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COMPOSITION OF PLANT COMMUNITIES DRIVEN BY ENVIRONMENTAL GRADIENTS IN ALPINE PASTURES AND COLD DESERT OF NORTHWESTERN HIMALAYA, PAKISTAN

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Abstract

Alpine life zones exist at the cold edge above the tree line in mountains where tree species do not grow, however, a large plant diversity thrives due to alpine climate adaptations to short growing seasons and low temperatures. Keeping this phenomenon in view, study was designed to determine the influential environmental variables responsible for structuring the plant communities in the alpine pastures and cold desert of Northwestern Himalayas, Pakistan. The vegetation of the aforementioned study area was quantified by following the Line transect (50 meters) method along the geographic, slope, edaphic and climatic gradients. All the recorded data of plant species and environmental variables were analyzed by various statistical softwares' (*i.e.,* PCORD, CANOCO and R 3.6.1). Thirty-nine species recorded in 13 stands were grouped into two major plant communities (i.e., *Poa-Bistorta-Primula* and *Bistorta-Poa-Primula). Poa-Bistorta-Primula* community has the highest number of plant species (39 species) as well as the highest value of alpha and beta diversity (2.785 and 0.916, respectively) and Pielou's evenness (0.865) in *Bistorta-Poa-Primula* community. Due to the high elevation, severe low temperature is the feature throughout the growing season. Such severe climatic environment is worsened by xeric conditions which led to very short growing season from July to September. The recognized indicators of such harsh environment might be useful in monitoring variations in plant communities resulted in response to environmental changes.

Key words: Plants communities; Alpine zone; Environmental gradients; PC-ORD; Himalaya.

Introduction

Alpine zones occurs above the tree line in mountains where trees are incapable of growing, nevertheless, another group of plants diversity thrives due to alpine climate adaptations (Nagy & Grabherr, 2009; Winkler *et al.*, 2019). Occupying 3% vegetation land area on earth (Koerner, 2011), alpine zones host approximately 4% plants of the world (8000–10,000 species) (Körner, 2003). They are primarily perennial species adapted to this seasonally extreme environment. Alpine plant lifeforms include forbs, graminoids, mat-forming cushion species, and succulents (Jabis, 2018). The composition and diversity of plant species vary across the zones, due to latitudinal and altitudinal gradients, as well as across mountain ranges (Malanson *et al.*, 2020). Geographically, the physical classes of alpine ecosystems varies on the basis of elevation, seasonality as well as water availability (Grabherr *et al.*, 2010; Koerner, 2011), all of these govern the biotic makeup of plant communities.

The composition of alpine plant communities is driven, as in many other systems, by a combination of biotic and abiotic elements. Among the abiotic elements, altitude, seasonality, and water availability are greatly affecting the alpine ecosystems (Grabherr *et al.*, 2010; Koerner, 2011), indeed these climatic elements overpower the biotic ones in these ecosystems that the impacts of climate change may be more noticeable than in lower altitudinal communities (Grabherr *et al.*, 2000; Mohan, 2019). The alpine ecosystem experience extreme abiotic conditions, including long periods of snow cover, strong wind scouring, large temperature fluctuation, poor soil development, early- and late-season frosts and soil moisture dry-down during the growing season (Jabis, 2018). Since alpine environment is expected to experience a considerable rapid environmental change compared to lower elevation environment, the alpine environment presents a challenge to its plant inhabitants which are mostly long-lived species that could be slow to respond (Jabis, 2018).

Alpine ecosystems display micro-topographic relief that has historically structured communities on a relatively small scale (Scherrer & Körner, 2011). Distinct community types may exist in relatively close proximity based on small-scale differences in aspect, slope, or depressions that accumulating snow, thus generating dry meadow, wet meadow, or snow bed communities (Opedal *et al.*, 2015). This research aims to investigate plant communities in the alpine pastures and cold deserts at the great mountain system of Asia, the Himalayas. By examining the plant diversity among sites, while taking into account the various environmental variables, we intent to classify and examine the distinct plant communities in the region.

Materials and Methods

Study area: The present field investigation was carried out in the alpine pastures and cold desert of Manoor Valley (34.68165 N to 34.83869 N latitude, and 73.57520 E to 73.73182 E longitude; 1580 to 4677 meter elevation above sea level), which is a mountainous valley (Fig. 1) in the Northwestern Himalayan belt of Pakistan (Rahman *et al.*, 2016a; b, 2018b; a, 2019). At the Himalayas, monsoon winds are the main source of precipitation as well as the primary determinant of erosion, climate, topography, and vegetation (Khan, 2012).

Field investigation, data sampling and plant identification: The vegetation of the alpine pastures and cold desert of the studied area was recorded from 13 stands and quantified by following the Line transect (50 meters) method (Haq *et al.*, 2017) along the geographic, slope, edaphic and climatic gradients. The phytosociological attributes (*i.e.*, density, frequency, cover and their relative values, and importance value index) were used for calculation of the data from each stand (Curtis & McIntosh, 1950; Curtis, 1959; Jayasuriya & Pemadasa, 1983). Global Positioning System (GPS) tool was used to record the locations of each sampling site, as well as the slope angle, aspect and exposure using clinometer feature of the tool. Within each sampling site, 200-400 g soil samples from the depth of 0-30 cm were collected from three random points (Rahman *et al.*, 2015, 2017) and were processed for physicochemical analyses such as pH, soil texture, organic matter, phosphorous, nitrogen, potassium, calcium carbonate and electrical conductivity (Mc Lean, 1982; Soltanpour, 1991; Nelson & Sommers, 1996; Ravindranath & Ostwald, 2007; Wilson & Bayley, 2012). Besides, the data regarding climatic variables was also measured using handheld weather station following (Rahman *et al.*, 2020a). Plants specimen collection, labeling, pressing and other herbarium work methodology was adopted following (Ijaz, 2014; Ijaz *et al.*, 2018). Their identification was done based on the Flora of Pakistan (Nasir & Ali, 1971-1989; Ali & Nasir, 1989-1991; Ali & Qaiser, 1995-2017). Voucher herbarium specimens were made for each plant species and deposited at the Herbarium of the Hazara University, Pakistan.

Statistical analyses: PC-ORD software (Haq *et al.*, 2017) was used to identify plant communities (Rahman *et al.*, 2020a) by processing Cluster analysis, two-way cluster analysis (Bano *et al.*, 2018) and two way indicator species analysis. RStudio 4.0.0 and R 3.6.1 softwares (R Core Team, 2020) were used for processing Non-multidimensional scaling ordination (NMDS) and Principal Component Analysis (PCA) (Terzi *et al.*, 2019), GLM with Gaussian error distribution followed by Likelihood ratio test (Fox & Weisberg, 2018), Non-multidimensional scaling ordination (NMDS) and Principal Component Analysis (PCA) (Oksanen *et al.*, 2018; Terzi *et al.*, 2019) canonical correspondence analysis and variation partitioning tests were performed using the software RStudio 4.0.0 (R Core Team, 2019). Detrended correspondence analysis (DCA) was done by using CANOCO version 5.

Results

Thirty-nine plant species were record from thirteen stands in alpine pastures and cold desert (Fig. 2) of Manoor valley (Himalaya), Pakistan which completely lacks shrub and tree species. TWINSPAN grouped all the recorded alpine native species within 13 stands into two plant communities in response to climatic, edaphic, topographic and physiographic gradients (95% confidence level; Fig. 3a). TWCA further pointed out the distribution of species at each stand (Fig. 3b).

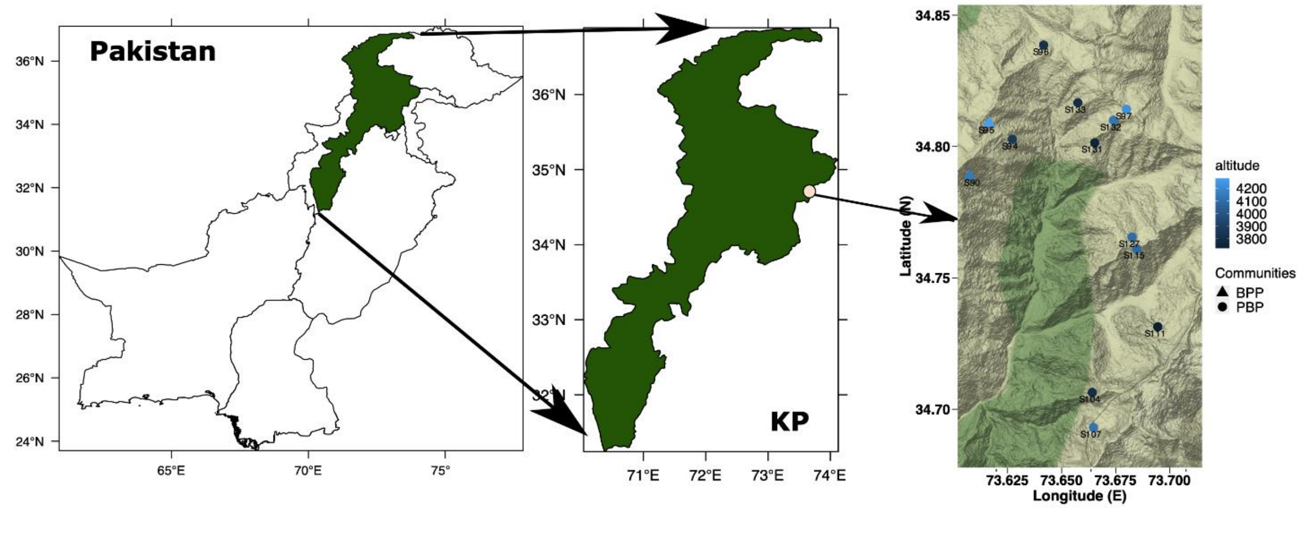

Fig. 1. Map of Manoor Valley indicating the studied sites with hosted plant communities. Triangles and circles indicate the vegetation of the alpine Poa-Bistorta-Primula (PBP) and Bistorta-Poa-Primula (BPP) communities, respectively, and the colour of each symbol demonstrates the altitudinal range.

Fig. 2. Panoramic views of alpine pastures and cold desert of the study area: a) Ansoo Lake (4127 m.a.s.l), b) route leading towards Ansoo Lake near Dhir, c) *Hylotelephium ewersii* (diagnostic species of cold desert community), d) alpine pastures indicating the indicator species (*Bistora affinis*).

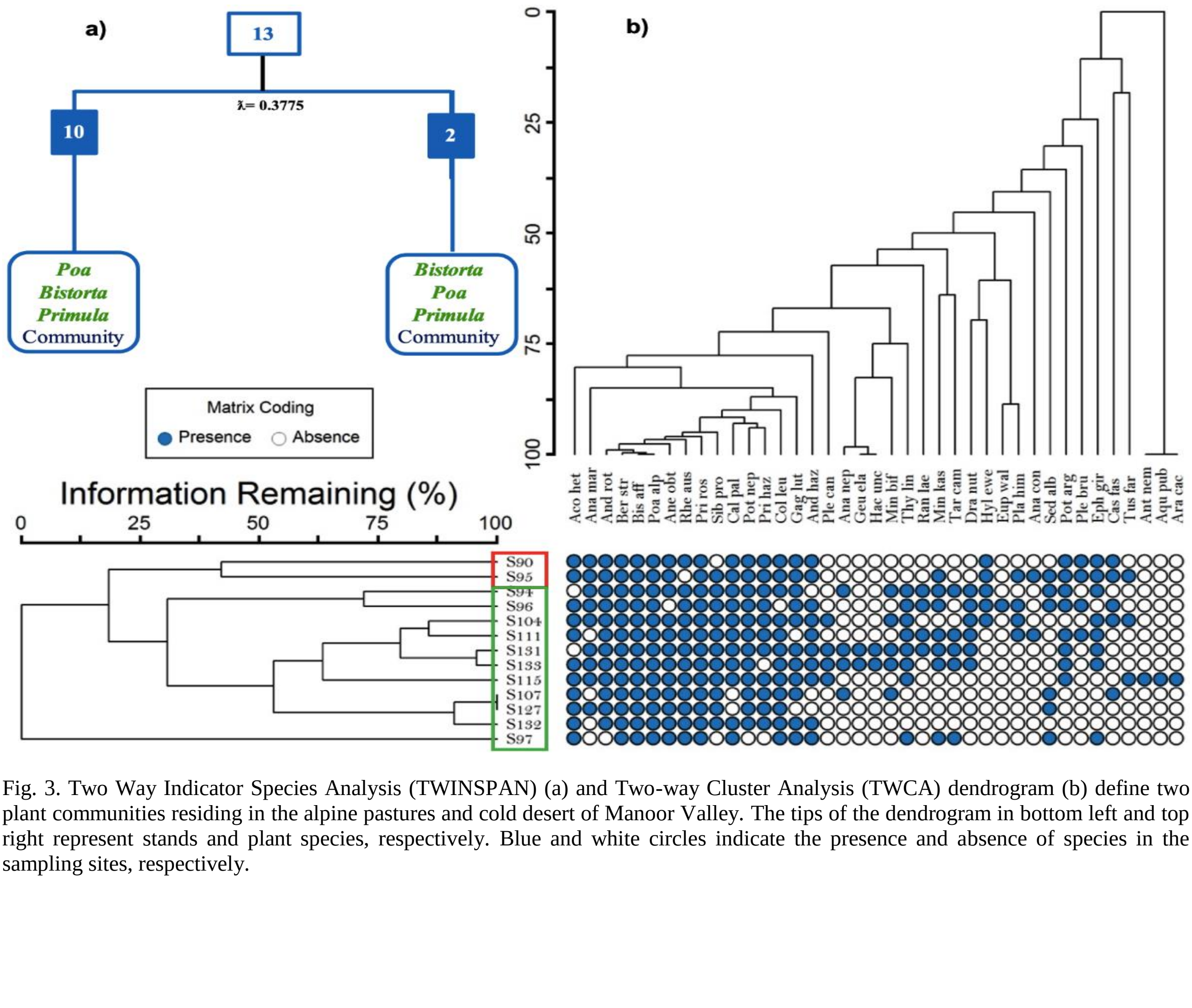

Fig. 3. Two Way Indicator Species Analysis (TWINSPAN) (a) and Two-way Cluster Analysis (TWCA) dendrogram (b) define two plant communities residing in the alpine pastures and cold desert of Manoor Valley. The tips of the dendrogram in bottom left and top right represent stands and plant species, respectively. Blue and white circles indicate the presence and absence of species in the sampling sites, respectively.

Plant Communities: The TWINSPAN results revealed the recognition of two major plant communities in the alpine pastures and cold desert of the studied area. Moreover, the description of the said communities along with their associates and influential environmental variables are as follows:

***Poa-Bistorta-Primula* community**: This is the highest altitude (3724-4227 m) alpine pasture plant community recorded from 11 stands on 34.69306 - 34.83861 N and 73.62722 - 73.69444 E from south to northern aspect with 28º to 85º slope exposure (Fig. 4a, b). This community has higher species richness compared to the alpine cold desert plant community described below. All 39 species recorded in this research are found in this plant community. *Poa alpina* (9.57 IVI), *Bistorta affinis* (8.10 IVI) and *Primula rosea* (7.49 IVI) are the major indicators of this community. Other co-dominant alpine natives were *Sibbaldia procumbens*, *Rheum australe*, *Bergenia stracheyi*, *Androsace rotundifolia* and *A. hazarica.* Among the climatic gradients, temperature (average: 6.1ºC), wind speed (3-6.5 m/sec, Fig. 5), humidity (51.8%) and dew point (12.1) were found to be the strong influential drivers of this community (Fig. 4d). The soil linked with this community was mostly loamy to sandy clay loamy in texture (Fig. 4c) with lowest ranges of potassium (196-206.9 mg/kg), pH (4.9-5.7) and organic matter (1.15-2.64%, Fig. 5).

Bistorta-Poa-Primula* community:* A total of two sites hosted BPP plant community, an alpine cold desert, on 34.78889 - 34.80889 N and 73.60750 - 73.61639 E (Fig. 4a, b) at an elevational range of 4145-4278 m. Only 26 plant species are recorded in this community. Leading indicators of this cold desert plant community are *Bistorta affinis* (15.29 IVI), *Poa alpina* (12.47 IVI) and *Primula rosea* (06.81 IVI). Other prominent associated herbs of this community are *Bergenia stracheyi, Sibbaldia procumbens, Gagea lutea, Hylotelephium ewersii, Sedum album, Caltha palustris, Rheum australe, Primula hazarica* and, *Androsace rotundifolia.* Located above the alpine pasture PBP community, this community experiences lower temperatures (average: 4.4ºC) and higher wind speed (4.5-6.5 m/sec); these two climatic gradients are the key features of this community throughout the growing season (Fig. 4d). Such severe climatic environment (Fig. 5) was worsened by xeric conditions which led to very short growing season from July to September. This community grows in sandy loam soil and is driven by high phosphorous (8.1-9.3 $mgkg^{-1}$), organic matter (1.49-1.79%), pH (4.7-4.9), calcium carbonate (2.18-6.34 $mgkg^{-1}$) and potassium (200-203 $mgkg^{-1}$, Fig. 5). Correlation between alpine pasture and cold desert plant communities and environmental gradients were illustrated through NMDS (Fig. 4a-d) and Principle Component Analysis (PCA, Fig. 4e).

Species richness and diversity indices: Maximum number of species, or species richness values, were recorded in *Poa-Bistorta-Primula* community (39 species) followed by *Bistorta-Poa-Primula* (26 species) of cold desert (Fig. 5, Table 1). High species richness variability between the aforementioned communities might be due to altitudinal ranges differences and variability in other gradients. Within sampling sites, species richness values ranged from 14 (stand S127) to 27 species (stand S131; Fig. 5 and 6d, Table 1). Pielou's evenness index ranged between 0.7.66 to 0.865, the highest values belonged to the *Bistorta-Poa-Primula* community (0.865, Fig. 5). The Shannon Diversity indices (H') ranged from 2.075 to 2.785; the highest indices of PBP and BPP communities are 2.785 and 2.625, respectively (Fig. 5). The Simpson's dominance indices ranged between 0.822-0.916; the highest indices of PBP and BPP communities are 0.916 and 0.894, respectively (Fig. 5).

Ordination of species: Regarding the association among species, within all sampling sites, Detrended Correspondence Analysis (DCA) shows that *Primula rosea*, *Bistorta affinis*, *Poa alpina*, *Gagea lutea*, *Geum elatum*, *Bergenia stracheyi*, *Anaphalis nepalensis*, *Androsace hazarica* and *Rheum australe* were positively correlated with each other (Fig. 7a). Similarly, *Sibbaldia procumbens, Anaphalis margaritacea, Potentilla nepalensis, Hylotelephium ewersii*, *Plantago himalaica* and *Dracocephalum nutans* are positively correlated with each other, however, they are negatively associated with each other plant species. In the other hand, *Sedum album*, *Euphorbia wallichii*, *Taraxacum compyloides* and *Tusilago farfara* species are found isolated (Fig. 6a).

Ordination of stands: Regarding the association among sampling sites, DCA shows that five sites of PBP community (S107, S111, S127, S131, S132, and S133) are positively correlated with each other (Fig. 6b). The other five of its sites (S94, S96, S97, S104 and S115), however, are found to be isolated based on the variation in their environmental sets. NMDS ordination between the sampling sites with their respective species shows that BPP community is separated from the PBP community (Fig. 6c). Nevertheless, each stand consisted of different number of species ranged 14 (S127) to 27 species (S131, Fig. 6d).

Partial CCA: Total inertia results of CCA is 0.434, where the ten final variables (Temperature, Clay, pH, EC, Loam, Slope S, Longitude, Wet bulb, Slope N, and Altitude) together explained 89.5% of variation (sum of canonical eigenvalues is 0.388). The first two canonical axes explained 43% of variation. CCA model is significant with pseudo-F value=0.388; $p<0.05$; df=10 and permutations=999. Simple term effects are tested for the ten explanatory variables and showed that Clay, EC, and pH, in decreasing order of importance, are significant driver to species distribution ($p<0.05$; Table 2). The 10 explanatory variables are grouped into four classes: Climatic (Temperature, Wet bulb); Edaphic (Clay, pH, EC, Loam); Geographic (Longitude, Altitude); and Slope (Slope S, Slope N), and then, we performed variation partitioning tests (partial CCA) for all 15 possible classes (Table 3). Class [b] is the most explanatory variable (94.4%), followed by class [c] (77.8%), [j] (62.6%) and class [l] (38.8%) (Fig. 7).

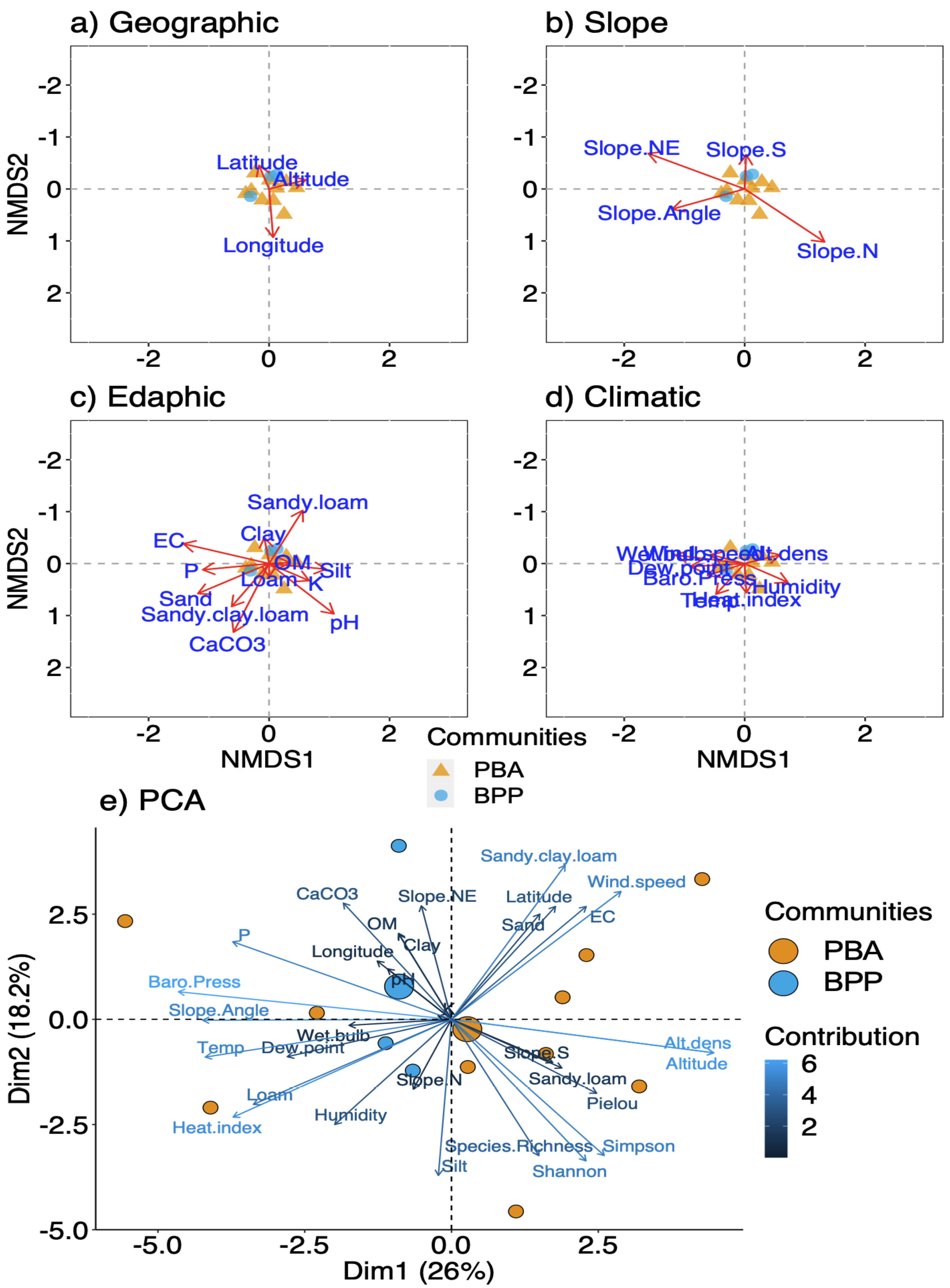

Fig. 4. Correlation between alpine vegetation and environmental gradients (geographic, slope, edaphic, climatic) visualized through Non-multidimensional Scaling Ordination (NMDS; a-d) and Principle Component Analysis (PCA; e). Direction and length of the arrows indicate the correlation of each environmental gradient and the strength of the gradient, respectively. which helped in structuring of these plant communities. Yellow and blue circles indicate the vegetation of the alpine Poa-Bistorta-Primula (PBP) and Bistorta-Poa-Primula (BPP) communities, respectively, and the size of each circle demonstrates the ecological amplitude of the communities.

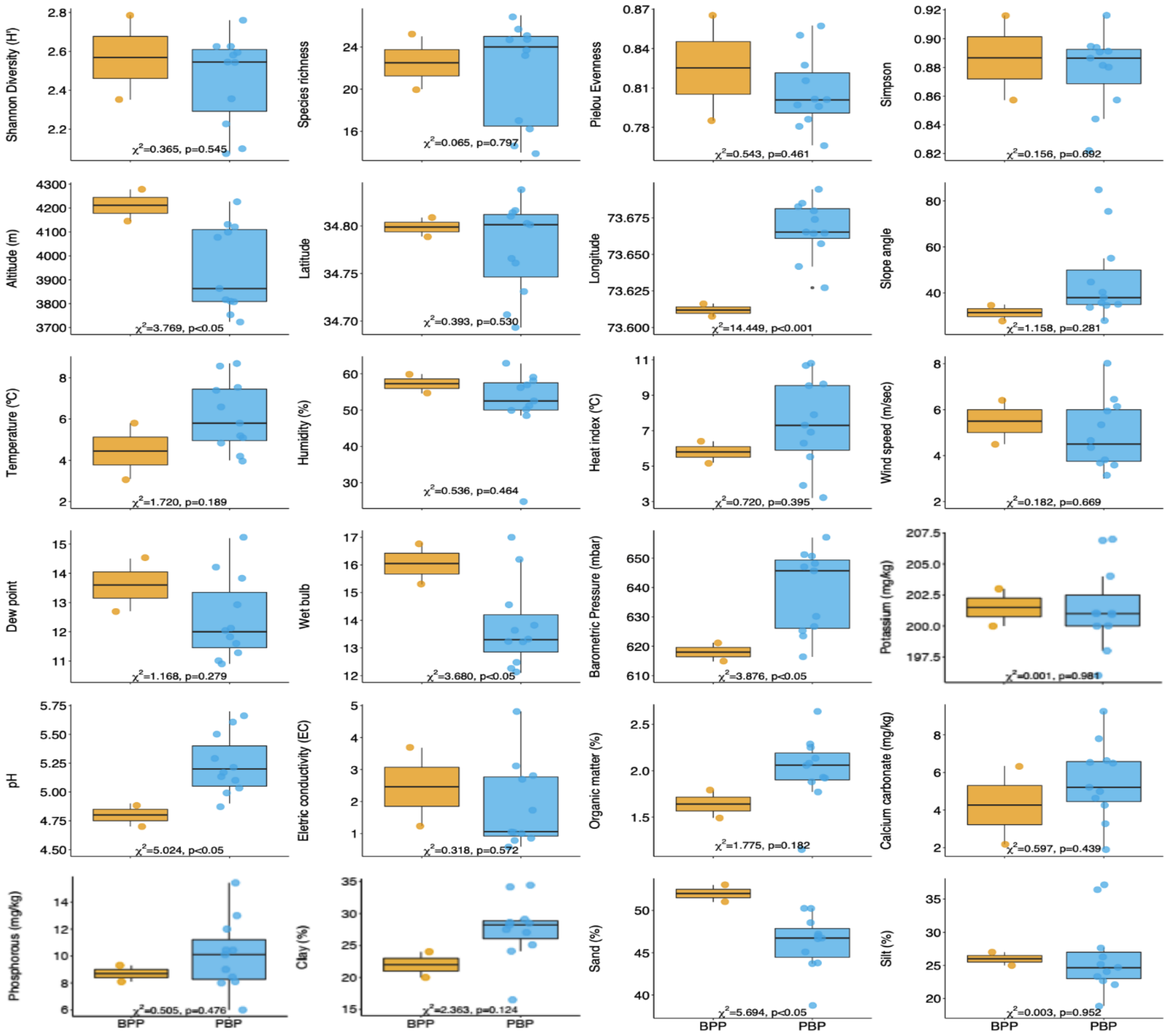

Fig. 5: Relationship between environmental gradients and two plant communities (*i.e.*, *Poa-Bistorta-Primula* and *Bistorta-Poa-Primula*): **a).** Species richness, **b).** Pielou's evenness, **c).** Alpha diversity (Shannon diversity), **d).** Beta diversity (Simpson's diversity) among two plant communities in relation to elevational gradient. **e-x).** Relationship of the two plant communities with other geographic, slope, climatic and edaphic gradients. In each diagram, left and right box plots represent BPP and PBP communities, respectively. (For complete name of plant communities see Figure 3).

Table 1. Species richness, Pielou's evenness, Shannon diversity and Simpson dominance indices of each stand.

Stands	Altitude (m.a.s.l)	Shannon index	Species richness	Pielou's Evenness	Simpson index
S104	3810.0	2.581	25	0.802	0.895
S107	4122.0	2.227	17	0.786	0.857
S115	4078.0	2.595	23	0.828	0.891
S127	4099.0	2.100	14	0.796	0.844
S132	4132.0	2.075	15	0.766	0.822
S90	4145.0	2.352	20	0.785	0.857
S95	4278.0	2.625	25	0.815	0.894
S96	3817.0	2.760	25	0.857	0.916
S97	4227.0	2.357	16	0.850	0.880
S111	3724.0	2.545	24	0.801	0.886
S94	3863.0	2.785	25	0.865	0.916
S131	3753.0	2.626	27	0.797	0.891
S133	3808.0	2.544	26	0.781	0.881

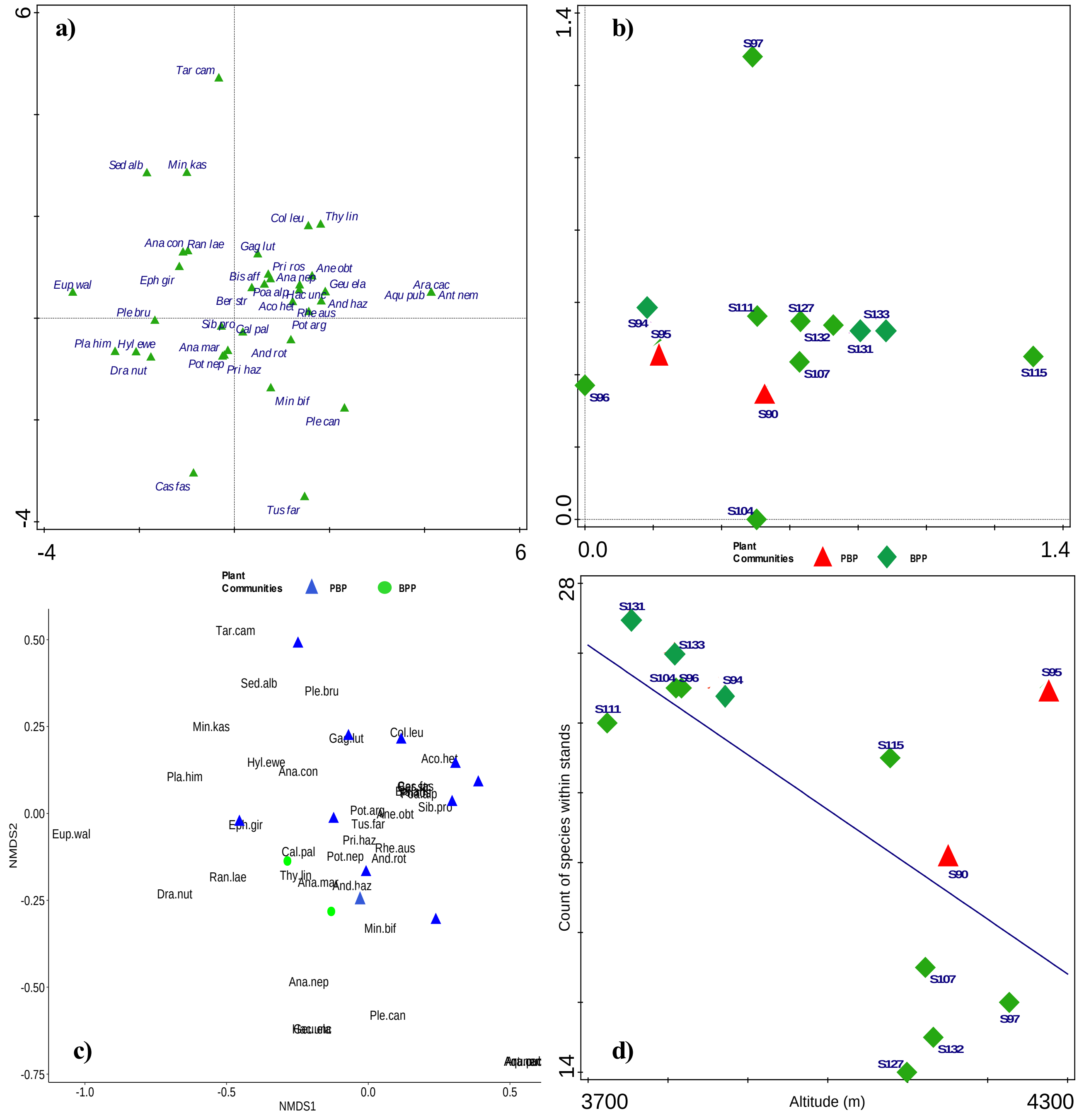

Fig. 6. **a-b**). DCA ordination of **a**). alpine plant species (39 species) and **b**). sampling sites (13 sites; Green diamonds and red triangles represent PBP and BPP communities, respectively). **c**). NMDS of stands with their associated species (blue triangles green circles represent indicate *Poa-Bistorta-Primula* and *Bistorta-Poa-Primula* communities, respectively) and **d**). Species richness within each stand.

Table 2. The contribution and ranking of the studied gradients. Significant p-values are displayed in bold.

Gradients	Df	Chi-square	F	Pr(>F)
Temp	1	0.030968	13.641	0.212
Clay	**1**	**0.058969**	**25.976**	**0.006**
pH	**1**	**0.048957**	**21.566**	**0.025**
EC	**1**	**0.054214**	**23.882**	**0.016**
Loam	1	0.037965	16.724	0.091
Slope (S)	1	0.034124	15.032	0.164
Longitude	1	0.034802	15.330	0.140
Wet bulb	1	0.023312	10.269	0.479
Slope (N)	1	0.035768	15.756	0.105
Altitude	1	0.029726	13.094	0.211

Table 3. Variation partitioning analysis of four variable classes (climatic, edaphic, geographic, and slope) (Fig. 7).

Individual fraction	Adjusted R2	Variation explained (%)	% of all	Df
[a]	0.055	30.7	12.8	2
[b]	0.170	94.4	39.1	3
[c]	0.140	77.8	32.2	3
[d]	-0.056	-31.3	-13.0	2
[e]	-0.100	-55.5	-23.0	0
[f]	-0.145	-80.6	-33.4	0
[g]	0.009	5.1	2.1	0
[h]	-0.010	-5.3	-2.2	0
[i]	-0.004	-2.3	-0.9	0
[j]	0.113	62.6	26.0	0
[k]	0.001	0.4	0.2	0
[l]	0.070	38.8	16.1	0
[m]	-0.019	-10.6	-4.4	0
[n]	-0.093	-51.5	-21.3	0
[o]	0.046	25.3	10.5	0
Total explained	0.180	98.2	40.7	10
All variation	0.434	/	100	

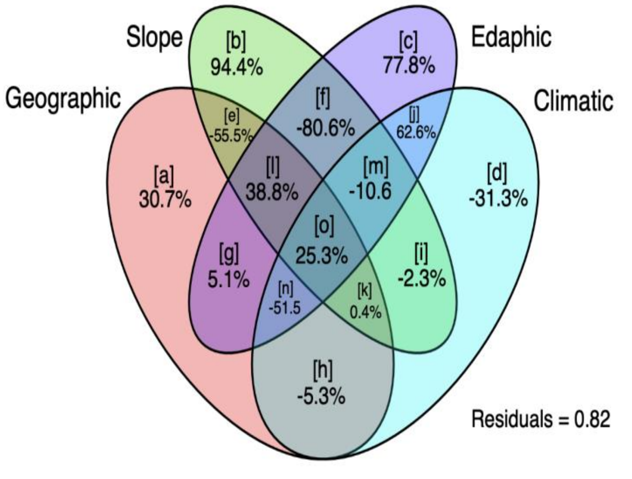

Fig. 7. Venn diagram (Legendre, 2008) showing variation partitioning results (partial CCA) and contribution (%) of the four variable groups studied (climatic, edaphic, geographic, and slope).

Discussion

This study investigated the plant community in the alpine zone of Manoor Valley, part of the Himalayas. We found a total of 39 plant species distributed in two types of plant communities, the alpine pastures (PBP, *Poa-Bistorta-Primula* community; 3724-4227 m) and the cold dessert (BPP, *Bistorta-Poa-Primula* community; 4145-4278 m). The vegetation is dominated by herbaceous layers, which might be due to harsh environment conditions, and characterized by *Poa alpina, Bistorta affinis*, *Primula rosea*, *Rheum australe*, *Bergenia stracheyi* and *Androsace hazarica*. Similar pattern was observed in the neighboring valley in the Himalayas, Naran Valley, which is differentiated into different communities based on the altitude (Khan, 2012). Due to the high elevation, alpine ecosystems are strongly controlled by extremely low temperature throughout the growing season (Körner, 2003; Rahman *et al.*, 2020b). Low temperature is the key feature throughout the growing season of alpine flora as it might be due to the high elevation. Such severe climatic environment is worsened by xeric conditions which led to very short growing season from July to September, with similarities to the Trans-Himalayan (Kala and Mathur, 2002) and Tibetan Plateau of the Karakorum Mountains (Eberhardt *et al.*, 2007; Marston, 2008).

The alpine pastures (3724-4227 m) and cold desert (4145-4278 m) of the study area were characterized by *Poa alpina*, *Bistorta affinis*, *Primula rosea*, *Rheum australe*, *Bergenia stracheyi* and *Androsace hazarica.* Alpine plant communities vary, and their environmental covariates could influence their response to climate change (Malanson *et al.*, 2017). Understanding the underlying determinants of the diversity of alpine vegetation might help to anticipate the effects of climate change (Malanson *et al.*, 2017, 2019; Amagai *et al.*, 2018). Regional plant diversity in alpine habitats is expected to change as a result of global warming due to shifts in temperature niches and species' distributions (Ohler *et al.*, 2020), which may result in increased competition because species distributions shifts to higher elevations followed by the assembly of new communities (Pauli *et al.*, 2012; Steinbauer *et al.*, 2018). A decade ago, similar alpine vegetation of Manoor Valley (this study; *i.e., Rheum australe*, *Sibbaldia procumbens*, *Poa alpina, Bergenia stracheyi*, *Thymus linearis* and *Bistorta affinis*) was recorded in allied valley (Naran Valley) at lower altitudinal ranges of (3300–4000 m.a.s.l) (Khan *et al.*, 2011; Khan, 2012). Such variability in the indicators and other co-dominants strongly affect species richness through the modification of plant–plant interactions, including competition and facilitation (Michalet *et al.*, 2014; Olsen & Klanderud, 2014; Amagai *et al.*, 2018).

Conclusions

This research recognizes two plant communities in alpine pastures and cold desert of Manoor Valley of the Himalayas. Among the main influential drivers of alpine plant diversity and community structuring are low temperature, wind speed and species interactions (Cavieres *et al.*, 2014; Mayor *et al.*, 2017). Nevertheless, plant community composition and diversity are not only shaped by environmental gradients but also by local micro-abiotic filtering (Conti *et al.*, 2017). The recognized indicators of such harsh environment might be useful in monitoring variations in plant communities resulted in response to environmental changes.

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