	-	0	0	0	0	0	0	0	10	0
Clematis montana Buch.	-	0	0	0	0	0	0	25	0	0
Clinopodium vulgare L.	Cvu	0	0	0	0	0	5	30	25	30
Codonopsis clematidea (Schrenk) C. B. Clarke	-	0	0	0	0	15	0	0	0	0
Codonopsis rotundifolia Benth.	-	0	0	0	0	0	0	5	5	0
Comastoma falcatum L.	Ct	60	0	0	0	0	0	0	0	0
Conyza canedensis (L.) Cronquist	Ca	0	0	0	0	0	7	15	13	0
Cortia depressa (Don) Norman	Cod	75	0	0	0	0	0	0	0	0
Cortusa brotheri Pax ex Lipsky.	-	0	0	0	0	0	0	0	15	0
Corydalis crithmifolia Royle	-	0	0	0	0	15	5	20	0	0
Corydalis govaniana Wallich	Cg	0	0	0	10	20	22	10	5	0
Corydalis stewartii Fedde.	-	0	0	0	0	0	0	0	8	0
Cotoneaster affinis Lindley	-	0	0	0	0	0	0	35	0	0
Cotoneaster bacillaris Wallich ex Lindley	-	0	0	0	0	0	5	20	0	0
Cotoneaster microphyllus Wallich ex Lindley	Cz	0	0	0	0	70	0	0	0	0
Cousinia thomsonii C. B. Clarke	Cx	0	0	0	0	35	0	35	5	0
Crepis sancta (L.) Babc	-	0	0	0	45	0	0	0	0	0
Cynoglossum glochidiatum Wallich ex Benth.	Cy	0	0	0	0	15	0	60	0	0
Dactylus glomerata L.	Dg	0	0	0	0	0	22	25	3	0
Daphne mucronata Royle	-	0	0	0	0	0	0	0	15	0
Delphinium cashmerianum Royle	-	0	0	0	0	0	10	0	0	0
Desmodium elegans DC.	De	0	0	0	0	0	0	0	40	20
Dianthus anatolicus Boiss.	Da	0	0	0	0	0	7	60	0	0
Dioscorea deltoidea Wall. ex Kunth	-	0	0	0	0	0	0	0	20	0
Dipsacus inermis Wall.	-	0	0	0	0	0	0	0	8	0
Draba oreades Schrenk	-	20	0	0	0	0	0	0	0	0
Dracocephalum heterophyllum Benth.	Dn	0	0	0	40	0	0	0	0	0
Dracocephalum nutans L.	-	50	32	35	20	35	28	20	0	0
Dryopteris ramose L.	Dr	0	0	40	5	25	3	30	83	65
Elsholtzia eriostachya (Benth.) Benth.	-	0	0	0	0	0	0	0	18	0
Elymus semicostatus (Nees ex Steud.) Meld.	Es	0	18	40	20	0	20	30	0	0
Epilobium angustifolium L.	-	0	0	0	0	0	12	10	0	0
Epilobium laxum Royle.	El	0	37	45	10	15	15	20	10	0
Epilobium royleanum Hausskn.	Er	10	27	20	20	30	28	65	13	0
Epipactius helleborine (L.) Crantz	-	0	0	0	0	0	0	0	0	15
Equisetum arvens L.	Ea	0	0	0	0	0	18	10	0	0
Eremurus himalaicus Baker	Eh	0	0	0	0	0	5	0	0	0
Erigeron bellidioides (Buch. -Ham. ex D. Don) Benth. Ex C. B.	-	0	0	0	0	0	2	0	5	0

Carke										
Erigeron canedensis L.	-	0	0	0	0	0	0	0	3	0
Erigeron multicaule Wall.	Em	0	0	0	25	0	23	0	0	0
Erysimum hieraciifolium L.	-	0	0	0	0	0	0	45	0	0
Euphorbia cornigera Boiss	-	0	0	0	0	0	0	0	25	0
Euphorbia wallichii Hook. f.	Ew	0	0	0	0	0	0	45	15	0
Euphrasia himalayica Wettst	-	20	18	60	10	20	13	25	0	0
Festuca rubra L.	-	0	0	0	20	0	7	0	0	0
Filipendula vestita (Wallich ex G. Don) Maxim.	Fv	0	0	0	0	0	0	15	15	25
Fragaria nubicola Lindley ex Lacaita	Fn	0	3	0	0	55	53	45	83	75
Fritillaria cirhosa D. Don	Fc	0	0	20	0	0	7	15	0	0
Gagea elegans Wallich ex D. Don	Ge	0	20	0	0	25	0	0	0	0
Galium aparine L.	Ga	0	0	45	0	40	30	25	45	60
Galium boreale L.	Gb	0	0	0	0	0	32	25	18	0
Gentianodes argentea (Royle ex D.Don) Omer, Ali & Qaiser	-	0	5	10	0	0	0	0	0	0
Gentianodes cachemirica (Decne.) Omer, Ali & Qaiser	-	20	0	0	0	0	0	0	0	0
Gentianopsis paludosa (Munro ex Hooker) Ma.	-	0	3	0	0	15	2	0	0	0
Geranium lucidum L.	Gl	20	8	25	0	0	5	20	0	0
Geranium nepalense Sweet.	Gn	0	12	0	0	0	7	15	73	30
Geranium wallichianum D. Don ex Sweet	Gw	35	18	70	20	0	10	60	75	80
Geum roylei Bolle	-	0	0	0	0	0	0	0	13	0
Hackelia uncinata (Royle ex Benth.) Fischer	-	0	0	0	0	0	7	0	0	0
Hedera nepalensis K. Koch	Hn	0	0	0	0	0	0	20	13	75
Helictotrichon virescens (Nees ex Steud.) Henr.	Hv	0	7	0	5	55	10	40	8	0
Heracleum candicans Wall. ex DC.	Hc	0	0	0	0	0	8	30	8	0
Hylotelephium ewersii (Ledeb.) H. Ohba	Hv	45	27	60	0	40	17	30	10	0
Hypericum perforatum L.	-	0	0	0	0	0	2	10	18	0
Impatiens bicolor Royle	Ic	0	0	0	0	0	12	15	13	0
Impatiens brachycentra Kar. & Kir.	Ib	0	0	0	0	0	23	25	50	0
Impatiens edgewrthii Hook. F.	Ie	0	0	0	15	0	3	30	20	50
Impatiens flemingii Hook. f.	-	0	0	0	0	0	0	10	10	0
Impatiens glandulifera Royle	Ig	0	0	0	65	0	0	15	0	0
Indigofera atropurpurea Buch	-	0	0	0	0	0	0	30	0	0
*Indigofera heterantha*Wallich ex Brandis.	Ih	0	0	0	0	0	3	60	85	20
Iris hookeriana Foster	Io	0	42	60	40	55	0	0	0	0
Isodon rugosus (Wallich ex Benth). Hara	-	0	0	0	0	0	0	0	18	0
Jaeshkea canaliculata (D.Don) Knobloch	Jc	0	0	0	0	15	23	20	0	0
Jaeshkea oligosperma (Griseb.) Knobloch	Jo	0	7	20	30	25	20	25	0	0
Jasminium humile L.	-	0	0	0	0	0	0	0	0	15
Juglans regia L.	-	0	0	0	0	0	0	15	18	0
Juncus thomsonii Buchen	-	0	0	35	0	0	2	0	0	0
Juniperus excelsa M.Bieb.	Je	0	0	0	95	0	28	0	0	0
Juniperus squamata Buch. Ham. ex D. Don	Js	0	33	100	0	0	0	0	0	0
Jurinea ceratocarpa (Decne.) Benth.	-	0	0	0	35	0	0	0	0	0

Kobresia capillifolia (Decaisne) C. B. Clarke	Kc	100	22	0	0	0	0	0	0	0
Lactuca lessertiana (DC.) C. B. CLarke	Li	0	0	0	0	0	12	20	3	0
Lamium album L.	La	0	0	0	0	0	0	15	20	20
Lathyrus pratensis L.	-	0	0	0	0	0	12	0	0	0
Lavatera cachemiriana Camb.	Lk	0	0	0	0	0	12	35	0	15
Leontopodium himalayanum DC.	Lh	70	8	0	0	0	0	0	0	0
Leontopodium jacotianum Beauverd	Lj	75	35	70	5	0	0	0	0	0
Leonurus cardiaca L.	-	0	0	0	0	0	0	0	13	0
Lepidium apetalum Willd.	Lp	0	0	0	0	0	20	15	5	5
Lespedeza elegans Camb	Le	0	0	0	0	0	0	35	18	45
Ligularia fischeri (Ledeb.) Turcz.	-	0	0	0	0	0	0	0	5	0
Lindelofia anchusoides (Lindley) Lehm.	Lu	0	0	0	55	35	30	10	0	0
Lindelofia longiflora (Benth.) Baill.	Lf	0	0	45	0	20	0	0	0	0
Lolium persicum Boiss. & Hohen. ex Boiss	Lp	0	0	0	25	0	0	60	0	0
Lomatogonium carinathiacum(Wulff.) A.Br.	Lc	35	13	45	5	0	0	0	0	0
Lonicera quinquelocularis L.	Lq	0	0	0	0	0	0	0	33	15
Lotus corniculatus L.	Lo	0	0	0	0	0	47	45	0	0
Malva neglecta Wallr.	Mn	0	12	0	0	0	25	55	0	15
Medicago lupulina L.	-	0	0	0	0	0	0	0	8	0
Melilotus alba Medicus ex Desr	Ma	0	0	0	0	0	7	40	5	0
Mentha longifolia (L.) Hudson	Mi	0	0	0	5	0	2	40	10	25
Micromeria biflora Benth.	Mb	0	0	0	0	0	15	45	25	60
Minuartia kashmirica (Edgew.) Mattf.	Mk	0	7	50	65	0	32	15	3	0
Myosotis alpestris F.W. Schmidt	Mp	30	17	0	70	30	37	40	73	25
Myricaria germanica (L.) Desv.	Mg	0	0	0	0	0	0	55	0	0
Nepita clarkei Hook. f.	Nc	0	0	0	0	0	7	0	0	0
Nepita connate Royle ex Benth	-	0	0	0	20	0	42	0	0	0
Nepita erecta (Royle ex Benth.) Benth.	Ne	0	0	0	0	0	3	0	10	35
Nepita govaiana (Wall. ex Benth.) Benth.	-	0	0	0	5	0	7	0	0	15
Nepita laevigata (D.Don) Hand-Mazz.	Nl	0	0	0	50	0	2	70	0	15
Nepita podostachys Benth	-	0	0	0	10	0	8	0	0	15
Onychium contiguum Wallich ex C.	-	0	0	0	0	0	0	0	3	20
Ophiopogon intermedius D. Don.	-	0	0	0	0	0	3	10	0	0
Origanum vulgare L.	Ov	0	0	0	0	0	7	30	13	0
Oxalis corniculata L.	Oc	0	0	0	0	0	0	0	28	65
Oxyria digyna (L.) Hill	Od	10	0	65	5	15	42	60	0	0
Oxytropis mollis Royle ex Benth.	Om	75	38	20	15	20	13	65	0	0
Paeonia emodi Wallich ex Royle	-	0	0	0	0	0	0	0	3	40
Papaver nudicaule L.	Pn	60	0	0	0	0	0	0	0	0
Parnassia nubicola Wall.ex Royle	-	40	0	0	0	0	0	0	0	0
Parrotiopsis jacquemontiana (Dcne.) Rehder	Pj	0	0	0	0	0	0	0	0	100
Pedicularis pectinata Wallich ex Benth	Pt	0	0	45	10	0	0	50	0	0
Pedicularis rhinanthoides Schrenk	Pr	0	23	0	0	0	2	0	5	0
Pedicularis roylei Maximowicz	-	40	0	0	0	0	0	0	0	0

Persicaria nepalensis (Meisn.) H. Gross	Pe	0	0	0	0	0	0	70	0	0
Persicaria hydropiper (L.) Spach	-	0	0	0	0	0	12	15	0	0
Persicaria lapathifolia (L.) S. F. Gray	-	0	0	0	0	0	7	50	28	35
Phacelurus speciosus (Steud.) C.E. Hubbared	Ps	0	0	0	0	0	17	35	0	0
Phlomis bracteosa Royle ex Benth	Pb	70	10	0	0	45	0	0	0	0
Phytolacca latbenia (Moq.) Walter	Pi	0	0	0	0	0	0	0	8	45
Piceae smithiana (Wall.) Boiss	-	0	0	0	0	0	0	60	50	20
Pilea umbrosa Blume	Pu	0	0	0	0	0	0	15	10	60
Pimpinella diversifolia DC.	Pd	0	0	0	0	0	0	15	13	15
Pinus wallichiana A. B. Jackso.	Pw	0	0	0	0	0	17	50	95	75
Plantago lanceolatus L.	Pc	0	40	70	35	80	22	45	35	70
Plantago major L.	Pm	50	0	30	0	10	47	60	70	25
Poa alpina L.	Pap	25	82	85	80	40	3	0	0	0
Poa pratensis L.	Ppr	0	0	35	0	50	20	0	33	0
Podophyllum emodi Wall. ex Royle	Pf	0	0	0	0	10	3	50	20	35
Polygonatum multiflorum (L.) All.	-	0	0	0	0	10	0	0	0	20
Polygonum aviculare L.	Pv	0	0	60	60	0	32	0	18	25
Polygonum cognatum Meisn.	Pg	45	15	0	0	10	10	25	0	0
Polygonum paronychioides C. A. Mey. ex Hohen.	Pp	0	0	0	35	0	22	0	0	0
Potentilla atrosanguinea Lodd.	Po	75	5	0	0	0	0	0	0	0
Potentilla cuneata Wallich ex Lehm.	Pcu	25	30	45	40	25	18	35	0	0
Potentilla eriocarpa Wallich ex Lehm.	Pr	30	20	20	0	0	0	0	0	0
Prenanthes brunoniana Wallich ex DC.	Ph	0	0	0	0	0	0	50	0	20
Primula denticulata Smith	Py	0	0	0	0	30	20	15	23	65
Primula elliptica Royle.	Pz	15	17	20	0	15	17	45	18	0
Primula floribunda Wall.	-	0	0	0	0	0	0	0	20	0
Primula microphylla D. Don.	Pq	20	20	0	25	25	27	25	13	0
Primula rosea Royle	Px	0	20	30	25	35	17	20	0	0
Prunella vulgaris L.	Pk	0	0	0	0	0	10	35	53	15
Prunus cornuta (Wallich ex Royle).	-	0	0	0	0	0	0	0	13	0
Pteris vittata L.	-	0	0	0	0	0	0	0	20	0
Quercus baloot Griff.	-	0	0	0	0	0	2	0	13	0
Rannunculus sceleratus L.	-	0	0	0	0	0	3	0	8	0
Ranunculus laetus Wall. ex Hook.f & Thoms.	Rl	0	0	0	0	0	8	0	20	0
Rheum austral D.Don	-	0	0	0	20	0	2	0	0	0
Rhodiola quadrifida (Pallas) Schrenk	Rq	25	12	0	0	0	0	0	0	0
Ribies orieneale Desf.	Ro	0	0	0	0	0	0	45	10	0
Rorippa islandica (Oeder) Borbas	Ri	0	0	0	25	0	8	35	0	0
Rosa macrophylla Lindley.	-	0	0	0	0	0	0	0	13	0
Rosa webbiana Wallich ex Royle	Rw	0	0	0	30	20	30	55	0	0
Rosularia alpestris (Kar. & Kir.) Boriss.	Rp	30	15	75	10	30	18	35	0	0
Rubia Cordifolia L.	-	0	0	0	0	0	0	45	0	0
Rubus fruticosus L.	-	0	0	0	0	0	0	0	0	20
Rubus niveus Thunberg	Rv	0	0	0	5	0	42	25	15	0

Rumax acetosa L.	Ra	0	18	0	80	30	25	30	15	0
Rumex neplensis Spreng.	Rn	0	0	0	0	20	20	30	38	50
Salix karelinii Turcz.	-	0	0	0	0	0	0	0	25	0
Salvia nubicola Wallich ex Sweet	-	0	0	0	0	0	0	0	13	0
Sambucus wightiana Wall. ex Wight & Arn.	Sw	0	0	0	0	25	78	50	33	45
Saussurea albescens (DC.) Sch. Bip.	-	0	0	0	0	0	0	10	10	10
Saxifraga flagellaris Willd ex Sternb.	Sl	70	7	0	0	25	0	0	0	0
Saxifraga jacqemontiana Decne	Sj	15	13	45	0	0	0	0	0	0
Saxifraga moorcroftiana (Ser.) Sternb.	Sm	0	23	40	0	0	0	0	0	0
Saxifraga sibirica L.	Ss	0	12	0	0	25	13	0	0	0
Scrophularia decomposita latifolia (Bth.) Pennell	-	0	0	0	15	0	2	15	5	0
Senecio Chrysanthemoides DC.	Sh	0	8	15	0	10	47	15	0	0
Seriphidium brevifolium (Wallich. ex DC.) Ling & Y. R.	Sf	0	0	0	70	0	25	65	0	0
Sibbaldia cuneata Hornem ex Kuntze	Sb	90	75	95	10	75	10	50	0	0
Silene laxantha Majumdar	Sx	0	0	0	0	0	0	0	15	25
Silene viscose (L.) Pers.	So	0	0	0	30	0	8	0	0	0
Silene vulgaris (Moench) Garcke.	Sg	0	7	0	0	0	18	15	0	0
Siline indica Roxb. ex Otth in DC.	Si	0	0	0	0	0	0	0	10	45
Solidago-virga aurea L.Goldenrod	-	0	0	0	0	0	0	0	15	0
Sorbaria tomentosa (Lindley) Rehder	St	0	0	0	0	0	0	0	53	30
Spiraea canescens D.Don	Sv	0	7	0	25	15	17	0	15	45
Stachys emodi Hedge	Se	0	0	25	5	0	22	20	3	0
Stellaria decumbens Edgew	Sd	25	35	40	30	25	25	35	13	0
Strobilanthes urticifolia Wall. ex Kuntze	Su	0	0	0	0	0	2	0	33	25
Swertia ciliate (D. Don.) B. L. Burtt	Se	0	0	0	0	0	0	0	18	15
Swertia cordata (Wallich ex G. Don) Clarke	Sc	0	62	75	35	60	42	0	13	0
Swertia speciosa D. Don.	Sp	0	13	0	5	5	3	0	0	0
Taraxacum officinale Webb.	Tf	25	33	35	15	20	17	25	30	30
Thalictrum fotidum L.	Ts	0	7	15	10	0	0	0	0	0
Thalictrum secundum Edgew.	-	0	0	0	0	0	0	40	0	25
Thymus linearis Benth. Ex Benth	Tl	60	17	35	45	20	25	25	0	0
Tragopogon pratensis L.	Tt	0	0	0	0	0	23	10	15	0
Trifolium pratense L.	Tp	0	60	65	85	65	53	25	53	0
Trifolium repens L.	Tr	0	38	0	0	0	23	50	28	30
Trigonella emodi Benth.	Te	0	0	0	0	10	47	55	10	0
Urtica dioica L.	Ud	0	0	0	0	0	25	45	15	40
Valeriana himalayanna Grub.	-	0	15	0	0	0	0	0	0	0
Valeriana jatamansi Jones	-	0	0	0	0	0	0	0	10	0
Verbascum thapsus L.	Vh	0	7	25	60	50	13	40	18	25
Veronica laxa Bentham.	Vl	0	0	0	0	0	2	40	18	0
Veronica nutans L.	Ve	20	28	5	0	0	0	0	0	0
Veronica serpyllifolia L.	Vs	0	43	0	0	35	0	30	13	0
Vibernum cotinifolium D. Don	Vc	0	0	0	0	0	0	0	35	0
Vibernum grandiflorum Wallich ex DC.	Vg	0	0	0	0	0	8	25	35	75

Vicia tenuifolia Roth	Vt	0	0	0	0	30	2	50	13	0
Viola rupestris Schm.	Vr	0	0	0	0	0	0	20	45	70
Wikstroemia canescens Meissner	-	0	0	0	0	0	0	0	23	0
Wulfenia amherstiana Benth.	-	0	0	0	0	0	0	0	23	0

The timber line association (2.2) is distinctive by having *Artimisia amygdalina* with high dominance of *Achillea millefolium* and *Bistorta amplexcaulis*.

Montane Forest Zone

Group III (associations 3.1-3.2)

Low and mid elevations (2000 – 2400 m, a.s.l.) are occupied by fairly complete forest cover with shrubby under layer vegetation. It is characterized by annual rainfall between 1000 and 1200 mm and the vegetation benefits from runoff. Group III is distinctive in combination of high dominance of *Pinus wallichiana* (association 3.1) with *Cedrus deodara* (association 3.2) and shrubby *Parrotiopsis jacquemontiana*, *Indigofera hetrantha* and *Dephne mucronata*. Among the tree species, *Aesculus indica*, *Acer caesium*, *Juglans regia, Prunus cornuta* and *Quercus baloot* are the major broad-leaved species in wetter places. Other characteristic species are mixture of annual and deciduous perennials which develop during summer but disappear in winter.

Table 4. Mean values and slandered deviations (S.D) for soil variables for nine vegetation types, identified by clustering analysis : *Kobresia capillifolia* High alpine meadows (1.1), *Bistorta affinis* open pastures (1.2), *Juniperus squamata* mid-alpine prostrate scrub (1.3), *Juniperus excelsa* mid alpine upright scrub (1.4), *Cotoneaster microphyllas* low alpine moranic scrub (1.5), Tree-line *Abies pindrow* krummholz (2.1), Timberline *Abies pindrow* forest (2.2), *Pinus wallichiana* Forest (3.1),*Cedrus deodar* Forest (3.2).

Associations		1.1	1.2	1.3	1.4	1.5	2.1	2.2	3.1	3.2	*D*
pH	Mean	6.3	6.3	6.1	5.5	6.3	6.4	6.9	6.8	6.8	0.001
	S.D	0.5	1.3	0.9	0.9	0.5	0.8	0.4	0.3	0.4	
EC (dS/m)	Mean	0.4	0.4	0.4	0.4	0.5	0.5	0.6	1.5	0.6	0.002
	S.D	0.2	0.2	0.1	0.1	0.2	0.1	0.2	0.5	0.1	
MC (%)	Mean	13.8	15.5	13.8	14.4	11.6	10.9	12.7	22.3	24.0	6.556
	S.D	8.7	8.8	7.4	8.4	5.3	4.8	4.6	10.3	13.9	
OM (%)	Mean	1.8	1.7	1.8	1.7	1.2	2.0	2.7	3.0	2.2	0.401
	S.D	0.6	1.0	0.3	0.5	0.1	0.9	1.2	0.8	0.1	
SOC g/kg	Mean	1.2	1.0	1.0	1.0	0.7	1.2	1.6	1.7	1.3	0.001
	S.D	0.4	0.6	0.2	0.3	0.1	0.5	0.7	1.3	0.1	
P (ppm)	Mean	18.3	13.4	15.9	23.0	17.8	9.8	8.9	10..88	12.8	0.001
	S.D	2.3	8.2	7.3	5.4	0.8	0.6	6.1	5.5	1.3	
K (ppm)	Mean	168.5	279.9	272.1	263.1	252.5	197.4	131.0	132.4	133.0	0.003
	S.D	18.6	61.5	50.0	53.7	25.8	59.3	30.6	60.6	31.1	
N (%)	Mean	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.03
	S.D	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.3	
Sp (%)	Mean	57.3	60.4	46.0	49.0	71.0	52.4	57.4	67.2	65.0	2.567
	S.D	3.3	7.7	7.9	9.7	4.7	6.5	5.0	3.0	3.2	
Soil texture		Clay loam	Clay loam	Clay loam	Loam	Clay loam	Clay	Clay	Clay	Clay	

***D*,** Duncan least significant range at $P< 0.05$; EC, Electrical Conductivity; SMC, Soil moisture contant; SOM, Soil organic matter; SOC, Soil organic carbon; N, total nitrogen; P, Exchangeable Phosphorus; K, Potassium; SP, Soil saturation percentage.

Soils

Table 4 shows the properties of the soils of nine vegetation types. The most common soil texture was a clay loam developed from glacial till and has acidic to moderately acidic properties with pH ranges from 5.25-6.85. The sites occupied by alpine communities (1.1-1.5) had often lower pH, organic matter, soil organic carbon and total nitrogen than the woodland sites. The treeline alpine ecotone exhibited the intermediated values for all these parameters. Similar comments can be made for soil moisture content. When data for soluble salts are considered, it can be seen that soils of most of the treeless alpine communities had significantly higher Phosphorus and Potassium content than the woodland communities. The sites of *Pinus wallichiana* (3.1) had the highest electrical conductivity while that of *Cedrus deodara* (3.2) exhibited the highest total nitrogen. The lowest nitrogen and organic content were recorded from moraines (*Cotoneaster microphyllus scrub*).

Table 5. Pearson product-moment correlation coefficients of qualitative Detrended Correspondence Ordination axes scores and environmental variables for forest-alpine transect. Asterisk code of significance: *significant at *P* (0.05), **significant at *P* (0.01), ***significant at *P* (0.001).

	Axes			
Variables	X I	X2	X3	X4
Geographical variables				
Mid point of latitude (°)	0.87***	-0. 28***	- 0.02	- 0.07
Mid point of longitude (°)	- 0.17**	- 0.05	0.27***	- 0.48***
Elevation of sampling point (a.s.l)	0.92***	- 0.26***	- 0.01	0.04
Climatic variables				
Mean annual temperature (°C)	- 0.87***	0.31***	- 0.05	- 0.11
Mean minimum temperature (°C)	- 0.88***	0.35***	- 0.11	- 0.10
Mean maximum temperature (°C)	- 0.85***	0.25***	0.02	- 0.11
Annual precipitation (mm)	- 0.92***	0.20***	0.09	0.08
Annual snow fall depth (cm)	0.88***	- 0.33***	0.15**	0.20***
Wind speed (Km/h)	- 0.86***	0.31***	- 013*	- 0.08
Major climate type (Koeppen's rating)	0.86***	- 0.16**	0.05	0.15
Edaphic factors				
Soil pH (scale)	- 0.14*	- 0.09	0.02	-0.09
Soil EC (dS/m)	- 0.59**	0.02	- 0.29***	0.14*
Soil moisture (%)	- 0.28***	- 0.01	0.05	0.22***
Soil organic matter (%)	- 0.26***	0.04	- 0.08	-0.01
Soil organic carbon (g/kg)	- 0.48***	0.06	-.031***	0.12*
Soil potassium (ppm)	0.25***	-0.10	- 0.01	0.17**
Soil phosphorus (ppm)	- 0.26***	0.42***	- 0.04	0.19***
Soil nitrogen (%)	- 0.36***	0.10	0.11	0.05
Soil saturation (%)	- 0.23***	- 0.07	0.02	0.28***

Ordination

The results of DCA ordination are used in Figure 5 & 7 to plot the scatters of classificatory results. The eigenvalues of first and second axes (0.642 & 0.271, respectively) were very large in comparison with lower order axes, and the latter were ignored. Ordination of all 280 samples (Fig. 5) shows continuous distribution across a broad range from alpine to montane forests rather do the groupings produced by classification. Again when the nine associations produced by cluster analysis are plotted on the first two axes as a scatter diagram (Fig. 7), the hazy boundaries of the vegetation types reflected the difficulty of describing clearly the vegetation in terms of disjunct communities in mountain landscape with their variable disturbances. The first DCA scores were strongly correlated with elevation (*R* = 0.92, *P* <0.001, Table 5) but this axis is much more than simply an elevation gradient. Indeed, most of the environmental factors measured have highly significant correlations with the first and second axes through its sample scores; in particular, annual rainfall, temperature and winter snow accumulation. The consistent significant interaction terms between these factors and altitude (Table 5) suggested that some combine effect is important to govern the vegetation distribution along the first ordination axis.

Vegetation samples belonging to alpine zone are clearly grouped at one end (high score) and those of low altitude belonging to montane forests on the other end (low score).

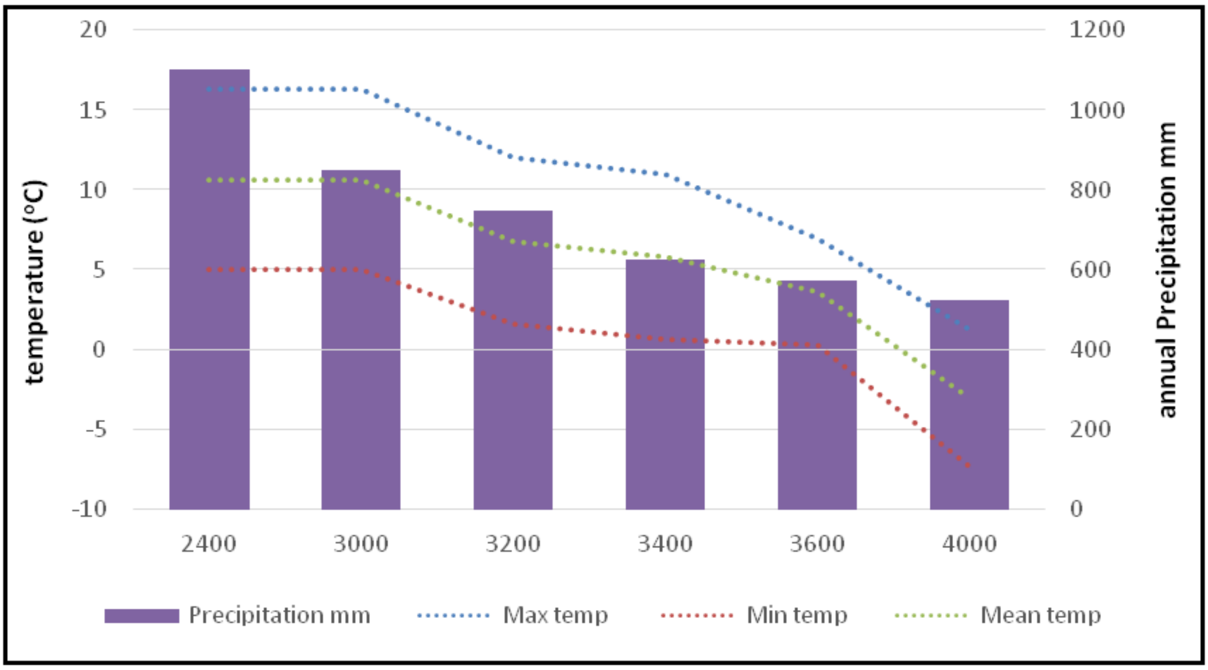

Fig. 2. Mean annual precipitation and temperature along the elevation gradient. The mean values from three stations have been used: Julkhand (73.94 °E, 35.02 °N), Naran (73.75 °E, 34.93 °N), Kaghan (73.6 °E, 34.85 °N).

The samples belonging to subalpine zone lie between those of alpine and temperate montane forest zone (Figs.5 & 7). This sequence strongly suggested one – directional gradient in the ordination diagram from montane forests through subalpine forest to alpine pastures. It is clear that the main ordination is along the elevation gradient from bottom to the top of transect. Beside the climatic variables most of the soil parameters measured have significant correlations with the first axis (Table 5), but are mostly much lower in value, the notable exceptions are soil organic carbon and soil nitrogen, arguably the two most significant elements in plant nutrition affecting species distribution. These results suggested that in the study area climatic variation is more important cause of vegetation pattern across the elevation gradient than soil heterogeneity. The eigenvalue for the second axes was lower than for axes 1. This shows that the first axis, can be regarded as a reasonably good characterization of the species spatial distribution and is more important to explain most of the variations in the data than the second axis. The geo-climatic variables that show significant correlations on axis 2 (Table 5) are mostly much lower in value than on axis 1.The remaining two axes had low values (0.20 and 0.18, respectively) and no further use was made for these axes.

Ordination of all 280 samples shows continuous variation in composition across a broad range from alpine to montane forests. Species such as *Leontopodium jacotianum, Bistorta affinis, Sibbaldia cuneata, Rosularia alpestris, Aconitum heterophyllum, Poa alpina, Primula rosea* with high scores are at the alpine end, while, *Pinus wallichiana, Picea smithiana, Viburnum grandiflorum, Spiraea* *vaccinifolia* with low scores lie towards the forest end of the axis 1. The mid of the diagram is occupied with species belonging to subalpine-alpine ecotone formation such as *Juniperus excelsa, Cotoneaster microphyllus, Rosa webbiana, Fragaria nubicola, Podophyllum emodi, Achillea millefolium*. Similarly on axis 2, *Impatiens glandulifera, Nepeta laevigata, Geranium wallichianum* are at the upper , phosphorus rich end of the axes; while species of *Chenopodium, Trifolium pratens, Seriphidium brevifolium, Cerastium dhuricum* are at the opposite end (Fig.6).

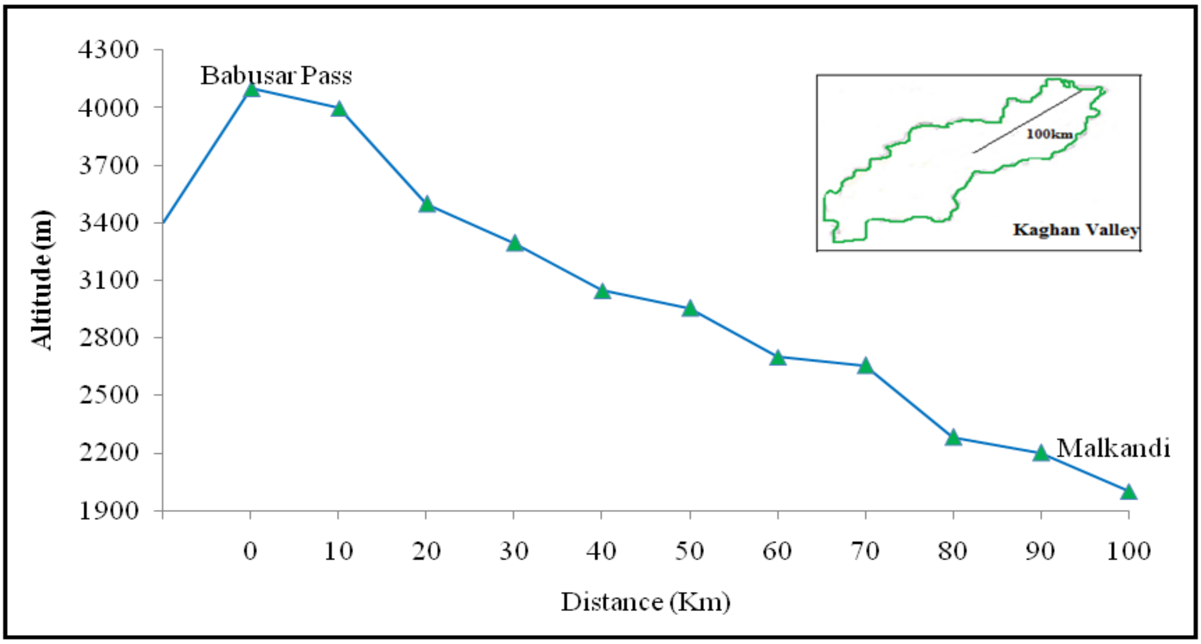

Fig. 3. Profile diagram of the study area from Malkandi (2000 m, a.s.l.) to the summit of Babusar (4100 m, a.s.l.). Study sites are indicated with arrows. Marks on the horizontal distance axis show 10-km intervals. Inset map: location of the study area Kaghan-Naran Valley, Pakistan.

The distribution and assemblage pattern of species along the DCA axes suggested that factors associated with altitude such as temperature, precipitation, winter snow thickening, soil nutrients and underlying lithology (Table 5) were the driving factors to produce continuous changes in vegetation from close forests to treeless alpine pastures from the bottom to the top of transect. The overlay of the major vegetation types produced by cluster analysis on first two axes as a scatter diagram (Fig. 7) demonstrates the overlapping nature of the associations in space defined by the ordination axes.

Discussion

The results of the cluster analysis delineated three major bioclimatic zones at two levels of hierarchical divisions. These are: (i) Montane forests at low altitudes (2000-2400 m) (ii) subalpine vegetation on the high mountains extending from timberline to treeline-alpine ecotone (2500-3200 m), (iii) the alpine pasture scrubs and meadows above the treeline (3200-4100 m). The three vegetation zones defined by cluster analysis differ in physiognomy and had already been subjectively identified by previous ecological work on vegetation of the sub-continent (Champion *et al.* 1965).

The alpine belt is being distinguished by absences of tree species and the occurrence of several alpine species such as *Kobresia capillifolia, Androsacea mucronifolia, Sibbaldia cuneata, Saxifraga flagellaris, Cerastium ceratiodes, Rosularia alpestris* and *Oxytropis mollis* which were altogether absent in either subalpine or lower montane forest zone.

The vertical (among the zones) and horizontal (within the zone) hierarchical divisions indicate the finer altitudinal zonation in vegetation.

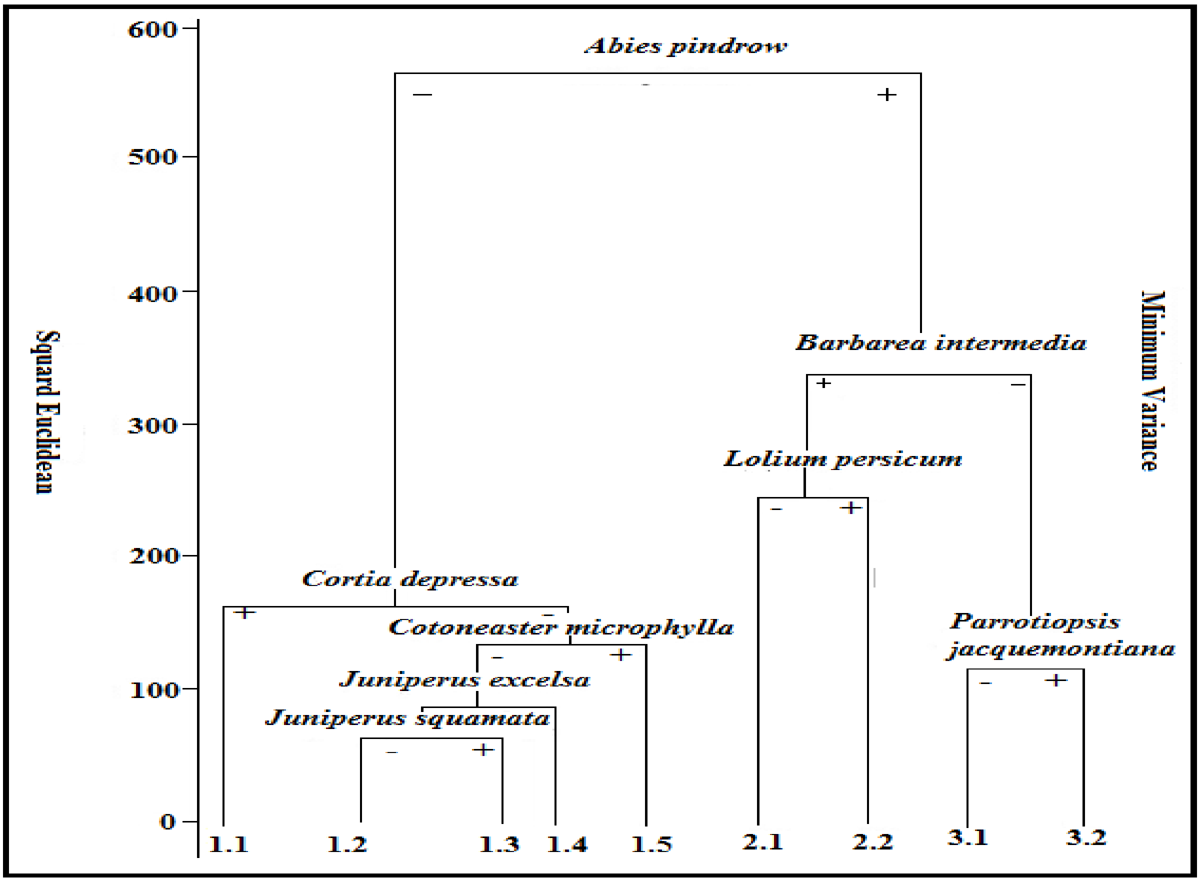

Fig. 4. Dendrogram of the hierarchical classification from the cluster analysis of the 280 samples from Kaghan valley, W. Himalaya, Pakistan. Divisor species are given.

The horizontal subdivisions produced recognizable vegetation groups vary at local scale owing to differences in floristic and minor variation in climate and substrate. The results of hierarchical divisions indicate that the vegetation closely follows a topographic sequence from alpine to montane forests through subalpine timberline-treeline ecotone.

The importance of altitude as a major determinant of plant assemblage within a mountain landscape is essentially due to its close association with temperature, snowfall, rainfall, and down-slope movement of water (Evenari *et al.* 1982), and its impact on edaphic conditions Grubb and Tanner, 1976; Bellingham, 1991). The accumulation of run-off takes place at various scales from small depression to large enclosed basins and lakes on run-on sites. Thus niches, habitats and microhabitats of various kinds and sizes are formed which have decisive impact on the structure and composition of vegetation and overall landscape structure (Orshan, 1986). Similarly, temperature decreases linearly with increasing elevation. This could be attributed to the draining down cool air to low elevations and uplifting of warm air mass to the higher elevations (Zhong and Guo, 1997). The importance of temperature in determining the macroclimatic gradients and creation of various thermal niches along the altitudinal gradient is well documented. Beside the temperature factor of the climate, the three bioclimatic zones identified by cluster analysis also differ in terms of magnitude of snow fall accumulation in winter. Snowfall increased gradually in sequence from montane temperate forests to alpine meadows.

The gradual melting of winter accumulation ensures adequate soil moisture during short growing period in summer at high altitudes. Hence, winter accumulation, in terms of presence, duration, thickness may be considered as one of the important differentiating factors between the sites along the altitudinal gradient.

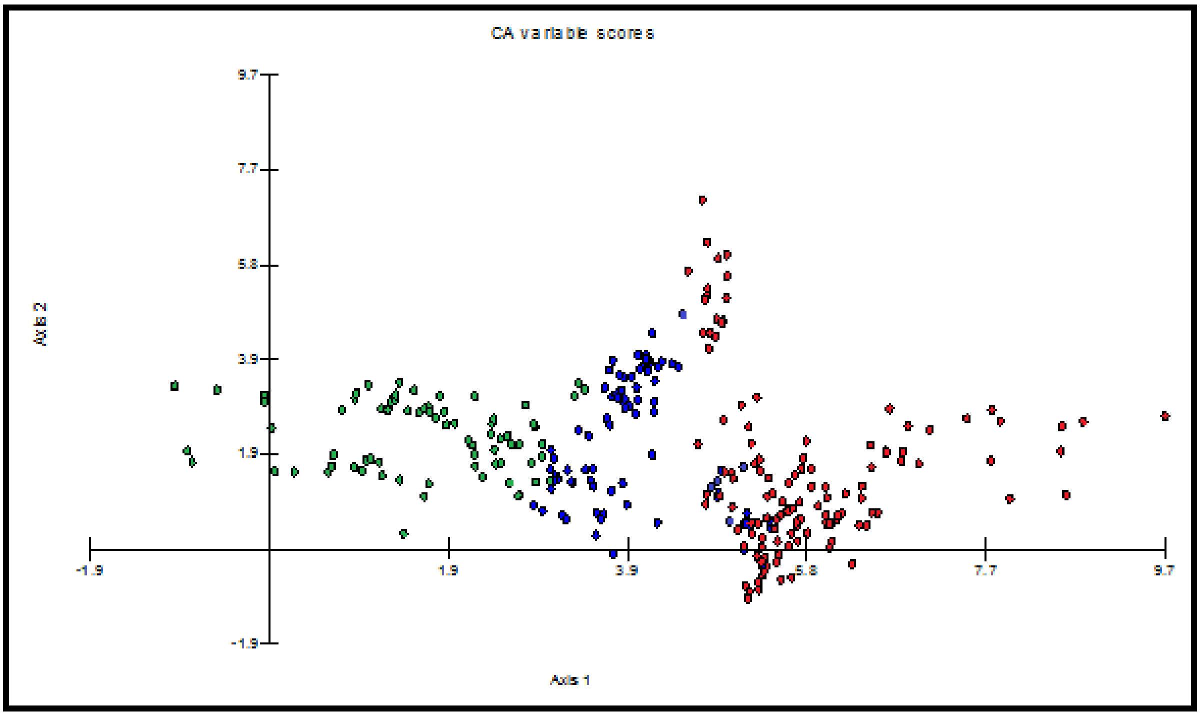

Fig. 5. Detrended correspondence sample ordination of qualitative data of the Kaghan Valley, W. Himalaya, Pakistan.

The other major effect of variation in the magnitude of snow accumulation is related to the consequent variation in soil temperature. Wundram *et al.* (2010) observed significant differences in soil temperature among the sites with shallow snow cover and the sites with thick snow cover during winter. The spatial variation in the magnitude of snow cover is important in determining various thermal niches harboring different combination of species. Generally, the extent of snow cover affect soil temperature in the first instance, but even more influential on the vegetation through the effect of soil moisture that affect the vegetation pattern and diversity along the altitudinal gradient.

Beside the difference in climatic parameters, significant edaphic differences are observed along the elevation gradient. Soil moisture regime was highly contrasting as a function of altitude. In general, the clay-loam soils below the timberline were moist compared to the sandy-loam soils above the timberline. The pH was in a moderately acidic range (5.52 to 6.85) and became more acidic at higher elevations. The acidic nature of the soil in upper Himalayan forests had already been discussed by various workers (Kumar *et al.* 2004; Sheikh *et al.* 2010, Hashim and Dasti, 2019), but contradicted the findings of Veneklaas (1991) who reported higher pH on upper montane than soils on lower montane. The soil organic carbon decreased with increasing elevation confirming the results of Sturm and Abouchaar (1981) and Luteyn (1999). Soil organic matter and available nitrogen had shown the same trends with elevation. These changes in soil properties along the altitudinal gradient might be associated with down-slope movement of water, soil particles, soil cations and organic matter and exercise marked effect not only on the distribution of individual species but also affect the vegetation as a whole (Dasti and Malik, 1998).

Almost all the environmental factors associated with altitude are also significantly correlated with vegetation gradient. The results demonstrate that changes in vegetation occurred gradually along the altitudinal gradient and show significant associations between landscape patterns of environmental heterogeneity from top to the bottom of the transect. This agrees with findings of Whiittaker (1967); Hamilton *et al.* (1989); Hemp (2005).

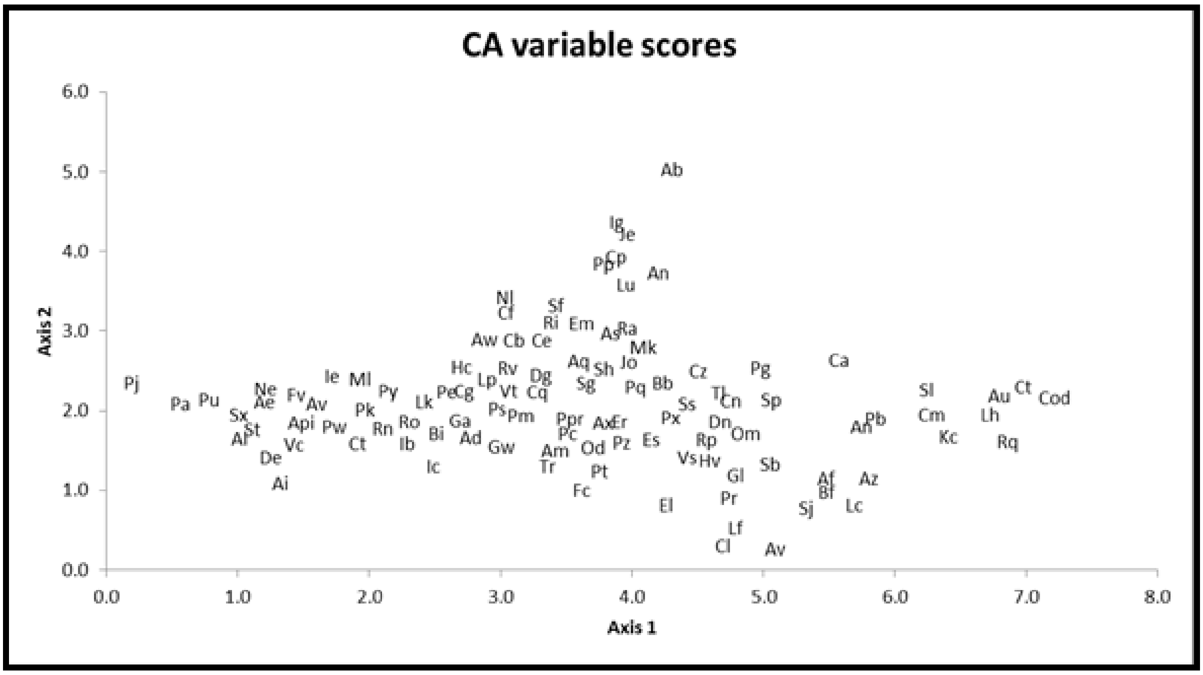

Fig. 6. Detrended correspondence analysis (DCA) showing position of plant species on the major climatic gradient (altitude). Species codes are those given in Appendix 1.

Despite significant differences in soil properties along the elevation gradient, there are weak correlations with vegetation patterns than the climatic factors along the first DCA axes. The weak correlations could be due to temporal modification in soil properties (Robertson *et al.* 1997). These edaphic modifications may be appeared to be associated with allochthonous and the basic geo-morphological processes of surface movements mainly through the action of water and glacial retreats (Van der Hammen *et al.* 1967; Vuilleumier, 1971) and human disturbance such as grazing (Dager, 1987).

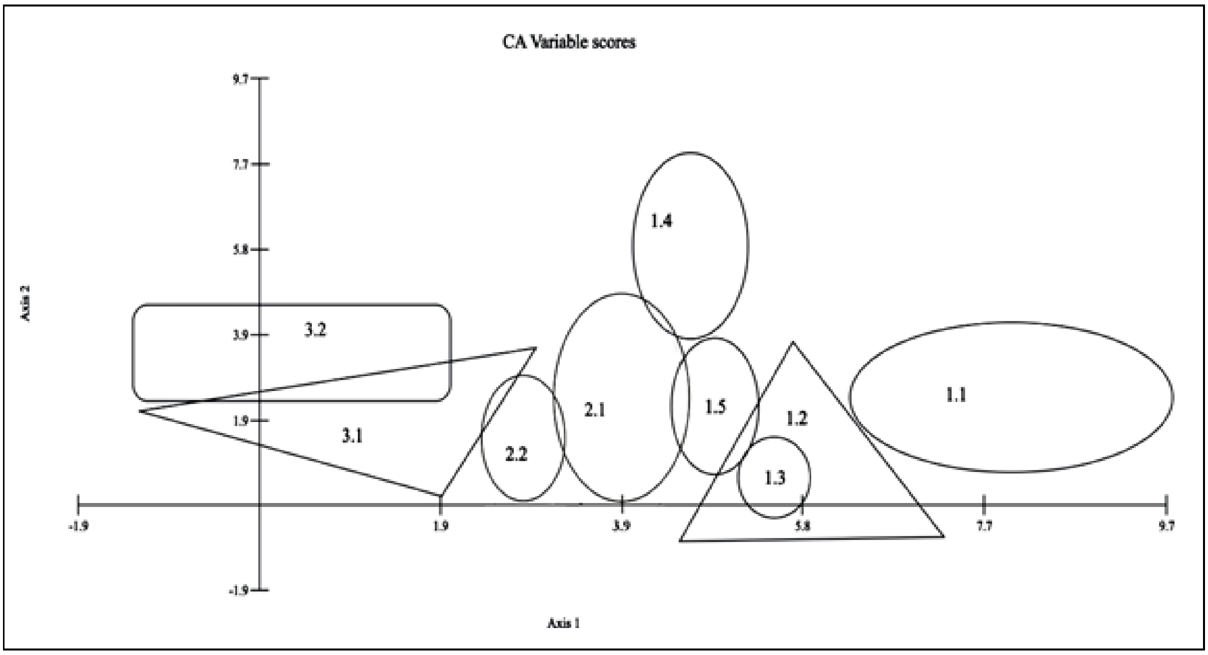

Fig. 7. DCA (axis 1 & 2) plots of the 280 samples from the Kaghan Valley, W. Himalaya, Pakistan. Points are not plotted individually. Instead zones are shown in which each of the nine associations segregated through the cluster analysis as given in Table 2.

These changes might be contemporary or historical; it is difficult to assess the relative importance of these factors in comparison with elevation. However, the consistent negative interaction terms between these factors and first DCA axes indicate that some integrated effect is important.

The correlations of different environmental factors found here demonstrate significant association between environmental factors and assemblage of the species at landscape level. Two factors appear to be the decisive: elevation and substrate. The overriding importance of elevation as an environmental factor affecting plant species distribution and zonation is not surprising, considering its close correlation with climatic and edaphic features (Evenari *et al.* 1982). The relative magnitude of the various correlations shows that elevation as a proxy for climatic has the overriding importance in determining the vegetation pattern. Soil properties are of secondary importance for the separation of vegetation types. Support for this interpretation comes from both the ordination and classification ordered groups on the basis of their floristic composition in a sequence that correlated more closely with altitude. These results confirm the findings of several other researchers (Hamilton *et al.* 1989; Vazques and Givnish, 1998; Hemp, 2005). The role of altitude in determining the climatic gradient and vegetation zonation in mountain ecosystem has been thoroughly reviewed by Ninot *et al.* (2007) and concluded that altitudinal and latitudinal zonation show parallelism, from their ecological factors to vegetation structure and plant composition.

Vegetation patterns

The results of the present investigation suggest that main ordination is along the altitudinal gradient (R = 0.92). The first DCA axis is also significantly related to most of the soil variables. The arrangement of the nine floristic groups along first two axes of the ordination suggests a complex mosaic of herbaceous and woody plant communities along these axes. The overlay of classification groups on ordination displays the introgression of one association in to another and do not support the idea of discrete communities or zones. The boundaries imposed by cluster analysis seem to be arbitrary and the zones defined on the basis of physiognomy do not differ in floristic. The overlapping nature of plant communities in space defined by the ordination axes reinforce the concept of vegetation continuity proposed by Gleason (1926) and thereafter supported by Curtis and McIntosh (1951). Several other studies in temperate and tropical forests (Austin, 1985; Vazquez and Givinish, 1998; Dolezal and Srutek, 2002) support the individualistic hypothesis which posits that the distribution and assemblage of each species is determined by its own ability to cope with different environments, resulting in each species having its own distinctive distribution, and in community composition changing more or less continuously along the ecological gradients.

For the landscape described in this paper, therefore, we suggest that the flora is a residual one of the generalists capable of persisting through disturbance regimes of various time-scale and destructiveness, and that this can explain the difficulty of describing clearly the vegetation in terms of discrete communities. The hazy boundaries of the plant associations along the altitudinal gradient indicated the lack of specialized species in our restricted plant communities. Because of the special nature of the de-glaciated landscape with their variable disturbances, the difficulty of describing vegetation boundaries may be general one.

Distribution of samples reflected certain discontinuities. Sporadic discontinuities despite a continuous gradient have been reported in other studies (Beals, 1969; Stohlgren and Bachand, 1997). The observed discontinuities may be contemporary and ranges from sweeping changes brought by snow slides that wipe out strips of vegetation along their course to current harvesting activities by local villagers which may remove, say woody species from a wide area for fuel and timber. The latter disturbance could well give rise to the observed, apparently arbitrary changes in vegetation pattern and dominance. Grazing and its concomitant lopping for fuel and fodder also have exerted very great influence on vegetation pattern and structure.

The dominance of only one plant species at most sites was obvious in the field, and this is notable character of the vegetation in the study area. Yet most of the associations identified by cluster analysis exhibit consistent dominance patterns. Again, the scatters of the DCA show the hazy boundaries between vegetation types and species distribution: some species were restricted but the majority had wide ranges across communities. No changes of definition of 'stopping' rules or divisive protocols increased the separation. Because of the special nature of mountain landscape with their rapid environmental changes, the difficulty of describing vegetation boundaries may be a general one. The distribution of dominant species may determine vegetation differentiation along the altitudinal gradient (Zhang and Ru, 2010; Zhong *et al.* 2013). This is also true for the present investigation. Herbaceous and woody dominant species such as *Kobresia capillifolia, Bistorta affinis, Juniperus squamata, Juniperus excelsa, Sibbaldia cuneata, Sambucus wightiana, Persicaria nepalence, Geranium wallichiana* and *Parrotiopsis jacquemontiana* play an important role in vegetation patterning in the area. In tree strata, staggered dominance of *Pinus wallichiana*, *Cedrus deodara* and *Abies Pindrow* along the altitudinal gradient give a characteristic physiognomy in woodland zone of the area (Hashim and Dasti, 2019). The staggered altitudinal distribution of dominant tree species is consistent with the Gaussian individualistic hypotheses with the fact that such ecological dominants develop different strategies for coping with rapidly changing environment along the elevation gradient. Similar results have been reported from other temperate forests (Bunker and Carson, 2005) as well as from tropical forests (Poulos *et al.* 2007). The dominant species has inherent specialization to use resources in their environment, adapting to stress, competing with other coexisting species. The ecological niches in which a species realized its maximum growth also exhibit its maximum dominance (Grime, 1979; Lambers and Poorter, 1992). These assumptions suggest the relative importance of species functional traits to resolve the paradox of dominance in high elevation species. In addition to dominant species, the divisor species (which governs the divisions of the samples) of the classificatory procedure such as *Barbarea intermedia, Lolium persicum, Cortia depressa, Juniperus squamata, J. excelsa, Cotoneaster microphylla,* and *Parrotiopsis jacquemontiana* have proved important for community heterogeneity (Liu and Ren, 1992). The herbaceous layer contributes a large share in community composition than the woody species in the study area.

Conclusion

The vegetation follows a topographic sequence and changes continuously along the altitudinal gradient. It supports the individualistic hypothesis of plant community organization and the hazy boundaries of plant association along the altitudinal gradient indicate the continuous rather than discrete pattern of vegetation in Himalayan Mountains. Two factors seem to be operative: Altitude and substrate.

The overriding importance of elevation as an environmental factor is entirely due to its close correlation with various climatic factors. Because of the special nature of the mountain landscape with their rapid climate change, the difficulty of describing vegetation boundaries may be a general one.

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