SPECIES RICHNESS, ALPHA AND BETA DIVERSITY OF TREES, SHRUBS AND HERBACEOUS PLANTS IN THE WOODLANDS OF SWAT, PAKISTAN

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Abstract

The variation in species richness and diversity of trees, shrubs and herbs in the mountains of Miandam, Swat, North Pakistan, along an elevation gradient between 1600 m and 3400 m was explored. Field data were collected in 18 altitudinal intervals of 100 m each. Polynomial regression was used to find relations of the different growth forms with elevation. The Shannon index was used for calculating α-diversity and the Simpson index for β-diversity. Species richness and α-diversity of herbs were unrelated to elevation. Herbaceous species turnover was high, ranging between 0.46 and 0.89, with its maximum between 2700 and 3000 m. Hump-shaped relationship was observed for shrubs with maximum richness between 2000 and 2200 m; and α-diversity decreased monotonically. Turnover of shrub species was highest between 2000 and 2500 m. Tree species richness was highest at low elevations, and α-diversity was relatively low along the entire gradient. Tree species turnover was also high in the lower zone and again at 2600-2800 m. Species richness of all vascular plants was highest at 2200-2500 m, and α-diversity was highest in the lower part of the gradient. Beta diversity of all growth forms was quite high ranging between 0.53 and 0.87along the entire gradient reflecting high species and structural turnover.

Key words: Elevation gradient, Himalayas, Mountain woodlands, Plant diversity, Shannon index, Simpson beta diversity, Vegetation zonation.

Introduction

Variation in species richness along elevation has been observed for over a century (Wallace, 1878; Pianka, 1966; Lomolino, 2001; Sanders & Rahbek, 2012). Rahbek (1995; 2005), in his reviews of scale and species richness, found that most studies showed mid-elevation peaks along elevation gradients. He identified three main patterns of richness: (1) monotonic decrease with increasing altitude, (2) a plateau at low altitudes and (3) hump-shaped distribution with high richness at intermediate altitudes. Similarly, according to (McCain, 2009) elevational patterns in species richness fall into four common patterns (1) decreasing, (2) low plateau, (3) low plateau with mid-elevational peak and (4) mid-elevation peak. Evidently, the pattern of species richness along elevation differs in different regions, with monotonic decrease (Austrheim, 2002; Ohlemüller & Wilson, 2000; Trigas *et al*., 2013), hump-shaped relationship (Lomolino, 2001; Acharya *et al*., 2011; Bhattarai & Vetaas, 2006), or both patterns in the same region (Grytnes, 2003). In some studies even bimodality has been reported (Xu *et al*., 2011). Wang *et al*. (2007) found that richness and density (richness/log-transformed area) of seed plants at species, generic, and family levels all showed hump-shaped patterns along the altitudinal gradient. Bhattarai & Vetaas (2003) found that shrubs, trees and total species (sum of all life forms) showed unimodal responses, ferns decreased monotonically and woody climbers increased monotonically. Richness of all woody groups increased monotonically with increasing mean annual rainfall and humidity. Some researchers, like Grytnes & Beaman (2006) and Kessler (2000),established that elevational patterns in species richness depend on the group studied and on the region, e.g., ferns in Mexico (Tyron, 1989), Bolivia (Kessler, 2000) and Malaysia (Parris *et al.*, 1992). Ren *et al*. (2006) found that total vascular plant species richness did not exhibit a linear altitudinal pattern, albeit species groups with different ecological features showed strong elevational patterns. Individual growth forms vary in response to elevation, e.g. herbs in New Zealand (Ohlemüller & Wilson, 2000), trees and shrubs in South Africa (O' Brien, 1993) and climbers in Mexico (Vazquez & Givnish, 1998).

The South Asian mountain ranges (Himalayas, Hindukush, Karakorum), with the highest peaks in the world, comprise a very wide range of ecoclimate zones (Dobremez & Jest, 1976). These mountains are therefore an excellent system for evaluating ecological and biogeographical patterns and theories of species richness (Körner, 2000). Some authors Khan *et al*. (2010); Khan *et al*. (2011); Saqib *et al*. (2011); Shaheen & Shinwari (2012) provided studies related to species diversity, community structure and distribution patterns of plant species in the Hindukush-Himalaya region in Northern Pakistan. Hussain & Perveen (2015) studied phytosociological attributes of plant biodiversity of the fort Ranikot and adjoining areas. Our study is the first for any area in northern Pakistan with statistical determination of species richness and diversity of different growth forms along elevation. We focused on two questions: (I) Do species richness and diversity vary along elevation and among different growth forms? (II) Is variation along the elevational gradient monotonic, unimodal or otherwise?

Materials and Methods

Study area: The study was carried out in the area of Miandam, district of Swat, North Pakistan (35°1-5′ N, 72°30-37′ E; Fig. 1). The mountainous area, about 50 km NNE of the district capital, Saidu Sharif, is part of an offshoot of the Himalaya range ascending to 3500 m According to Zahid & Rasul (2011) and based on

Thornthwaite's index of thermal efficiency (ratio of temperature to evapotranspiration), the research area falls in the "mild microthermal" zone. March, July and August are months with heavy rainfall (New *et al.*, 2002). December and January are the coldest months with temperatures down to a mean minimum of -10°C in the higher reaches of the nemoral forest areas (Saeeda, 2005).On the valley sides at 1600-1800 m the area is dominated by sparse shrubby vegetation of *Berberis*

lycium, *Isodon rugosus* and *Sorbaria tomentosa*. In the boreal belt as defined by Schroeder (1998) *Picea smithiana* is the dominant tree and *Taxus wallichiana* associated. The upper and lower nemoral belts are characterized by *Abies pindrow* and *Pinus wallichiana* forests,respectively. *Indigofera heterantha* and *Viburnum grandiflorum* are common understory shrubs of *Pinus* and *Abies* woodlands. In the subalpine belt *Betula utilis* and *Salix* spp. dominate; in the alpine zone *Sibbaldia cuneata* is common.
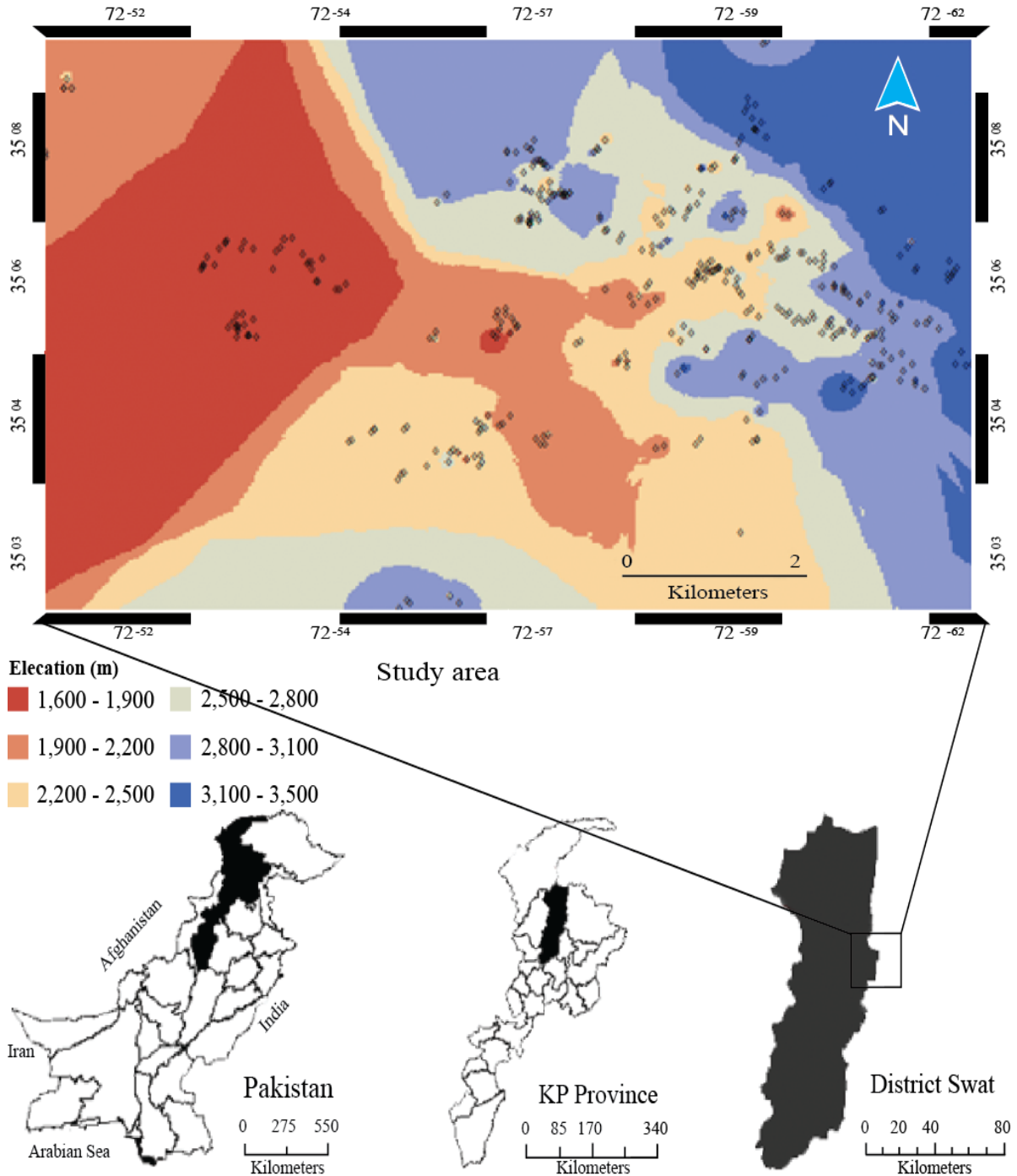

Fig. 1. Georeferenced map showing the sampling sites (rhombi) and topography of the study area in the district of Swat, Khyber Pakhtunkhwa (KP) Province, Northern Pakistan.

Field sampling: Field work was carried out in the summer months of 2010 through 2012. The elevation gradient between 1600 and 3400 m was divided into 100 m intervals. Four hundred vegetation quadrats of 10 × 10 m were placed along the gradient in stratified wooded and sparsely wooded areas covering all intervals and the entire vegetation zonation. Elevation was measured using GPS device. Plant samples were collected of almost all vascular plant species and identified using Ali & Qaisar (1995-2009); Nasir & Ali (1971-1995); Breckle *et al.* (2010); Urrahman (2012). Herbarium collections of the Botanische Staatssammlung (M), München, Germany, were compared for confirmation.

Data analysis: In our analyses, we distinguished the growth forms herb, shrub and tree. Three indices were chosen to estimate richness and diversity: (1) species richness, i.e., the total number of plant species recorded in each 100 m elevation interval (Bhattarai *et al.*, 2004; Grau *et al.*, 2007; Vetaas & Grytnes, 2002). (2) Shannon ("Shannon-Wiener") index of diversity:

$$H' = -\sum_{i=1}^{S} pi \ln pi$$

where S is the total number of species at the elevation and *pi* is the proportion of all the individuals in the quadrat. Instead of counting the individual plants species, cover relative to the total cover was calculated (Fosaa, 2004). Values of Shannon index were exponentiated as suggested by (Jost, 2006). (3) Simpson beta diversity index:

$$\beta_{simp} = 1 - \frac{a}{\min(b,c)+a}$$ (Koleff *et al.*, 2003)

where α is the number of shared species between two quadrats while b and c are numbers of species unique to either quadrat. In our case β_{simp} is pairwise comparison among quadrats based on presence and absence of species. Here min(b, c) is the minimum number of unique species of either b or c. As the sample plots were unequally distributed in the study area we calculated the three indices based on seven quadrats per100 m interval (seven quadrats being the minimum number sampled in any interval). We randomized our samples five times in each elevation interval where more than seven quadrats were sampled. After randomization mean values were taken for further analyses. To find patterns of diversity, species richness, Shannon and Simpson beta diversity indices were regressed against elevation. Diversity indices were computed in JUICE 7.0 (Tichý, 2002) and polynomial regression in R 2.15.3 (R Core Team, 2014). Akaike's information criterion (AIC) was used for model selection, with the minimum AIC as the best-fit estimator.

Results

Species richness in relation to elevation: We recorded a total of 411 species in the samples. Most of the species were herbaceous (77%), trees account for 8%, shrubs constitute 12%, and woody climbers 3% of the total number of species.

The variation in species richness of the three growth forms and total species richness is shown in Fig. 2. The polynomial regression models did not predict a significant relationship between herb richness and elevation. A hump-shaped relationship was found between shrub richness and elevation with maximum richness between 2000 and 2200 m. Minimum shrub richness was observed between 3000 and 3200 m. Tree species richness initially decreased until 2200 m, then increased and from 2800 m onward decreased again. Total species richness followed a unimodal pattern along the elevation gradient; quadratic regression showed a significant fit to the trend of variation.

Alpha diversity in relation to elevation: Shannon diversity for herbs was insignificant to elevation. All polynomial models up to 4th order failed to predict any significant relationship of herb diversity with elevation (Fig. 3). For shrubs the Shannon diversity decreased monotonically. The lowest Shannon diversity of 1.02 for shrubs was observed at about 3150 m and the highest Shannon diversity of 3.15 was observed at low elevations of about 1800 m. Shannon diversity for trees was also low along the gradient studied. Alpha diversity for vascular plants as a whole was highest at low (1600 m) and medium (2700 m) altitudes and lowest in the uppermost forest zone (3100 m).

Beta diversity in relation to elevation: Between 1600 and 2000 m there was gradual decrease in β-diversity of herbs. Then a sudden decrease beyond 2900 m was observed (Fig. 4). Shrubby species turnover fluctuated along the gradient. First it decreased between 1600 and 2000 m, then increased up to 2500 m, then gradually decreased up to 3100 m, and in the subalpine zone once again increased. Tree species turnover was high at low elevations, then decreased as the elevation increased, remaining fairly constant along the forest zones until a further decrease at and above 3000 m. Species turnover for vascular plants *in toto* ranged between 0.53 and 0.87 showing overall high β-diversity.

Discussion

Variation in species richness: Similar to Bhattarai & Vetaas, 2003 the relationship between herb richness and elevation was statistically insignificant but for shrubs, trees, and vascular plants as a whole richness was significant. In a study from New Zealand, Ohlemüller & Wilson (2000) found no relationship between herbaceous species richness (groundflora) and elevation. In terms of species richness herb diversity is high if compared to the findings of(Khan *et al.*, 2011). In lower areas, annual disturbance indicators such as *Dicliptera bupleuroides*, *Sonchus* spp., *Cannabis sativa*, *Lepidium pinnatifidum, Chenopodium album, Solanum pseudocapsicum* and many others are common and outnumber genuine woodland plants. At subalpine reaches light-demanding perennial species such as *Potentilla atrosanguinea*, *Pedicularis pyramidata*, *Sibbaldia cuneata*, *Impatiens thomsonii*, *Pleurospermum stellatum* and *Clinopodium umbrosum* are common. Effects of different life forms may blur a possible richness response of woodland herbs among which hemicryptophytes and geophytes are prevailing. Mahdavi *et al.* (2013) found a decrease in annuals and increase in hemicryptophytes along a 3000 m altitudinal gradient in Iran.
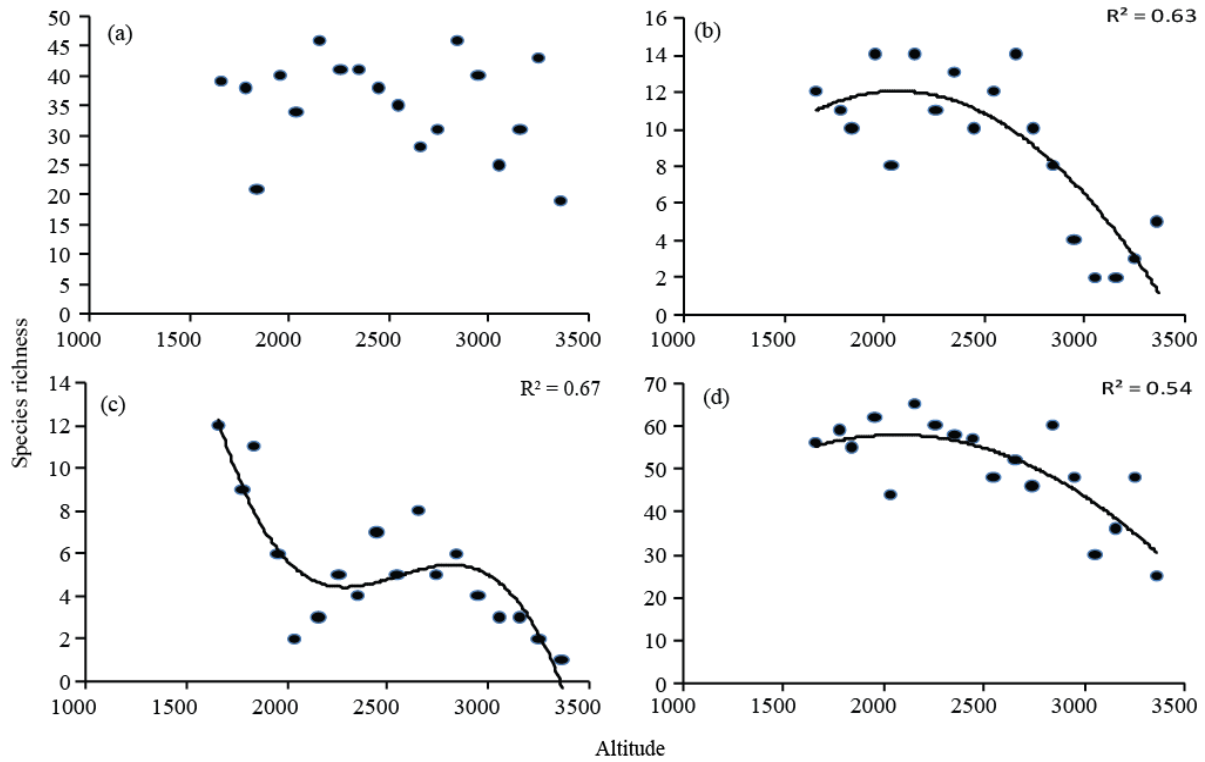
Fig. 2. Relationship between species richness and elevation for (a) herbs, (b) shrubs, (c) trees, and (d) total vascular plants. R^2 value is adjusted. While herb richness along elevation was statistically insignificant, quadratic, cubic and quadratic regressions based on significant F and AIC values were significant for richness of shrubs, trees and total vascular plants, respectively.
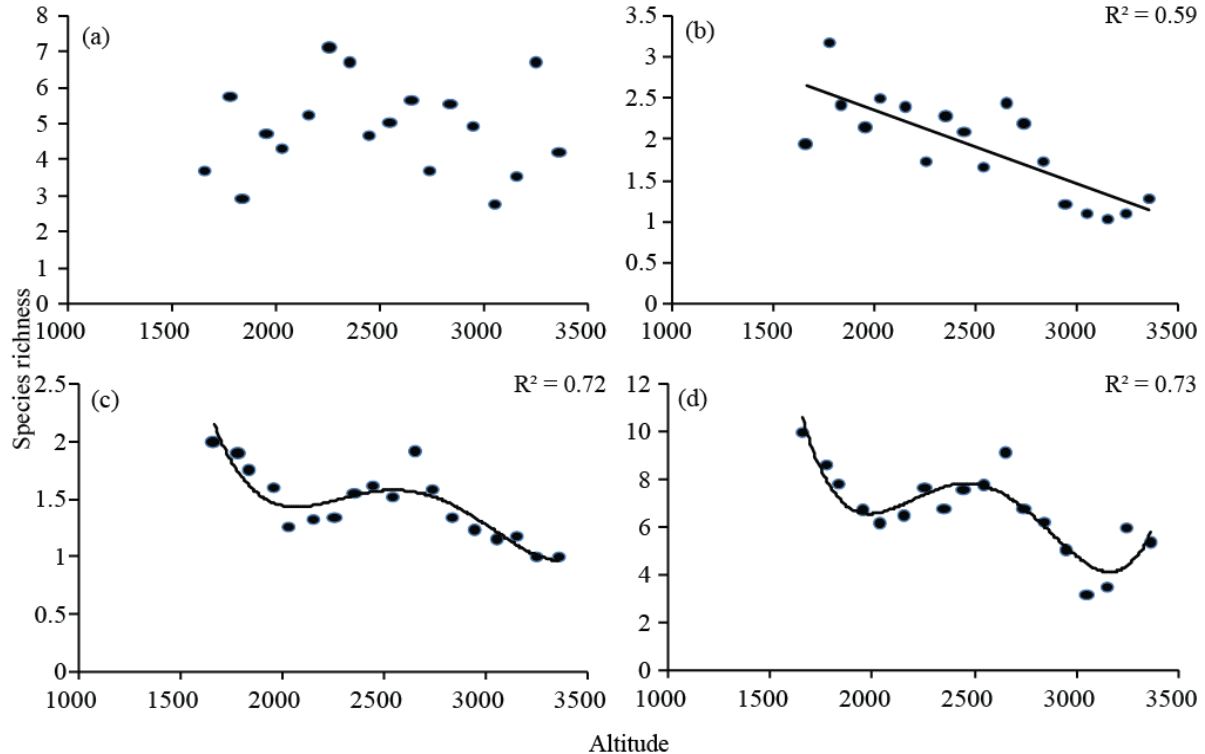

Fig. 3. Relationship between exponentiated Shannon diversity with elevation for (a) herbs, (b) shrubs, (c) trees, and (d) total vascular plants. R^2 value is adjusted. Based on significant F and AIC values linear, cubic and quartic regressions were significant for alpha diversity of shrubs, trees and all vascular plants, respectively. For herbs Shannon diversity was insignificant.
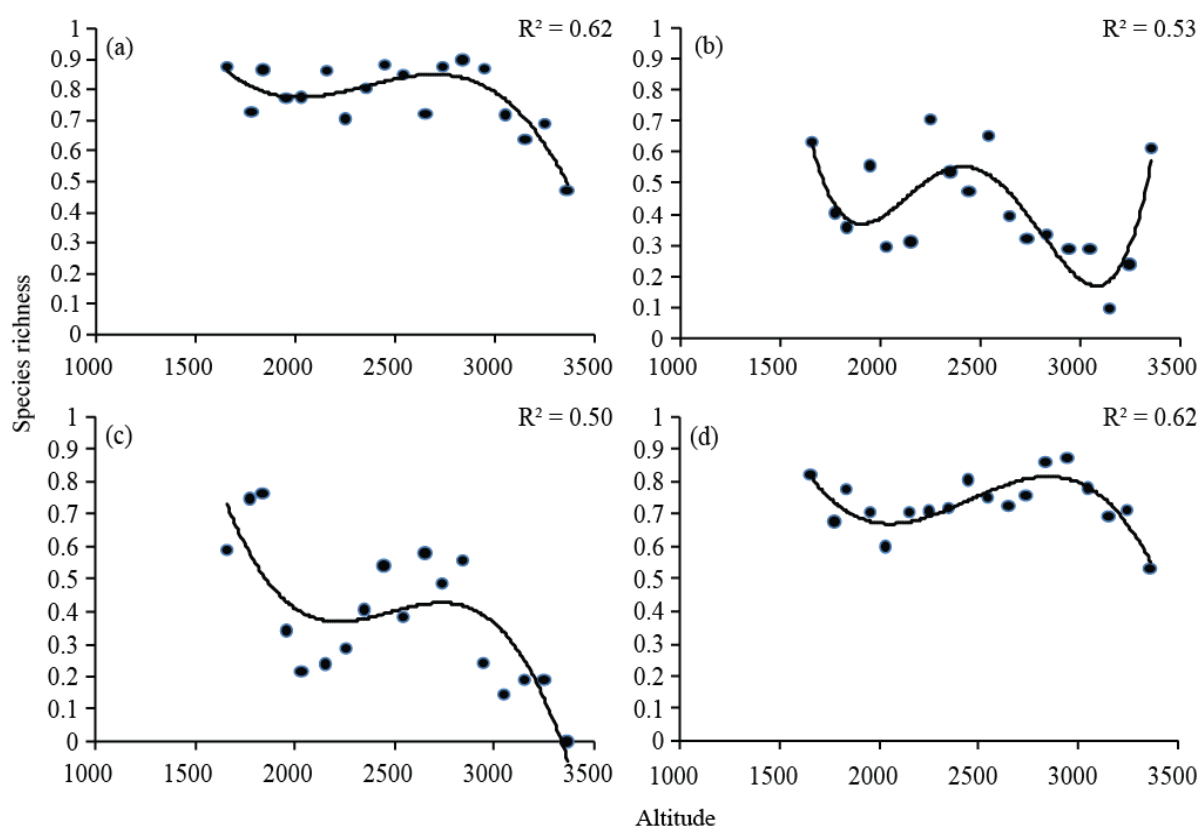
Fig. 4. Relationship between β-diversity with elevation for (a) herbs, (b) shrubs, (c) trees, and (d) total vascular plants.R^2 value is adjusted. Based on significant F and AIC values cubic, quartic, cubic and cubic regressions were significant for beta diversity of herbs, shrubs, trees and all vascular plants, respectively.

Shrubs showed a unimodal pattern in the studied area with maximum richness in the middle of the elevation gradient. Transhumance affecting shrub growth in woodlands particularly at lower and at subalpine levels close to the winter and summer pastures, respectively, may explain such a pattern. High tree species richness in the lower zone is probably due to anthropogenic habitat disturbance and deforestation supporting alien tree species such as *Ailanthus altissima* and *Robinia pseudoacacia*, but also opportunistic native trees such as *Ficus palmata* . Infrequent deciduous tree species like *Rhamnus purpurea* and *Prunus cornuta* which are largely confined to the nemoral zone add to the relatively high mid-elevation tree species richness.

Decreasing total species richness above about 2700 m may be due to increasingly harsh natural conditions in the upper boreal and subalpine belts (Colwell & Lees, 2000; Grytnes & Vetaas, 2002).A mid-elevation peak of species richness as observed in Swat is a common pattern on many mountains (Grytnes, 2003).

Variation in α-diversity: In our index for α-diversity we used relative species cover. As with richness,and probably for the same reasons (see above) we could not identify a relationship between herb diversity and elevation. Alpha diversity of shrubs, being low throughout, decreased along the gradient. Some shrub species, e.g., *Isodon rugosus*, *Desmodium elegans*, *Sorbaria tomentosa*,are more or less equally distributed but decrease at upper levels. Patterns of tree species richness and α-diversity are quite similar and indicate that abundance of different tree species seems to affect α-diversity in much of the elevation gradient. Quartic regression model shows a significant trend of variation of α-diversity of the vascular plants against elevation. The pattern is similar to α-diversity of trees and, interestingly, in consonance with a 1300 m elevation gradient in the Sierra Nevada, Mexico (Sánchez-González & López-Mata, 2005).

Variation in β-diversity: Beta diversity is a key concept for understanding ecosystem patterns, for biodiversity conservation and ecosystem management (Legendre *et al.*, 2005). In the study area, species turnover of herbs varied along the gradient between 0.46 and 0.89.Beta diversity of the herbs and of the vascular plants as a whole were similar. Low-elevation woodland disturbance indicators including neophytes such as *Cannabis sativa*, *Datura innoxia* and *Galinsoga parviflora* add to the high level of beta diversity at lower altitudes. From 2900 m onward, there is low turnover of herbs, probably due to the increasingly controlling effect of climate over other environmental factors. Increase in beta diversity of shrubs at 1800-2400 m and 3100-3350 m reflects the effect of certain range-restricted native species. Between 1800 and 2400 m *Indigofera heterantha*, *Viburnum grandiflorum* and *Sarcococca saligna* appear. The first two are among the most widely distributed shrub species of the area. At and

beyond the subalpine belt characteristic species such as *Salix* spp. and *Cassiope fastigiata* cause high beta diversity at the high end of the gradient. Species turnover of trees is high only on the valley sides and rather low at higher reaches. This is due to the dominance at nemoral through boreal levels of the competitive forest trees *Pinus wallichiana*, *Abies pindrow* and *Picea smithiana*.

Conclusion

We confirmed our initial research questions. Shrubs, trees and non-woody plants varied in richness and diversity along the investigated elevation gradient of 1800 m from the valley bottom to the summits. Much of the richness and diversity variation along elevation of shrubs and trees could be explained by different response models including monotonic, hump-shaped, and more complicated relationships. The growth form category 'herb' seems to be too unspecific to reveal a significant elevational pattern. Life form categories responding to the climatic change along the altitudinal gradient may be expected to perform better. There is considerable redundancy in our study in what is revealed by the concepts of species richness and α-diversity, while β-diversity provided additional clues for interpretation. The detailed interpretation of the findings proves difficult and is likely to be multi-faceted. Apart from the obvious, increasing precipitation and decreasing temperature with increasing altitude, disturbance effects in the woodlands of Swat seem to be accountable for some of the altitudinal diversity and richness phenomena. The effect of ruderal annuals and arboreal and herbaceous neophytes, for instance, is most pronounced on the low valley sides close to settlements. In the higher reaches, especially towards the subalpine belt, decreasing richness and α-diversity as well as high turnover may reflect natural and human-made opening of woodland. Not all findings may be explained satisfactorily, though, and a much larger number and denser network of thorough descriptive case studies than available at present is urgently needed as reference data for the interpretation of spatial patterns and future change in plant and vegetation diversity of northern Pakistan.

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